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A serious maintenance management game for decision-making on digitized railway assets

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Abstract

The life cycles of information technology (IT) components are notably distinct in both duration and nature when compared to their physical counterparts, commonly referred to as operational technology (OT). However, OT is increasingly getting converged with IT technologies. To ensure effective oversight of these converged IT/OT assets throughout their life spans, it is imperative to align the various stakeholders. Critical areas for achieving this alignment in the context of IT/OT converged assets encompass cybersecurity and the management of maintenance processes. This paper presents a design for a "Maintenance Management Game". The purpose of this game is to educate maintenance professionals managing IT/OT converged assets. As part of the game mechanics, the players must make decisions trading off the different objectives and needs of a fictional railway company. The game mechanics are developed using design science research and employ the iterative process of participatory prototyping. The initial findings indicate that the game is an engaging approach to learn about managing and maintaining digitized railway assets.

Keywords: Cyber-physical systems; Maintenance; Operational technology; Information technology; IT/OT convergence; Digitized systems; Asset management; Railway

1. Introduction

Physical machines or systems were (electro)mechanical and capable of functioning as stand-alone systems until the dawn of the twenty-first century. Engineers and (electro)mechanical mechanics were responsible for the development and maintenance of these systems. Operational technology (OT) is the term used to describe the systems that control these conventional systems [1], [2]. Whereas information technology (IT) systems are used to control data [2].

The result of this digitization is known as the IT/OT convergence of assets, which introduces (IT) elements into the OT domain [3], [2]. This convergence consists of both OT using real-time IT data to control processes and using IT hardware instead of traditional proprietary solutions [1]. Advantages of this convergence include cost savings, improved performance (higher reliability), increased system adaptability, and lower risks [4]–[6].

However, this IT/OT convergence requires a shift in maintenance practices as software becomes more important within an asset. For example, about a decade ago IT was introduced into Dutch rolling stock providing passenger information and Wi-Fi services for the passengers [7]. Nowadays, digitization (e.g. ERTMS) is essential for much-desired improvements in passenger service and for future improvement of the entire railway industry. Poliński & Ochociński [8] provide an overview of the different digital developments that can improve both the operation as well as the maintenance processes within the railway industry. In practice, the notion of maintenance diverges between the domains of Information Technology (IT) and Operational

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Technology (OT). Within the realm of software engineering, maintenance entails the identification and rectification of defects that have already been introduced into the system. Conversely, traditional maintenance engineering in the OT domain is focused on the prevention and resolution of issues that manifest during the operational phase [9]. Also, during design for maintenance of physical systems the main focus is on the actual hardware parts, often neglecting the IT [10].

Since the lifecycles of IT and OT components of the system are different, the question is to what extent this difference influences the management of these converged assets. The absence of asset management strategies tailored to IT/OT converged assets now does not imply a lack of study in this area. Scholars have recently highlighted several elements that must be in place to ensure the successful decision-making of IT/OT convergent assets during their lifetime [2], [5], [11]–[14]. For example, maintenance strategies change and cyber risks need to be identified and managed [2], [5], [12], [13].

In this paper, a Serious Game (SG) is presented to educate and connect design and maintenance professionals in exploring maintenance strategies for effective management decision-making in managing IT/OT converged railway assets.

2. Serious games

The selection of an SG as a method for facilitating an understanding of IT/OT challenges is based on previous research on the efficacy of serious gaming as an educational tool. This research suggests that: *"engagement, simulates a collaborative socialization, and transfers, at the same time, proper educational competencies."* [15]

Several literature reviews investigate the effects of serious gaming and the effect on achieving certain learning goals. For example, a literature review on the impact of specific learning objectives states that games promote effective learning. More specifically they suggest that effective learning can be achieved when games are created with a focus on multiplayer cooperation [16]. Game design elements like collaboration, competition and role play help to achieve the learning outcomes of a serious game, according to a literature review on the learning effects of different game design elements by Qian and Clark [17]. Also, Krath et al. [18] extract five basic principles from their review that explain gamification. For example, gamification can illustrate goals and their relevance and simplify content to manageable tasks.

In literature, several game design methods can be found. For example, in their book Salen & Zimmerman [19] provide a comprehensive introduction to the field of game design. This foundational work serves as a valuable resource for understanding the fundamentals of game design. Additionally, several game design frameworks can be applied in serious game design. For example, mechanics, dynamics, and aesthetics (MDA) [20] or the design, play and experience framework [21], these kinds of methods are often iterative.

SGs are rarely standalone exercises and require facilitation, briefing and debriefing [22], [23]. Furthermore, the literature indicates that SGs can be used as case studies [22], [24]. Lastly, Landers, Collmus et. al [25] show competition can increase human performance.

Currently, there are no solutions available to educate practitioners on how to approach the challenges of IT/OT converged systems. Therefore, a serious game on maintenance management of IT/OT converged systems is proposed.

3. Methodology

The SG has been developed utilising participatory prototyping, a unique method for developing serious games. In this method potential future players and different stakeholders co-design game components [26], [27]. To structure this research participatory prototyping is incorporated within the design science research methodology (DSRM) from Peffers et al. [28], see Fig. 1.

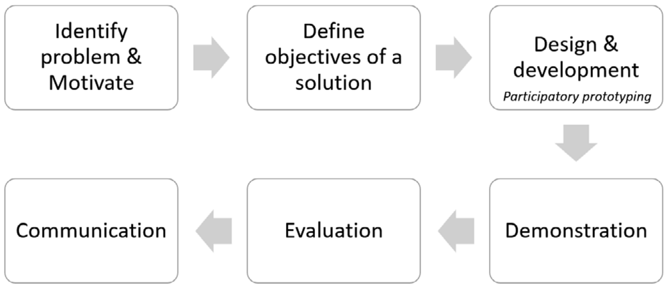

Fig. 1. Iterative game design process adapted from [28].

3.1. Identify problem and motivation

The primary issue is that, as assets become more complex, communication between departments within asset management organisations is needed to avoid sub-optimal decision-making [29]. Furthermore, current maintenance strategies are not always suitable for IT/OT converged assets [30].

3.2. Design objectives

The purpose of the proposed game is to educate and connect design and maintenance professionals in exploring maintenance strategies for effective decision-making in managing IT/OT converged railway assets. This game builds upon an existing logistics support game [31]. In this game, the focus was on the logistic impacts of train operation and maintenance. However, the newly developed game has a different objective. One of the objectives of the game is to introduce the players not only to the traditional asset management roles and responsibilities but investigate whether the inclusion of new IT-based game mechanics can help raise awareness of the effects of IT/OT converged assets. Based on semi-structured interviews with practitioners, the following learning goals (LG) were identified:

- LG1: Understand the different responsibilities (operations, maintenance, financial etc.) within an asset management organization and the effects of IT/OT convergence on these roles.
- LG2: Understand that communication between these different responsibilities is key in balancing resources and needs between maintenance and operations; and that the addition of IT creates additional (communication) challenges.

- LG3: Understand that maintenance practices change as the lifecycles of IT and OT do not necessarily match.
- LG4: Understand that IT/OT convergence might bring benefits and additional maintenance efforts.

3.3. Designing game mechanics

Within the design and development step the following iterative steps are followed:

1. Interviews with several practitioners
2. Prototype design by the researchers
3. Test session with the experts
4. Evaluation of the results via a questionnaire
5. Review of the results by the researchers

As a first step several practitioners from a Dutch railway company have been interviewed, using semi-structured interviews. Based on the output of the interviews and the experience of the researchers a basic prototype of game mechanics was made. Several iterations were made in the development of the additional game mechanics. Each design iteration is followed by a design review. This review is used to clarify the goals, mechanics, and details of the game design.

3.4. Evaluating game mechanics

Game validity can be established by applying three different steps [32]:

1. Use a participatory way of working.
2. Test the game content.
3. Verify game organization, e.g. are all the descriptions clear, are there enough game cards etc.

Steps one and two are implemented by involving future players in the design process, interviewing professionals and organizing test sessions among practitioners. Step three is done by organizing test sessions with students and staff members.

Evaluations are organised in three different ways. First, during each session, observations will be made by the researchers. Second, each participant will be asked to complete a digital questionnaire. Third, the session will be completed with a post-game discussion.

4. Game mechanics

Based on each of the different game mechanics, the final game design will be detailed in this part.

4.1. Objectives for the players

The players need to find a profitable match between the level of digitization, the operation of the train fleet and the maintenance system. The game provides opportunities to explore alternative asset management strategies and approaches. Therefore, the game simulates the deployment, operations and maintenance processes and the effect of IT on these existing processes.

4.2. Roles within the game

During the progression of the game, participants assume various roles, and they are required to make decisions from their viewpoints. There are four distinct roles within the game:

1. The **operations manager** is responsible for the operation of the train fleet. He/she must make sure that the right amount of capacity is available at the requested moment. For example, if a capacity of 150 persons is needed but there is maintenance upcoming which reduces the availability of the current trainset by 50% and there might be unexpected failures. Should an extra trainset be acquired and is there a budget to do this?
2. The **maintenance manager** is responsible for the maintenance facilities. He/she must make sure that the right facilities are available to maintain the different types of trains. For example, should the IT facility be upgraded to be able to upgrade current trains with IT capabilities and thus increase revenue? Consultation is needed if there is a budget and facilities available to do this? Or should we continue with the current fleet and only invest in IT when buying new trains?
3. The **financial manager** is responsible for managing the finances of the operation. For example, end of each round the revenues and costs incurred need to be calculated. So that at the beginning of each round, the financial manager can aid the other players if there is sufficient budget available to invest.
4. The **fleet manager** is responsible for the maintenance profile of each type of train. He/she must make decisions over the different lifecycles and communicate what type of maintenance is coming up. For example, if two types of trains have an overhaul coming up in the same round, this will have severe consequences on the availability of the fleet, the fleet manager will have to decide to either defer the maintenance or discuss it with the operations manager and the financial manager to buy an additional trainset.

4.3. The gameboard

The gameboard is where the game takes place [19]. The concept design of the gameboard can be found in [31, p. 142]. In this gameboard, several different train cards are presented at stations A, B and C. Each station also depicts the required capacity per round. Next to this several maintenance facilities are shown along the railway tracks.

4.4. Fleet management board

A fleet management board is available for the fleet manager, this board gives an overview of the upcoming maintenance activities of each of the train types located on the game board.

4.5. IT game mechanics

Next to the traditional OT game mechanics from the previous sections each train can be upgraded to an “IT-enabled” train, see Fig. 2a. The positive side of this upgrade is that more revenues are being generated due to higher customer satisfaction, due to better passenger services (e.g. Wi-Fi, Realtime passenger information etc.) and better performance due to predictive maintenance capabilities.

The downside however is that this upgrade costs money and extra maintenance is needed. To provide for this maintenance an IT maintenance facility is needed, see Fig. 2b. for this game mechanic. For the IT maintenance facility, three modules are available:

1. Software maintenance
2. Firmware maintenance
3. Hardware maintenance

These modules are to be bought separately within the game.

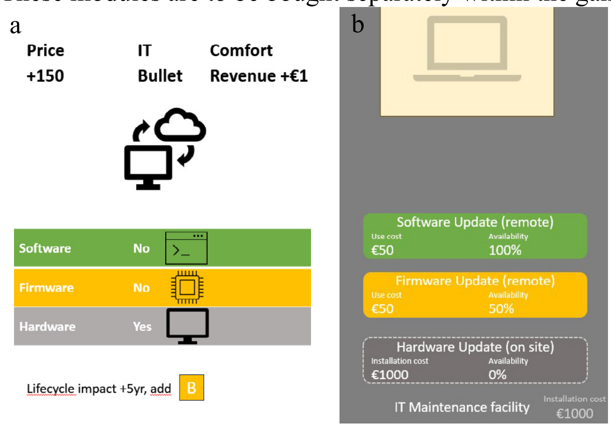

Fig. 2. (a) IT-enabled train card (b) IT Maintenance facility including software and firmware building blocks.

4.6. Playing the game

4.6.1. Players and game leader

The game can be played by four or five players. Multiple game sessions can be held at one time where different teams can compete against each other. Each of the game sessions is guided by a game leader.

The complete instructions on how to play the game are available to the different game leaders in an instruction manual.

4.6.2. Game session

At the start of each game session, the players start with a predefined setup consisting of an allocated budget, two maintenance facilities, one IT facility and several modules within the facilities enabled. Also, the players have a fleet of trains, both regular and IT-enabled. The age of the trains is different, as are the types of trains in the fleet.

Each game session consists of multiple game rounds. One round consists of four different steps. The first step, planning and investing, here the players decide if new trains and maintenance facilities need to be acquired. The primary target is the passenger capacity demand for each route. It is the participant's responsibility to ensure that their trains have enough capacity, taking any (partial) unavailability due to maintenance and overhauls for this round into account. The second step is the planned maintenance. Maintenance is performed on the trains in the fleet that are operational, this maintenance impacts the availability of the trains. This results in that trains may be taken out of service either partly or entirely depending on the type of maintenance.

What type of maintenance is needed in each round is shown on the fleet management schedule. The different types of maintenance are regular maintenance (R), basic maintenance (B) and overhaul (O). In the next step, unplanned maintenance is done, by rolling a dice. Depending on the number rolled and the type of train either no unplanned maintenance, extra basic maintenance or fault diagnosis is needed. In the final step, the financial inventory is updated. This consists of calculating the operational capacity that is met and deducting the investments made and the number of moments of the fleet. IT-enabled trains receive a higher revenue due to increased passenger satisfaction.

5. Results and discussion

5.1. Demonstration

The game was demonstrated within a group of 14 maintenance professionals from different industries including the steel and defence sector. Most of the group members were maintenance managers and maintenance engineers. Experience ranged from 5-10 years up to >25 years of experience. For the demonstration, the group was randomly divided into three separate groups. Two groups consisted of five people and one group consisted of four people. Also, each player was assigned one of the four roles, that are available within the game. Each of the groups was guided by a game supervisor. This game supervisor was one of the authors of this paper.

Before the start of the game, a plenary introduction was given to the distinct groups. After this introduction, a test round was played to get the players acquainted with the game and with their roles within the game.

After the test round, the actual game started. Eight game rounds were played. After each round, the game leader entered the results of his group into a spreadsheet. Within this spreadsheet, it is possible to visualise the results of each team and investigate the performance of each team on several KPIs. These KPIs are cash breakdown per round, overall cost breakdown and cash after each round.

5.2. Evaluation

In this section, the learning goals of the game will be evaluated using observations and the questionnaire as completed by the participants after playing the game, see Table 1.

Table 1: Feedback and observations on the learning goals

#LG	Feedback from observations and questionnaire
LG1	Balancing the different elements of the game is difficult, however, this corresponds to the daily practice of the participants.
	Four respondents indicated that the tradeoff between investments, operation, and maintenance was recognizable from the daily practice. However, the exact goal of the game could have been more clearly stated.

	The group that tested the game consisted of maintenance staff, which resulted in maintenance optimization. Instead of optimizing other aspects e.g., revenue or passenger satisfaction.
	Interestingly, the different groups had different strategies.
	Group 1: Invested in IT - Mixed fleet both trains with and without IT.
	Group 2: Invested heavily in IT - All trains had IT.
	Group 3: Did not invest in IT - Fleet with limited use of IT.
LG2	One of the teams decided to have a separate IT maintenance manager as it was too difficult to oversee both the OT as well as the IT maintenance by one manager.
	Consistency and cooperation between the different roles were needed.
	Interdepartmental communication was needed, and the common goal helped to achieve this.
LG3	The IT maintenance is not clear enough implemented in the game. For example, one team forgot to execute IT maintenance.
	Wheel maintenance has a big impact on availability. It was suggested to simplify this to better balance IT and OT maintenance.
	One team acquired a spare trainset to cope with unexpected failures.
	Maintenance was seen by one group as a cost center and not as an opportunity to generate revenue, “we don’t invest, only maintain”.
	One group was very lucky with the dice and thus had very little random maintenance. One other group had a round with bad luck and thus had much random maintenance.
LG4	Within the game, it is possible to invest in IT to generate extra revenue. However, the IT costs are too low compared to the investment cost of OT.
	Rolling with the dice for random failures seems to give limited IT failures.
	An additional IT investment step would emphasize the need to consider IT-enabled trains.

In Table 2 a summary of the learning goals, the related game mechanics, and the possible improvements is presented. The content of this table will be discussed in this section.

Table 2. Game mechanics mapped on the different learning goals.

Learning goal	Game mechanic	Feedback
LG1: Understand the different responsibilities within an AM and the effect of IT/OT on this.	Each of the players has one of the four defined roles.	Possible separate IT manager
LG2: Understand that communication is key; and that the addition of IT creates additional communication challenges.	The objectives of the different roles are different but also there is a generic objective for the team. Asset management board helps in communicating	Simplify OT maintenance and improve IT maintenance
LG3: Understand that maintenance changes as the lifecycles of IT and OT do not match.	IT game cards, IT maintenance facilities and fleet management board.	IT lifecycle needs to be implemented
LG4: Understand that IT might bring benefits and additional maintenance.	Supported by IT game cards and IT maintenance facilities.	IT costs should be higher

The first learning goal was to understand the different responsibilities within an AM organization. From the responses to the questionnaire of the players, this aspect is met by the current game. Also, the players recognized the merger of IT with OT from practice. However, the effects of IT/OT convergence on these roles were less clear. Currently, the maintenance manager is responsible for the IT and OT maintenance. However, this led to the optimization of OT maintenance where IT maintenance was sometimes forgotten. In a future version of the game, this could be solved by introducing a separate IT manager.

The second learning goal was to show that collaboration and communication between different departments will lead to better results. This part was clear to the players, however, the increased complexity due to IT was not clearly enough implemented. In the current game, the OT maintenance is a bit too complex. Also, IT has a very positive business case and the downsides - more maintenance and more unexpected failures - do not have a very prominent role. To overcome this the OT maintenance should be simplified and the IT maintenance tasks should be made clearer.

The third learning goal was to understand that maintenance practices change as the two lifecycles do not necessarily match, one of IT and one of OT. This aspect was not clear to the players as none of the players recognized this in the game. In a future version of the game, an IT lifecycle should be introduced, just like the current OT lifecycle.

The fourth learning goal was to understand that IT might bring benefits but also additional maintenance efforts. It was interesting to see that the different groups all had different strategies. Especially since the strategy was not predefined. The teams that did invest in IT made greater revenues than teams that didn’t invest in IT. These strategies were based on how maintenance is seen within the respective industries of the players. So, if the players were not used to investing in IT, but just keep “things running”, then they didn’t invest in IT in the game as well. For these players, the game provided an opportunity to learn about the potential benefits of IT. However, the cost of implementing IT seems based on the reactions and empirical findings currently too low compared to the benefits. This is another possible change for a future version of the game.

A limitation of this research is the single case study approach, common in SG research [33]. To deal with this aspect the game has been tested with experts who work in different industries such as defence and steel industry. To strengthen the scientific value of the findings, replication studies will be carried out. Alternatively, a different version of the game could be created that is more generic and not rail specific.

6. Conclusion

In this paper, a first edition of a “Maintenance Management Game” was presented. This game has been developed using participatory DSRM, in which the needs of future users have been incorporated by including them in the development of the game. The game has been tested in two internal test sessions and one session together with practitioners from the industry. Interesting findings are obtained from the analysis of the available post-game data. The players not only enjoyed playing the game but also gave feedback for further improvements like simplifying OT maintenance and adding a lifecycle for IT. In a future version of this research, these results will be presented in more detail. Also, work on the game is still in progress.

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