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Gaming Simulations for Railways: Lessons Learned from Modeling Six Games for the Dutch Infrastructure Management

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1. Introduction

The Dutch railway system is a highly complex and heavily utilized network (Goverde, 2005; CBS, 2009). Worldwide it is one of the most densely driven networks, yet its capacity has to increase further. Improvements in the domain of capacity management and traffic control are increasingly difficult to implement because of the large interconnectedness of all processes. The de-bundling of rail infra management (ProRail) and train services (predominantly NS, and some smaller regional lines by Syntus, Veolia, Arriva a.o. plus freight train operators) has created an operational process in which multiple offices and platform/line operations need to synchronize to control the daily train flow.

ProRail, the Dutch railway infrastructure manager, has stated a goal to increase the capacity by 50% as a challenge till the year 2020. This cannot be done the 'old way' through increased amounts of physical infrastructure, as both money and geographical space are insufficient. Furthermore, the complexity and interconnectedness of the network is yet at such a level that more of this will lead to less resilience and becoming (even more) prone to disturbances. Because of the 50% growth challenge till the year 2020, new and smarter ways of managing capacity and traffic are key for the success of the Dutch rail infrastructure for society. The ProRail organization has taken up gaming simulation as a key method to improve the innovation process (Meijer, forthcoming).

Unique for gaming simulation is the highly detailed simulation of both technical and process variables of rail infrastructures and the decision and communication function of real people in their real roles. The method does not assume models of decision-making but draws upon the real-world knowledge of professionals in the operation. Over the course of the projects that ran in 2009, 2010 and 2011, the specific setting of the ProRail organization proved to be both a complex and fruitful environment for gaming simulation. The complexity was found in the large number of stakeholders both in and outside the organization and in the interconnectedness of every aspect of train traffic control on the performance of passenger and freight train service providers.

In the year 2009, the gaming group of Delft University of Technology was asked to facilitate three projects using gaming simulation methodology. These projects ran so successful that the organization asked the Delft researchers to identify where in the organization large-scale implementation of gaming simulation methodology would be most promising. Based upon a series of interviews through the organization, ProRail and TU Delft jointly formulated a four-year research and implementation proposal that is now in operation. The first gaming sessions in this new collaboration have been held and results have led to methodological lessons-learned on how to model. This chapter reports on three modeling issues crucial to gaming simulation for railway and similar systems. How to abstract from the nitty-gritty details while keeping the simulation real and valid enough for real-world operators to participate and do their job is the focus of this chapter.

2. Problem description

Innovation in the Dutch railways is on one hand much needed, while on the other hand very complex to achieve. The 1995 politically instigated de-bundling of rail infra management (ProRail) and train services (predominantly NS, and some smaller regional lines by Syntens, Veolia, a.o.) has created an operational process in which multiple offices and platform/line operations need to synchronize to control the daily train flow. The increasing importance of rail services for individual provinces in the Netherlands has led to multi-party tendering (Van de Velde et al, 2008). In this complex multi-actor and multi-level environment the strategic safeguarding of public values in managing operations proofs often impossible (Steenhuisen et al, 2009). The combination of these events and trends leads to a challenge to innovate on two aspects, being quality in operations and ways to increase the capacity.

2.1 Quality in operations – Robustness and resilience

Over the past decade, the railways in The Netherlands have received major criticism for the quality of its operations. From a policy perspective this has led to performance contracts for both the main train service operator (NS) and the publicly owned infrastructure manager ProRail (Van de Velde et al, 2009). Over the past decade the performance has seen improvements on the critical performance indicators, but still it is not regarded to be a high quality service due to many small delays, overly crowded trains and non- or mal-informed passengers. The rail system often suffers from small defects, leading to bigger delays when the problems spread like an oil spill over the regions and lines. If we define robustness as the degree to which a system is capable to withstand problems within the limits of the designed system, then the robustness of the railways is questionable.

A lower score on robustness would not have been so detrimental is the railways were more resilient. Hollnagel et al (2006) define resilience as the ability of a system or an organization to react to and recover from disturbances at an early stage, with minimal effect on the dynamic stability. The challenges to system safety come from instability, and resilience engineering is an expression of the methods and principles that prevent this from taking place. Furthermore the recent years have shown that snow, storms, national festivities and other outliers in the situation for which the system is not specifically designed cause total or at best partial collapse of the national system, as soon as small problems start to occur. This has led to Parliamentary Investigation (Rekenkamer, 2011). According to Hale and Heijer

(2006), railways, from their assessment of safety operations at the Dutch Railways, would seem to be examples of poor, or at best mixed, resilience, which can, however, still achieve high levels of safety, at least in certain areas of their operations. Hence safety is achieved by sacrificing goals, traffic volume and punctuality. The system does not achieve all its goals simultaneously and flexibly and is not resilient.

2.2 Capacity increases

The Dutch railway sector will face a massive growth of transport demand in the forthcoming decade. This growth is both expected in passenger and in freight transport. Currently, the Dutch railway network is one of the most densely used networks in the world, approaching its maximum capacity given the current infrastructure and control mechanisms. The projected increase in demand requires a step-change in both the physical and control aspects of the railways. ProRail formulated an ambitious program, called 'Room on the Railways" (Ruimte op de Rails, in Dutch) to increase the number of trains on the network by 50% before the year 2020. One of the major components of this program is the plan for high-frequency passenger trains on the major corridors. Currently there are (on average) 4 intercity, 2 to 4 local and 1 or 2 freight trains per hour on the major corridors. This should increase to 6 intercity, 6 local and 2 freight trains before 2013. This new frequency of trains is often called 'untimetabled travelling" as the passenger can just go to a station without checking departure times: the next train will be there soon. The official title of the schedule is High Frequency Train Transport.

The projected increase of capacity cannot be achieved by building new infrastructure alone: the costs for the complete program would be around 9 billion euro, and the time for procedures and construction would frustrate the transport demand for years. ProRail has taken up the challenge to achieve the goals with only half of this budget by combining strategic choices for new infrastructure with new control and management solutions.

3. Gaming simulation for process innovations

Gaming simulation, here defined as 'simulating a system through gaming methods' is one of the terms in a loosely demarcated field of interactive participatory activities, aiming to involve participants, who may be the real stakeholders, in an activity. Other terms used are simulation game, policy exercise and serious gaming. The word gaming will be used here as the short term for gaming simulation. Different authors have different preferences, but in in general the terms depend on the intended use of the method.

Game theory and gaming simulation are often intertwined. Game theory is the mathematical approach of analyzing calculated circumstances where a person's success is based upon the choices of others. In games, these situations often occur, and therefore is game theory a popular method of modeling artificial intelligence in games. This chapter does not use game theory per se, however a more prominent and explicit use is foreseen in future games that incorporate automated agents.

Given the number of gaming titles and scientific publications, the use of gaming methods for learning is the most popular by far, typically occupying 'serious gaming' and 'simulation game' for usually computer-supported games that place the player in a simulated world

(Bekebrede and Mayer, 2005; De Freitas and Martin, 2006; Kriz and Hense, 2003). Learning about innovation in games is a popular topic for MBA-style versions, typically related to markets and supply chains (Meijer et al, 2006; Meijer, 2009). Learning and communicating complex issues are in this stream highly related. An important aspect for ProRail is the opportunity to communicate ideas. While a slideshow can communicate a message, a gaming simulation enables you to experience it for yourself (Bekebrede, 2010). The aspects about which it is sometimes difficult to communicate at present include: the impact of new timetables (on all categories of employees), the need for precision in carrying out tasks (employees), the influence of disruptions on the network as a whole (general public) and to experience the key aspects of traffic control / capacity management (general public). At present, visualizations of train flow models such as FRISO and SIMONE (Middelkoop and Loeve, 2006) are available, but it is not possible to experience these aspects by sitting at the controls. The opportunity for communication gives employees the chance to play a role that they do not have in reality. This can help clarify different points of view.

In the world of policymaking, there is half a century of history in using gaming as an intervention to bring together policy makers and other stakeholders in participatory events. Games provide a way to collectively decide firstly on the system boundaries and secondly on the dynamics of the system that will be played. Then, policies can be formulated in this simulated environment (Duke, 1974; Duke and Geurts, 2004; Mayer, 2010). This approach relies on Duke and Geurts' (2004) 5-C's of gaming simulation for improving policy making, namely by understanding the Complexity, enhancing Creativity, enabling Communication, reaching Consensus and Commitment to action. Within ProRail this role of gaming simulation is particularly relevant for management questions.

Increasingly popular is the possibility to try out the effect of policies on a simulated system, and see whether innovation in roles, rules, objectives and constraints can be made. This approach, although very relevant for policy-making, is actually a third use of gaming, for testing hypotheses (Peters et al, 1998). This application is less common and puts great emphasis on the verification and validation of the gaming simulation (Klabbers, 2003, 2006; Noy et al, 2006; Meijer, 2009). For innovation at ProRail, this use is at the core of the reasoning behind choosing gaming simulation as a new method in reducing uncertainty in more complex, system level changes.

A fourth use that is emerging is linked to the gamification of society (Hiltbrand and Burke, 2011). Innovation can take place through game play if the incentives are such that the crowd can generate and implement their ideas in a system. Few scientific literature on this exists as of yet, but examples are UK innovation in pensions (Gartner, 2011), crowd sourcing of ideas in an insurance company (Bekebrede and Meijer, Forthcoming)

4. Modeling challenges in gaming simulation for railways

In the world of gaming simulation several design guides and principles exist on how to capture real world problems in a gaming simulation. In the field of policy making the most important method is the one that Duke and Geurts (2004) describe, where for learning, sense-making and related issues the more recent work of Harteveld (2011) is gaining footage among some others. However, the problem is that these methods are so generic that the specific issues for technical domains like the railways have to be addressed specifically for that domain. A

second issue, especially with the more policy-oriented approaches and the popularity for learning in higher education is the focus on participants with a relatively large capability in thinking abstract, as policy makers and students tend to have more of this skill than the average operator. Peters et al (1998) describe the process from real world to simulated game world as a process of abstraction and reduction. The big question is how far can you abstract and reduce from reality before operators loose their grip on the simulated reality?

The operational skill training is recently getting more and more addressed in the gaming literature. Druckman (1994) proved already the need for more 'fidelity' (that could be translated as 'detailed realism') when training less abstract skills. Applications for operational skill training is getting common in the domains of image-based medical procedures (like laparoscopy, gastrointestinal flexible endoscopy, image-guided neurosurgery, and endovascular surgery) (Gaba, 2001; Botden et al, 2008; Hamdorf and Hall, 2000), aviation (Proctor et al, 2007), and safety training for dike inspection (Harteveld, 2011) and the oil and gas industry (Meijer and Poelman, 2011). Each of these domains finds a solution in 3D-based computer games that model an environment, either geographical or the organs in a body, through which the player has to navigate and perform a coherent set of actions. There is an overlap between the fields of virtual reality, simulation and gaming here.

Involving operators in games for policymaking or for testing hypotheses is almost undocumented, with some notable exceptions like the work at CIRAD and Cemagref (Barreteau, 2003). Traditionally the questions in policymaking and the hypotheses tested are at a higher level of abstraction. In Meijer (2009), the author argued that involving the real operators in a gaming simulation has the benefit of avoiding models and assumptions about their behavior, and thus can increase the validity of the behavior of the entire socio-technical system simulated. This has been proven in the domain of supply chain management research, studying the organization of transactions.

In our work we focus on the behavior of the people in the daily operations in railway systems, with a focal point at the train traffic controllers. Within the scope of the infrastructure management ProRail, their behavior has the most direct influence on the robustness and resilience of the network. To base decisions upon their behavior in gaming simulations it is essential to consider the validity of this behavior.

The most common critique for behavior observed in a session is "it is only a game.....". In the literal meaning the statement is true. A gaming simulation is a model of reality, and the roles, rules, objectives and constraints are necessarily different from the real world. The insinuation of the statement is, however, that behavior observed in a session is unlike behavior in the real world and is no valid representation of real-world behavior. Peters et al (1998) discuss the validity of games (gaming simulation) based upon the work of Raser (1969) who defined validity of models in the following way: "A model can be said to be valid to the extent that investigation of that model provides the same outcomes as would investigation in the reference system." Raser (1969) suggests four aspects of validity that apply to gaming simulation:

- Psychological reality: To what degree does the gaming simulation provide an environment that seems realistic to the participants?
- Structural validity: To what degree is the structure of the gaming simulation (the theory and assumptions on which it is built) isomorphic to that of the reference system?

- Process validity: To what degree are the processes observed in the gaming simulation isomorphic to those observed in the reference system?
- Predictive validity: To what degree can the gaming simulation produce outcomes of the historical or future reference system?

The psychological reality demands that sessions are conducted in such a way that participants are emotionally involved and really play their role. The situation of the session in the life of the participants, the consequences of participation or non-participation and the location and atmosphere of a session and its moderation are important factors. This requires craftsmanship of the game leader that is hard to operationalize in a scientific context. Various authors have made attempts at determining the quality of conducting sessions. Kriz and Hense (2006) offer an elaborate and theory-based evaluation methodology, that according to Klabbers (2008) does a good job in (temporarily) bridging the gap between analytical and design sciences. Kriz and Hense's approach is an adapted version of the theory-based evaluation method by Reynolds (1998). They distinguish between concept, design and application that can be evaluated.

The psychological reality and process and structural validity of Raser (1969) come together in the concept of situation awareness (Endsley, 2004) for operators. Operators should get involved psychologically when they can recognize sufficient components of the processes and structures they are used to in their real work. In the medical world this has led to consensus guidelines for validation of virtual reality surgical simulators (Carter et al, 2005), but in railways this work is only done for train drivers (Hamilton and Clarke, 2005)

When we take the concept of situation awareness as the central concept for considering the validity of railway operator behavior in gaming simulations, the list of items in the situation awareness still becomes vast. The modeling issue could include nearly any technical aspect of the railways, interface and representation items as well as the cognitive state of operators during their normal workdays. This chapter focuses on three important issues, posed as how-to questions:

1. How to immerse train traffic controllers in a gaming simulation?
   Immersion is one of the important indicators of presence and therefore psychological reality in simulated environments (Witmer and Singer, 1998). Therefore an indication of how to model a game so that railway operators get immersed in a first important step towards validity.
2. How to model time?
   Where real-world train flow is a continuous time process, this does not necessarily translate one-to-one to a gaming simulation, as the research question may ask for another solution than continuous, like step-wise, round-based, or asynchronous time.
3. How to present operational data?
   In the real operations the data flow to operators is bundled in machine interfaces or is fairly constant as time tables typically change only once a year, and infrastructure doesn't change fast either. In a game the standard tools may not be available and timetables and infrastructure may be new to the participants. How to present the information so that operators can still use it?

These questions will be answered in the remainder of this chapter. The next section discusses six projects from which the experiences are gained, then Section 6 translates this into lessons learned.

5. Modeling gaming simulations for rail innovation projects

As of 2011, the gaming collaboration resulted in six different gaming simulations, specifically built for innovation projects within ProRail. Each of these projects used gaming simulation to investigate various solution strategies with the aim of increasing capacity utilization, resilience and robustness on the rail network. The initial pilot project covered three projects while the long-term collaboration yielded three so far.

From the launch of the initial project, ProRail formulated three preliminary cases to study using gaming simulation. TU Delft was to developed unique approaches for each of these cases, after which the initial success of gaming simulation for the Dutch Railways would be re-evaluated. The cases differed in nature. The first was about the potential value of market mechanisms for management of demand of cargo capacity. This game could be seen as a management game on the tactical level. The second case was about studying a control concept for high-frequency train transport at the Bijlmer junction. This game was at the operational level of train dispatching and network control. The third case was about the opening regimes of the bridge over the river Vecht. This game was purely about train dispatching at the operational level.

During the course of these three cases, the success became very apparent to the senior management involved at ProRail. This led to an Intermezzo phase after the third game to reflect upon the results so far and to identify the value from interviews with ProRail internal stakeholder held by Delft researchers. The launch of a large four-year project was marked by a kick-off case that convinced the last skeptics. In the following sub-sections each of the cases and the intermezzo phase are described.

5.1 Rail cargo market game (RCM)

The first and kick-off subproject called Goederenmarktplaats (Freight Market) introduced ProRail to a paper-based and partly computer-supported game with a high degree of abstraction. This game type was referred to as a management game, due to the focus on more abstract policy-related aspects. Most of the participants were managers, with one session including a small number of network controllers.

Table 1 lists the core description of this game, more information can be found in Meijer et al (2009).

The game sessions delivered results timely, and in a positive and active manner. This game is still referred to two years later in the organization. Important to note for the introduction of gaming is that this project happened to have many people on board in senior staff functions from two different divisions (Traffic Control and Capacity Management) who appeared to be key people in later problems that called for gaming simulation methodology. The foundation in terms of exposure to key personnel therefore couldn't be better.

The research team then conducted interviews within ProRail to evaluate the pilot project and identify the opportunities it presented. In these interviews, the management game was repeatedly described positively. However, this generated few new ideas as regards applicability. Many of the issues encountered within the ProRail organization are operational and thus call for less abstract forms of gaming simulation.

Core aspect	Description
Purpose	Studying the potential value of various market mechanisms for better capacity allocation of cargo paths.
Roles	Clients with demand for transport, Rail Cargo Transporters, Passenger Transport, Rail Capacity Planning, Rail Asset Management
# of players	15 – 25 depending on step
Own/real/fictitious role	Real role, but selected for knowledge for instance from previous job position.
Scenarios	3 – 4 scenarios per session. First scenarios that explored the more fundamental market mechanisms. Then scenarios to validate the successful configurations.
Intervention range	Facilitator could start and stop the scenario and dissolve disputes only on the process steps.
Simulated world	Stylized train path market, stylized transport demand
Immersion	Fast, once roles were clear and adopted. Lively play including some conflicts. Capacity planners in second session had issues getting insight in their track system.
Time model	Continuous
Data presentation	Simplified to stylized network, simplified timetable and simple contracts. Big jump between session 2 and 3 when replacing capacity planners with computer reservation system that was similar conceptually.
# of sessions	3 subsequent games each with 1 session during 1 full day.
Type of data generated	Quantitative and qualitative, testing hypotheses about mechanisms that are assumed to have a certain effect on capacity allocation.
Consequences	Policy formulated but put out of scope for 2010/2011, possible application in 2012. Politically very sensitive.

Table 1. Core description of Rail Cargo Market Game

With respect to the three modeling issues we learnt that it is very hard to have operational level people in an abstract simulation when they have to work on infrastructure and timetabling they do not recognize. The usual flexibility that is commonly found in gaming with groups of higher education is not working here. To overcome this, we automated some of their tasks in the game into a computer model for train path reservations. This worked flawless for the more management-like question of this game.

5.2 Bijlmer junction game

This subproject introduced ProRail to a computer-based gaming simulation developed on ProRail's own MATRICS simulator (Van Luipen and Meijer, 2009). This simulation pushed the envelope in terms of utilizing the technical specifications of MATRICS. This type of game was described as a multi-player process simulation due to its detailed reflection of real-life operational processes. The participants play a pre-defined role that is 100% identical to their job description, to carry out their real-life duties in a simulated game environment. Table 2 lists the core description of this game. For a full description we refer to Meijer et al (2009).

Core aspect	Description
Purpose	Testing and validating a control concept for high frequency train transport.
Roles	Train driver (2), Train traffic controller (3), Network controller (5)
# of players	10 plus 2 facilitators and 2 experts.
Own/real/fictitious role	Own role, participant selected by their team leaders
Scenarios	3 Scenarios, gradually testing more complexity.
Intervention range	Facilitators could start, stop and pause scenarios and interfere with train driver behavior.
Simulated world	Detailed infrastructure between Amsterdam and Utrecht, detailed timetable.
Immersion	Very fast and deep for train drivers and network controllers. Difficult for train traffic controllers; see discussion in Meijer et al (2009).
Time model	Continuous
Data presentation	Highly detailed through computer interface. Interface different from real-world abstraction.
# of sessions	1 full day session
Type of data generated	Quantitative (failed) and qualitative.
Consequences	Data generated in the game yielded insights in key materials and resources needed for implementation of the control concept, and high-frequency planning in general.

Table 2. Core description of Bijlmer Junction Game

ProRail had assigned a project team to come to new control and steering procedures that suite the future reality of high-frequency passenger trains. The challenge of this project team was to come up with new concepts that would both be supported by train traffic controllers and network controllers, and would yield a stable, controllable control and routing operation when put into place. The question was raised: how to test new control and steering concepts when there is no option to test in real life? The Bijlmer Junction Game was targeted at this. In the game the interaction of train drivers, traffic controllers and network controllers was crucial, as studied earlier by Albrecht (2009).

The gaming simulation session yielded insights in key materials and resources needed for implementation of the control concept, and high frequency planning in general. The importance of buffer areas with sufficient space to side-track a train without disturbing other services, platforms asides the entire train for passenger exit, and alternative departure options for all passengers within reasonable time is a clear outcome for ProRail. Furthermore, train traffic controllers do not yet seem to realize what the projected high-frequency planning will mean in practice for their tracks.

As described in Meijer et al (2009), this game was not a break-through success. We learned that involving the operational people in the organization in a game that modeled the infrastructure and timetabling as detailed as they are used to, requires interfaces that connect to the situation awareness capabilities of these operators. Simple said: even though we checked our approach upfront with the operators, they were not able to do what they

though were capable of due to different visualization. Luckily, the debriefing and discussions still yielded sufficient data of sufficient quality for ProRail to be able to contribute to the problem solving. For the gaming team, this experience led to the development of the following game.

5.3 Railway bridge game

The subproject Railway Bridge Game (for a bridge over the river Vecht) introduced ProRail to the process management game, a computer-based gaming simulation for which new software was developed. Over the course of one week, various train traffic controllers played this game in a single-player environment using a series of scenarios. The type of game was described as a single-player process simulation. Table 3 gives the core description of this game. More information can be found in Kortmann and Sehic (2010).

Core aspect	Description
Purpose	Studying a new regime for bridge openings on the busy Amsterdam – Amersfoort corridor.
Roles	Train traffic controller. Bridge operator (simulated)
# of players	1
Own/real/fictitious role	Own role.
Scenarios	5, each subsequent day the same train traffic controllers played one scenario of increasing complexity
Intervention range	Facilitator played other roles
Simulated world	Detailed infrastructure, detailed timetable
Immersion	Good to very good. More experienced train traffic controllers had more hesitancy towards the computer system, but once used to it scored better with more situation awareness.
Time model	Continuous
Data presentation	Detailed through near-familiar computer interface.
# of sessions	1 session, full week
Type of data generated	Mainly quantitative (measured actions and train throughput, questionnaires) and qualitative from interviews
Consequences	None as of 2011, new game with improved interfacing planned for winter 2012 testing more details.

Table 3. Core description of Railway Bridge Game

The Railway Bridge Game was positively received. It learned that the drawbacks of the interface problem signaled in the Bijlmer Junction Game could be overcome by making special gaming modules. In these modules the representation of the infrastructure and the control options can be made closer to the real world systems. Given the differences between experienced and less experienced controllers we conclude that more resemblance is better for immediate immersion, but not necessarily related to the quality of the decision once a certain threshold of realism is reached.

Playing the game showed its potential to help solve the bottleneck of the Vecht Bridge on the OV-SAAL rail corridor. Under increasing loads of timetabling the experienced operators scored significantly better than operators in training. Under light loads this was the other

way around, showing the difficulty of experienced people to overcome differences in the user interface, but as soon as craftsmanship was required to minimize delays the experience helped keeping control.

Both single-player and multi-player gaming simulation were readily welcomed by almost all of the stakeholders in the organization as a valuable new resource for ProRail as an organization. The aspect of the multi-player gaming simulation that prompted a particularly positive response was the opportunity to test the feasibility of timetables, control concepts and exceptional situations in a setting that includes several layers of management and/or control areas. The aspect of the single-player gaming simulation that prompted a particularly positive response was the opportunity to train and practice in relation to exceptional situations and future timetables and infrastructures in an offline setting, using simulated trains.

5.4 ETMET 2010

One of the two strategic innovation trajectories to come to the desired capacity increase is the program to come to a metro-like timetable on the major corridors. On the Amsterdam – Eindhoven corridor this program is titled 'Every Ten Minutes A Train' (Elke Tien Minuten Een Trein – in Dutch), shortly ETMET. In the fall of 2010, the largest train operator National Railways (NS) and ProRail tested this concept for a full month in the real operation. This program required substantial preparation, and gaming simulation was selected through the senior staff involved in earlier games to answer questions about two ways of handling a major disruption under the new timetable. This resulted in the ETMET 2010 Game, described in Table 4.

In the ETMET 2010 Game we simulated the train flow and all processes and interactions in the train control, personnel and rolling stock processes. The wish was to have the train traffic controllers working on gaming modules similar to the one in the Railway Bridge Game. Soon during the development we found out that the underlying rail traffic simulators available did not support the required actions of turning around, skipping a service or renumbering rolling stock to different train services. Therefore the decision was made to create a complete manual, analog simulator, observed with cameras overhead the infrastructure maps, distributing views similar to the regular computer visualizations to three rooms with operators.

The session delivered the data required to answer the question on the differences between two methods of handling a major disruption. The project management assumed the new method to be beneficial for resilience, however they proved wrong. The new method essentially provided a pre-defined pattern for guiding trains over a double track where one track is blocked. The network and service controller had to makes their choices out of the set of trains currently running on the tracks, approaching the blocked track. Remaining trains have to be cancelled or coupled. This was assumed to be a better solution than the old solution in which there is a separate document for every possible interaction between two trains. It appeared however, that the choices for assigning trains to the pattern were impossible to make, given the interactions that all the trains available have with other parts of the system. While working on a solution the situation changed too fast to make a single decision in time, while overseeing all of the complexity.

Core aspect	Description
Purpose	Testing the differences between two mechanisms of handling a major disruption under High Frequency Transport scheduling
Roles	Train traffic controllers, Passenger information, Driver rescheduling, Rolling Stock rescheduling, Platform coordinator, Decentralized network controller Network controller, Service controller.
# of players	14 in role, 9 in support roles in analog simulator center, 6 observers, 1 host, 1 game leader
Own/real/fictitious role	Own roles, invited on personal title however with support of management.
Scenarios	2 scenarios: first the 'old' way and then a new mechanism
Intervention range	Facilitators could start, stop and pause the scenarios.
Simulated world	Detailed infrastructure Utrecht - Geldermalsen, detailed high-frequency timetabling, essentials of communication lines between different offices involved. Stylized passenger flow.
Immersion	Full immersion in a few minutes. Conflicts arose, leading to a time-out by the game leader to settle the issues and go back to a state all could agree on. Extremely involved and lively game play.
Time model	Continuous
Data presentation	Infrastructure representation in familiar schematics, detailed timetabling on paper, time and delays through simple interfaces.
# of sessions	1 session, full day
Type of data generated	Quantitative and qualitative, testing hypotheses about differences between 2 mechanisms.
Consequences	Proposed solution abandoned based on data generated in the gaming session.

Table 4. Core description of ETMET 2010 Game

In this game all data was completely detailed available to all participants, on paper, and mostly in a format they recognize, using all real-world abbreviations and notations. Contrary to many games in which the designer abstracts and reduces to a level where it is not about managing large amounts of data, it proves to be very well possible to give operators this data. It even helps to give them situation awareness, as in the debriefing all were confident that their behavior and reactions were similar to what they would to in practice, and all could work with the data supplied.

5.5 NAU

Utrecht Central station is the heart of the Dutch rail network: here come trains from all directions together in a versatile, but consequently complex knot. The complexity and interdependence of the many train movements and other activities makes Utrecht very vulnerable to chain reactions of delays. For large disturbances, history has repeatedly shown

that the risk of flooding and even completely crashing the traffic flow is high. Resilience and robustness of the Dutch rail network therefore has to consider Utrecht as a key parameter.

In previous years the timetable has been 'disentangled', meaning that trains are assigned to a corridor and that these corridors are planned to have as little interference with each other on the physical infrastructure as possible. Now, after ProRail disentangled the schedule the aim is to reduce the interference further by matching the control concept to the corridors. For this the NAU (New Action plan Utrecht) program was launched.

Within the NAU program five goals have been identified:

1. ensure that the basic plan remains within the corridors;
2. limiting defects through maintenance / inspection;
3. Limiting deviations from shunting;
4. limit abnormalities in major disruptions;
5. adjust the division of labor in the Traffic Control Post.

Gaming simulation has been selected as a tool to try out the concept first in a simulated environment before it will be brought to the control post. During the game the effect of the new concept on goals 1,4 and 5 had to be researched. Table 5 describes the game details.

The main result of the NAU game was empirically based insight in the fundamental consequences of reducing the number of switches used and corridor control on capacity, resilience and robustness. In the old situation, the capacity reduces rapidly as the disturbance level increases. Due to the many switches, many options remain in heavily disturbed situations to continue driving, requiring a mastery level of the train controller. These options cause 'infection' of problems of one corridor to others. When using corridor control in its strict sense, the process remains more manageable with mild to moderate disturbances. But because the control options are limited to the corridors, there comes a moment in the corridor that all capacity is lost, still not affecting the other corridors. There's a tipping point where the limits for a disturbed corridor become unacceptably high. At this tipping point it can help to deviate from the corridor principle. The ideal situation is to control & isolate the corridor as long as possible and use other parts of the infrastructure only when the critical level of disturbance is reached. In other words: you want to cash the potential of corridor control and avoid potential losses. Where the disturbance level is critical, how often this situation occurs and what specific deviations must be allowed, is still open for further research.

In the NAU game modeling we re-used the infrastructure schematic layout and timetabling information that was so successful in the ETMET game. Yet again this proved to immerse the participants in the simulation within a few minutes, and to make them enact their role perfectly. In this post-game evaluation the participants rated their behavior as highly realistic. The only exceptions to this were the network and service controller who both work at the national level. For them there was no game material to play with apart from information derived from the simulated area. This resulted in less emersion and a bit grumpy atmosphere in which they were mocking about the new concept. For the project this proved functional as their comments in the discussion raised important points for the improvement of the concept, but the game play from them was not optimal. Therefore no direct conclusions could be drawn from the interaction between the national and regional level.

Core aspect	Description
Purpose	Testing the improvements in resilience and robustness when introducing a new control concept for Utrecht Central station.
Roles	Train traffic controllers, Decentralized network controller, Driver rescheduling, Rolling Stock rescheduling, Platform coordinator, Network controller, Service controller.
# of players	9 in role, 4 in support roles for analog simulator, 3 observers, 1 host, 1 game leader
Own/real/fictitious role	Own roles, invited on personal title however with support of management.
Scenarios	2 scenarios: first the 'old' way and then a new mechanism
Intervention range	Facilitators could start, stop and pause the scenarios.
Simulated world	Detailed infrastructure Utrecht Central, detailed current timetabling, face-to-face communication lines between different offices involved. Stylized planning tools
Immersion	Instant and very good for all players, except for network controller and service controller who were less immersed, showing in discussions about other topics.
Time model	Continuous
Data presentation	Infrastructure representation in familiar schematics, detailed timetabling on paper, time and delays through simple interfaces.
# of sessions	1 session, full day
Type of data generated	Quantitative and qualitative, testing hypotheses about improvements with new control concept. Numbers real enough to base decisions on.
Consequences	New control concept embraced, actions defined to counterbalance penalty for major disruptions. Invention of the concept of pre-defined handling scenarios for non-availability of small parts of the infrastructure. Heavy post-game discussions leading to high-level decisions on the project.

Table 5. Core description of NAU Game

5.6 Platform overnight parking (POP)

In the capacity planning process for 2012, two service areas have been declared out of capacity and ProRail is obliged, according to law, to find solutions to solve these capacity shortages. The goal of this game is to determine whether it is possible to orchestrate a 'carousel process' around Hoofddorp so that scarce capacity in the service area can be increased. This means that after servicing and technical controls at the service area the train is then drawn along the (platform) tracks of Hoofddorp station or Middle Hoofddorp.

Core aspect	Description
Purpose	Answering the question how many pieces of rolling stock could be parked along the platforms of stations during the night, given the processes of cleaning and maintenance that have to be performed at service areas. Question asked for two locations: Amsterdam-Watergraafsmeer and Hoofddorp.
Roles	Train traffic controller (2), Foreman of cleaning (2), Train driver, Service area supervisor.
# of players	6 in role, 2 support for illiterate cleaning foreman, 3 observers, 1 host, 1 game leader
Own/real/fictitious role	Own roles, invited on personal title however with support of management.
Scenarios	1 scenario per location (Plus 30 minutes 'warm up' scenario)
Intervention range	Facilitators could start the simulation and determine the time required for each 5 minutes of simulated time.
Simulated world	Detailed infrastructure Amsterdam Central – Amsterdam Watergraafsmeer and Hoofddorp, detailed timetabling for end-of service of trains. Detailed service demand,
Immersion	Immediate for train traffic controllers and service area supervisor. Foremen took some time, being illiterate and not used to any abstraction, but came in role in 15 minutes.
Time model	Step-wise.
Data presentation	Infrastructure representation in familiar schematics, detailed timetabling on paper, time through simple interface, cleaning capacity in simple game objects.
# of sessions	1 session, full day
Type of data generated	Quantitative and qualitative, delivering a range of rolling stock feasible to park
Consequences	Potential yield for Amsterdam-Watergraafsmeer too unsecure given additional complexity of extra night maintenance in the years 2012 – 2013. Solution considered for 2014. For Hoofddorp the yield found in the game was verified in the field and implemented for 2012.

Table 6. Core description of Platform Overnight Parking Game

By 'gaming' these processes it should become clear whether and to what extent the (platform) rail capacity can be used for the preparation of passenger rolling stock. If a carousel process is theoretically feasible, then follow-up actions are defined to carry out a practical test. Table 6 describes the core features of the game.

The game delivered the results requested in time, by which it became the first game in the row of six that not only drew conclusions based upon the mechanisms of the game play, but also on the numbers generated in the game. Halfway the first scenario in the session there was an intervention required because the service area supervisor felt that the game play was 'not realistic'. After a thorough joint review it appear there were two trains left in the wrong location. The game leader corrected this, and from this point all agreed the outcomes were valid and representative for a normal evening with no major disturbances.

In this game the modeling of infrastructure and information followed the infrastructure schematic layout and timetabling information that was previously successful in the ETMET and NAU games. The time was for the first time not continuous but step-based. The reason for this was the long time to simulate (6 hours) during which many moments are trivial, as trains stand still and some cleaning is done. As no more game time than 2 hours per scenario was available, a speed-up was required, but just faster time would not contribute to the game as some time periods need more attention than others. The solution was found in 5-minute time steps in the game time that could take anywhere between 30 seconds to 20 minutes to execute in clock-time. In this way the players (most of them operational practitioners, two of them near illiterate) could keep up with the more abstract representation of their real work. The two foremen of the cleaning teams had most issues getting involved. Their whole task consisted out of taking 1 toothpick out of a wagon once it was cleaned, and they could each take out one stick per 5-minute step. Once they got used to this task they could make choices for priority over the service area easily and got their behavior realistic according to both their own and others judgments.

6. Methodological challenges

In this section the lessons learned on methodological challenges are discussed on two levels. The first subsection answers the three modeling issues raised in Section 4. The second subsection discusses how to guarantee validity in gaming simulations for railways.

6.1 Modeling issues

In the six projects, the modeling issues appeared to have a large interaction. The question how to immerse train traffic controllers in a gaming simulation appears to be largely dependent on the display of information. For train traffic controllers we learned that a detailed representation of the infrastructure is key for their involvement. However, the geographical representation did not work, where the common abstracted versions as used in practice performed flawlessly, both in digital (RBG) and in analog game board format (ETMET, NAU, POP). More abstraction and reduction of complexity of the infrastructure does not work for operators (RCM). For the timetabling and similar information like personnel and rolling stock planning similar mechanisms worked: give the players the information on a detailed level but keep the format they are used to in practice, even tough the medium (computer or paper) is different. The same held true for delays and other process information. Once the delays are presented directly after a train number in the format of +3, +5, + 10 minutes everybody understood it immediately. Once the players could understand the information well they could concentrate on their task, which they automatically did fully immersed.

Regarding the question how to model time we learned that the logical model of continuous time for rail operations works well and puts pressure on the process. In the ETMET game the frustrations over problems under time pressure became so high that the game leader had to intervene, and other games showed real pressure on the players who are so aware of the real-time nature of their real-world process that this can be triggered immediately in the game. Care should be taken to give players sufficient situational awareness without all their real tools available. Based on the experiences with the Railway Bridge Game versus the

analog games to expect that continuous time will improve on stress and pressure level when computer models are more easily deployable and integrated in the games. Analog simulators are surprisingly good but require extensive and thus expensive expert support.

6.2 Validation

The sessions usually run only once. Drawing conclusions on just one session puts emphasis on the validity of the behavior observed and decisions made in the simulation. The number of people to validate a full game with is limited in terms of availability (they work in de 24/7 operation) and costs, validation approaches need to be done differently. By modularizing the toolkit of gaming into sub-models and software components, validation of the components can be done outside of the final game sessions in analogy with the recent insights in multi-agent simulation of social systems (Gilbert, 2011). Work on the validation requires deeper understanding of train traffic control and train driver behavior. This encompasses the knowledge base in the organization. Work on this gives methodological challenges that go beyond the literature on gaming methodology (Peters et al, 1998).

In the railway gaming simulation described above (but for the RCG) processes of self-validation were used to overcome the validation issue for now. During every session signs of discomfort of the players and comments on 'how real' something was were constantly monitored and discussed openly even if this led to time-outs or moments of difficult discussion during the game play. The game leader always stated that everything to make the session better would be welcome at any time. In the debriefing the explicit questions were asked: which part is realistic and which part would be different in the real world, and why? This gave often very valuable information, even when in case of the NAU game when the network and service controller were not very involved in the game play, but could comment and criticize the validity very well.

By ensuring immersive game play and having the self-validation during the games the Raser categories of psychological reality and process validity are addressed to an extent that is satisfying for the organization. The structural validity is a design issue and is difficult to improve when using analog simulators. You simply cannot model the exact train flow and safety and interlocking systems in an analog way. Computer simulators have a lot to offer here in interaction with the players during a game session. This is future work for integration. The predictive validity is currently under review as the project follows all game projects longitudinally to determine the extent to which the conclusions based upon game sessions hold true in the real operation. Future work will report on outcomes.

7. Conclusions

The series of six projects shows the purpose and usefulness of building gaming simulations to help the Dutch railway infrastructure manager ProRail innovate on its core processes. Over the projects methodological lessons on involving operators as game participants have been drawn, as well as for the abstraction and reduction of information and the modeling of time. These modeling challenges appear to be highly interrelated. The lessons learned show the need, contrary to the traditional modeling approaches in gaming simulation, for very little abstraction and reduction in modeling the game where it concerns items that the operators have to play with. The model for less operational aspects can be more abstract, in

line with literature on the need for fidelity for learning in games. While this finding may be not surprising to experienced game developers, the value of using abstractions that are used in the real world for the game is new.

As the game projects reported in this chapter are not for learning but for testing of designs and hypotheses, the findings on how to make real operators show valid behavior in a game session contributes to the small but growing field of gaming simulation for testing. For the categories psychological reality and process validity the current approach has found ways to address given the limited time and capacity available for traditional validation. For structural validity and predictive validity future work is defined.

The sequence of gaming simulations led to a successful introduction in the ProRail organization of the gaming method. Full support has led to a four-year partnership between academics and the operation to make gaming suited for ProRail and ProRail suited for gaming. Once this project has been carried out, ProRail will have at its disposal a gaming suite that connects with existing rail traffic simulators. The gaming suite will make it possible to configure a game simulation session without the need to call in outside expertise by selecting timetables, locations, actors, duration and measurement variables. The key feature is the possibility to create 'what-if' scenarios. The outcomes of these scenarios support the decision-making process by providing an understanding of the problems and the pros and cons of the possible solutions.

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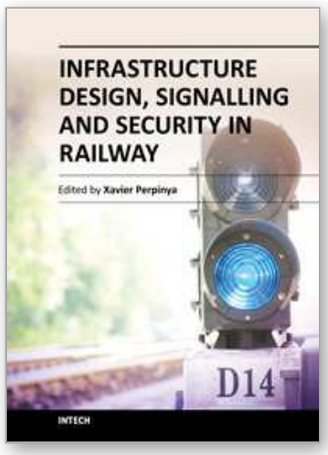
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Railway transportation has become one of the main technological advances of our society. Since the first railway used to carry coal from a mine in Shropshire (England, 1600), a lot of efforts have been made to improve this transportation concept. One of its milestones was the invention and development of the steam locomotive, but commercial rail travels became practical two hundred years later. From these first attempts, railway infrastructures, signalling and security have evolved and become more complex than those performed in its earlier stages. This book will provide readers a comprehensive technical guide, covering these topics and presenting a brief overview of selected railway systems in the world. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, and engineers.

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