Agent based simulation of workers' behaviours around hazard areas in manufacturing sites

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DESIGN OF A SERIOUS GAME FOR SAFETY IN MANUFACTURING INDUSTRY USING HYBRID SIMULATION MODELLING: TOWARDS ELICITING RISK PREFERENCES

Hanane El Raoui

Strathclyde Business School
Strathclyde University
199 Cathedral St
Glasgow G4 0QU, Uk

John Quigley

Strathclyde Business School
Strathclyde University
199 Cathedral St
Glasgow G4 0QU, Uk

Ayse Aslan

School of Computing, Engineering and
the Built Environment
Edinburgh Napier University
Merchiston Campus 10 Colinton Road
Edinburgh EH10 5DT, Uk

Jack Hanson

School of Engineering
Edinburgh University
Sanderson Building, Robert Stevenson Road
Edinburgh, EH9 3FB, UK

Vasantha Gokula

School of Computing, Engineering and
the Built Environment
Edinburgh Napier University
Merchiston Campus 10 Colinton Road
Edinburgh EH10 5DT, Uk

Jonathan Corney

School of Engineering
Edinburgh University
Sanderson Building, Robert Stevenson Road
Edinburgh, EH9 3FB, UK

Andrew Sherlock

National Manufacturing Institute Scotland
85 Inchinnan Drive
Renfrewshire, PA4 9LJ, UK

ABSTRACT

Reasoning about risk is an inherent part of the decision-making process, and consequently it is important to assess and measure individuals' risk preferences to inform policy recommendations. Traditionally, the evaluation of risk taking preferences has primarily relied on self-report questionnaires. However, these conventional methods have demonstrated significant disparities with real-world behaviours, which can compromise the validity of the data collected. To overcome this gap, serious gaming can be leveraged to replicate authentic scenarios, thereby supporting risk taking assessment. In this paper, we introduce a Serious Game (SG) designed to investigate workers' decisions to engage in risk-taking behaviour, in an

industrial manufacturing context. The developed SG serves as a tool to run incentivized experiments that aim to assess individual risk-preference, and incorporates two factors that can shape risk-taking behaviour in a manufacturing environment, namely the social learning and production pressure. To promote the players' motivation and engagement, we adopt the Learning Mechanics-Game Mechanics (LM-GM) framework in designing the game.

1 INTRODUCTION

Understanding the risk-taking behaviour of workers in manufacturing sites can inform decision-making, and help organizations to select the best strategies for improving the safety, and correct the deviant behaviour. This highlights the need for data on human decisions to engage in a risk-taking behaviour. In this study, we design a serious game to elicit risk-preferences of decision-makers, which differs from the classical methods used for gathering data on preferences. Before discussing the value of serious games as a data collection method, it is crucial to examine the conventional approaches used by researchers to gather information about risk-preferences.

Economists and psychologists have developed a variety of experimental methodologies to elicit and evaluate an individual's attitudes towards risk. The existing elicitation methods differs in their level of complexity. More complex methods are generally used for estimating parameters related to risk preferences in a model that assumes a specific functional form. These parameters are then used as a supporting evidence for or against specific theories of decision-making. In order to ensure meaningful results, these techniques demand a greater level of comprehension and mathematical proficiency from the participants, as inadequate understanding may compromise the accuracy of the outcomes.

Simple elicitation methods tends to be easier to comprehend for the subjects. For example, the Balloon Analogue Risk Task (BART) (Lejuez, Read, Kahler, Richards, Ramsey, Stuart, Strong, and Brown 2002) presents participants a series of choices wherein they must decide whether to increase their earnings by pumping air into a balloon, with each pump carrying the risk of losing all accumulated gains in case the balloon bursts. BART has also been used in investigating risk attitudes across various domains, including neuroscience (Fecteau, Pascual-Leone, Zald, Liguori, Théoret, Boggio, and Fregni 2007), drug and psychopathology (Hunt, Hopko, Bare, Lejuez, and Robinson 2005). Although, the applicability of risk preferences elicited through this method to other domains is uncertain.

Questionnaires are another frequently used method to elicit individual's risk preferences by relying on their self-reported propensity towards risk. Questionnaires basically involves general risk-related questions often assume that they are measuring a single, consistent risk preference that affects behaviour across multiple domains. Nevertheless, a significant body of evidence indicates that the risk preferences measured are significantly influenced by the domains in which they are elicited. Furthermore, questionnaires are commonly not directly incentivized. As a result, there is a debate whether the risk preferences elicited accurately reflect an individual's genuine attitudes towards risk.

Complex methods for eliciting risk preferences often involve presenting individuals with a sequence of choices between gambles. One such method, commonly used in economics, represents choices between gambles as multiple price lists (MPL) (Kahneman, Knetsch, and Thaler 1990). Although, despite its popularity, (Anderson, Burks, DeYoung, and Rustichini 2011) discovered that the risk preferences obtained through MPL had limited predictive ability regarding economic variables such as credit scores and job persistence, as well as non-economic behaviours such as driving accidents and smoking.

Given the limited predictive power of classical methods for eliciting risk preferences, using a serious gaming role-play experiment as a method of data collection could serve as a valuable addition to reported techniques. Indeed, serious games can replicate authentic scenarios, and provide a grounding choice context, which help in reducing the bias. According to (Koivisto and Hamari 2019), a well-designed game can elicit intrinsic motivation in players by providing feelings of mastery, competence, enjoyment, and immersion. However, traditional methods of gathering information through questionnaires and workshops often result in low participation and engagement, which can limit the validity of the data collected.

In this paper, we design a Serious Game (SG) to understand the workers decisions to engage in a risk-taking behaviour, in an industrial manufacturing context. The developed SG serves as a tool to run incentivized experiments towards eliciting risk-preference. The game include two effects that can shape human behaviour towards risk-taking in a manufacturing context : The social learning, and the production pressure effect. Details about the integration of these two effects in the game are provided in the section 2.

The reminder of this paper is organized as follows: Section 2 explains the relevance of serious gaming, and the features of our designed SG, Section 3 details the design elements, Section 4 introduces the Learning-Mechanics, Game Mechanics Framework, and demonstrates their implementation in the game, Section 5 presents the verification and validation techniques applied to the designed game, and we end up with concluding remarks and some perspectives.

2 THE SERIOUS GAME APPROACH

2.1 The Relevance of Serious Games

Serious games are games that are ‘designed and/or used for non-entertainment purposes’ (Bakhanova, Garcia, Raffe, and Voinov 2020). Such games have a wide range of developed uses in a variety of fields, and became particularly useful in education and healthcare (Bredl and Bösche 2013). There is also a wide diversity of serious game types: simulation games, quizzes, sandbox games, and video games, among others (Stanitsas, Kirytopoulos, and Vareilles 2019).

Over the past few years, there has been an increasing industrial interest in applying game mechanics to non-gaming situations, as noted by (Baptista and Oliveira 2019). This interest initially stemmed from the desire to enhance employee engagement in business processes by leveraging the social aspect of games (Sailer, Hense, Mayr, and Mandl 2017). The benefits of serious games for safety in various industries have been widely discussed. (Sitzmann 2011) present a meta-analytic review to evaluate the effectiveness of serious games for safety training across multiple industries. The authors found that serious games can improve safety knowledge and behaviour, as well as increase engagement and motivation. (Martín-Gutiérrez, Mora, Añorbe-Díaz, and González-Marrero 2017) reviewed the use of virtual technologies, including serious games, in education and training. They found that serious games can enhance the effectiveness of safety training by providing realistic and interactive simulations, immediate feedback, and engagement. Serious games have also been used to train manufacturing workers on machine safety and hazard communication (Landers 2014). These games simulate factory environments and scenarios to help workers identify and address potential hazards.

Despite the various existing application of serious gaming for safety, we have not come across any research exploring the utilization of serious games to elicit risk-taking preferences, in an industrial setting. In light of this, the aim of this study is to design a serious game as a data gathering tool, to understand the decisions of industrial workers to engage in a risk-taking behaviour which is outside the typical uses of serious games.

2.2 The Impact of Social Learning and Productivity/Safety Tension on Risk-Taking Behaviour

According to the social learning theory, individuals can acquire knowledge and skills through direct experiences, as well as by observing the behaviour and consequences of others (Bandura and Walters 1977). Previous research, in light of the social learning theory, has highlighted the impact of different types of coworkers’ behaviour on individuals, including absenteeism, and unhealthy practices (ten Brummelhuis, Johns, Lyons, and ter Hoeven 2016). The social learning theory suggests that when individuals repeatedly observe their colleagues engaging in unsafe actions, they may consider deviating from safety rule as acceptable, and may be more inclined to imitate these behaviours themselves.

On the other hand, the tension between productivity and safety can have a significant impact on human behaviour towards safety in the workplace. This tension arises when there is pressure to increase productivity, which can sometimes lead to cutting corners or taking risks that compromise safety. When individuals are faced with this tension, they may prioritize productivity over safety, believing that their performance will be evaluated based on their output rather than their adherence to safety protocols. In such cases, individuals may be more likely to take shortcuts or engage in risky behaviours that can compromise safety.

There is an increasing body of evidence that suggests that when trade-offs exist between productivity and safety, it can lead to the encouragement of unsafe work behaviours, such as taking shortcuts or implementing workarounds. Several studies, including (Clarke 2006), and (Morrow, McGonagle, Dove-Steinkamp, Walker Jr, Marmet, and Barnes-Farrell 2010) have reported on the negative impact of these trade-offs on work behaviour. Furthermore, such behaviours may ultimately result in an increased risk of workplace injuries.

In this study, we explore the use of a serious game to understand a worker's decision towards risk-taking by integrating the social learning effect, and creating a goal conflict between productivity and safety in the game design. The conflict is created by giving the Role-player a choice between a secure (but less productive) procedure, and an insecure and prohibited (yet more productive) one. To the best of our knowledge, we are the first to use a gamification approach to evaluate the impact of social learning and productivity-safety tension in an industrial context.

3 SERIOUS GAME DESIGN

Figure 1: The serious Game UI.

3.1 Serious Game Based on Hybrid Simulation Modelling

Hybrid simulation (HS) can be defined as a modelling approach that combines two or more of the following methods: discrete-event simulation, system dynamics, and agent-based simulation. HS is a powerful tool that can be used to develop serious games, and create a virtual environment that replicates real-scenario as accurately as possible. Although, despite the potential of simulation methods, its application in serious gaming still in its infancy. Only limited applications exist in the literature, authors in (Di Ferdinando, Schembri, Ponticorvo, and Miglino 2015) presents a methodology for building serious games using agent-based modelling. The authors propose an approach to create a game called "Learn to Lead," which aims to teach leadership skills to young people. (Zhang, Härenstam, Meijer, and Darwich 2020) presents the design and evaluation of a serious game aimed at improving logistics management in paediatric emergency medicine. The game, called "Paediatric Logistic Game" uses a Discrete Event Simulation approach to teach medical professionals how to manage patient flow and resource allocation in a paediatric emergency department. As far as we know, there is currently no study that uses hybrid simulation for the design of serious games.

To address the existing gap, this study is an attempt to design a serious game based on HS modelling using the AnyLogic simulation Software. The potential from discrete event simulation and agent based modelling are combined to create realistic scenarios that reflect complex industrial systems and real-world situations. The game will serve as a tool to gather data on risk-taking preference, in a context of conflict between the production goals, and safety rule compliance.

3.2 Discrete Event Simulation

The Discrete Event Simulation is used to model the lead acid battery production process. The process start by creating electrode batches. Once the electrodes have been grouped into batches, they are transferred to the curing oven using forklifts to extract any moisture, followed by the subsequent production stage where they are enveloped with a special covering. The next stage is the assembly process, where the electrode batches are placed in a battery plastic case using an assembly machine that is controlled by the role player in the game. The assembled electrode groups are placed on a conveyor with the help of an industrial crane, to be conveyed to the filling machine, where they will be filled with the acid.

3.3 Agent-Based Modelling (ABM)

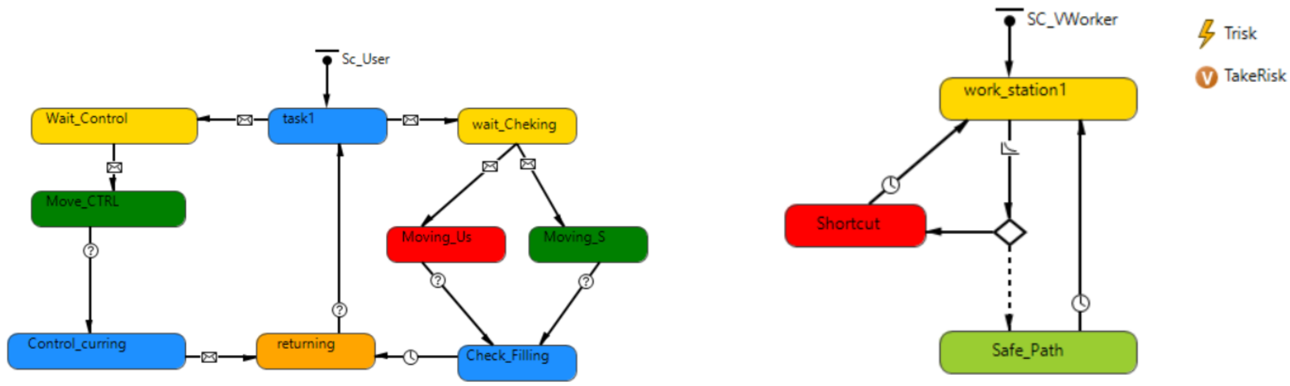
ABM is a frequently used modelling technique that can simulate a wide range of phenomena across various fields, including biology, psychology, and sociology (El Raoui, Oudani, and Alaoui 2018);(El Raoui, Oudani, and El Hilali Alaoui 2018);(El Raoui, Oudani, and Alaoui 2020); (El Raoui, Quigley, Aslan, Vasantha, Hanson, Corney, and Sherlock 2023). ABM models the actions and interactions of individual agents.

In this game, Agent based modelling is used to integrate and control two avatars corresponding to the role-player and another virtual worker by create two agents type. The avatar of a player holds significant importance in numerous digital games (Mancini and Sibilla 2017), serving as a representation of the player within the virtual world. Avatars enable players to explore their distinct or alternate identities (McKenna and Bargh 2000). Furthermore, the identification with one's avatar makes the game more enjoyable.

The main player and the virtual worker are both working on an assembly lines. The purpose behind integrating a virtual worker with the same activity, is creating a social learning effect on the player, and eliciting his risk taking preferences. The behaviour of the virtual worker is governed by a predefined set of rules to trigger the risk-taking and risk-aversion behaviour of the player. Indeed, the virtual worker is monitored using a UML stat chart to break the safety rules with a certain frequency by taking shortcuts through the danger zones indicated with a red rectangle in Figure 2b. The Virtual worker can get injured while moving on a danger zone with a certain probability. In such case, his assembly line stop producing for an amount of time, which decrease his productivity. This event is expected to trigger a risk aversion behaviour of our player, by changing his beliefs about the probability of injury on danger zones.

The player is given three tasks to perform during the game. These tasks are controlled using the UML stat chart in Figure 2a. His primary task involves operating an assembly machine. Although, he is asked to monitor the filling machine with a given rate. Whenever this task is scheduled, a notification appears on the user interface by highlighting the "filling" tab (Figure 1), This prompts the player to make a choice between a short and hazardous path or a longer but safer route to reach the machine. Opting for the risky path entails a probability of injury, which leads to a game pause, resulting in reduced productivity and missed rewards.

The third task consists of controlling the curing oven. This task basically doesn't include any risk taking decision. Although, it involves a cognitive effort to keep the player engaged in the game. Furthermore, it comprises specific procedures that are explained in subsection 6.4, and the software has the capability to identify any skipped steps. These violations are part of the assessment of the player performance.



(a) (b)

Figure 2: UML state-chart of the Role Player (a), the virtual worker (b)

3.4 The Tasks of The Role-Player

The Role-Player main task is to control the assembly machine and feed the machine with plastic battery cases, to assemble it with the electrode groups. The Objective of the player is to assemble a maximum of battery blocks to meet the demand. Two secondary tasks are integrated in the game. In addition to controlling the assembly machine, the player should monitor the filling machine, where he needs to make manual adjustment to the machine when changing the battery model. Once the model is confirmed, he set the acid volume via the human machine interface.

The lead-acid battery manufacturing process requires the essential steps of curing and drying, which necessitate precise conditions to be maintained within the curing chambers. Maintaining specific temperature and humidity levels is critical. Manufacturers typically safeguard the details regarding the specifics of this step, such as temperature, and humidity. Therefore, the third task of the operator is to monitor the temperature and humidity in the curing oven, and adjust it, if necessary, using a slider (Figure3).

The process involves 3 stages shown in Figure3, to correspond respectively to : quick surface drying, normal temperature curing, and plate drying of a pasted green plate. Each stage require the oven to be set to a specific temperature and humidity. We use in this study hypothetical values as follows:

- The quick surface drying stage requires a temperature of 35-50 DEG C, and humidity less than 20%.
- The normal temperature curing stage requires a temperature of 35-40 DEG C, and a humidity of 85-99%.
- The plate drying stage requires a temperature of 35-40 DEG C, and a humidity less than 20%.

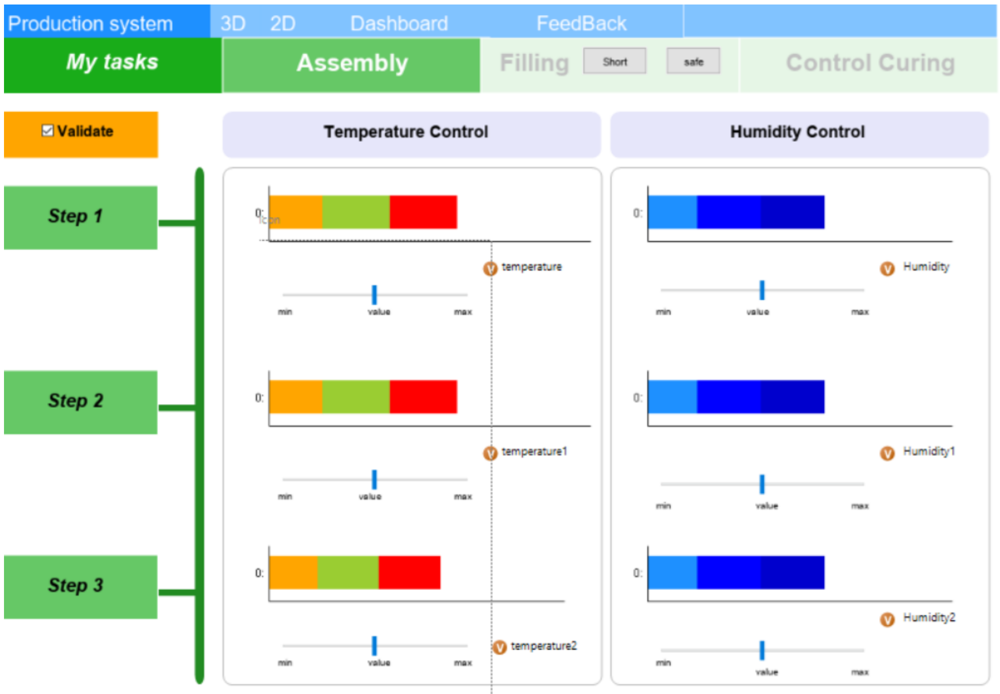


Figure 3: Role-Player Task.

3.5 Data Collection

Agent-based modelling offers accessibility for simulated entity state charts, which enables the tracing of events, activities, and variables of associated with an agent type. During the game, Anylogic creates a log file by default that records all procedural and temporal information in the database during runtime. To assess the risk-taking preference, and the performance of the role-player under a productivity/safety tension, we measure the following variable:

- The number of safety-violations by taking a short-risky path: The software detect whether the safe or unsafe path is chosen whenever there is a request to move to the filling machine.
- The number of procedural-violations that represent instances where parameter settings were not followed during the control curing task.
- The productivity in terms of the number of battery block assembled: The use of an unsafe procedure resulted in an output that exceeded the target. In contrast, when the extended and safe procedure was applied, production decreased due to the additional time required to correctly set the curing oven parameters and the longer paths taken to avoid risks.
- The number of near misses: This variable can further inform on the extent of safety-rule compliance. We display this indicator to the player on the tab 'dashboard' (Figure 4) dynamically during the game, to change his beliefs on the probability of getting injured, and cause a shift of his risk-taking behaviour.

4 LEARNING MECHANICS-GAME MECHANICS FRAMEWORK

The Learning Mechanics-Game Mechanics (LM-GM) model (Arnab, Lim, Carvalho, Bellotti, De Freitas, Louchart, Suttie, Berta, and De Gloria 2015) is a framework that facilitates serious game mapping by emphasizing the primary game mechanics and learning mechanics involved in each game scenario, thus supporting the identification and analysis of serious games.

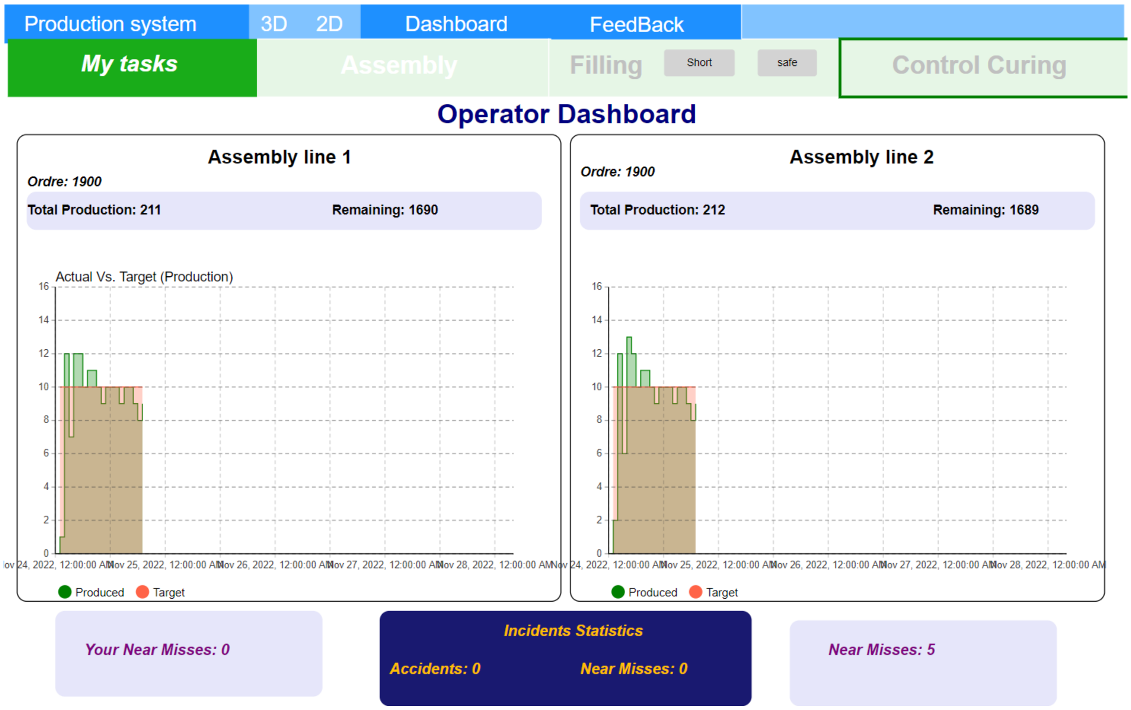


Figure 4: Role-Player Performance Measure.

Learning Mechanics refer to the fundamental mechanisms and processes that put into action the learning objectives. On the other hand, Game Mechanics are focused on defining regulations, interactions, and arrangements that aim to produce enjoyable and motivating gaming experiences. In the next subsections, we introduce the game mechanics and learning mechanics (Figure 5) within our game.

Figure 5: The Learning Mechanics-Game Mechanics Framework.

4.1 Game Mechanics

Role-Play: The incorporation of role play scenarios with the serious gaming approach holds great potential. Through role play, learners can explore new situations and develop skills related to responding and adapting to such circumstances, as stated by (Martens, Diener, and Malo 2008). In this game, the player takes a role of a worker in a lead acid manufacturing industry, where he is in charge of three realistic tasks.

Movement: The Role-player can navigate in a 3D environment, and see his avatar moving around in the production site.

Competition: In the tab "Dashboard"(Figure 4) we display the achievement of both assembly lines. Indeed, this technique creates a certain competition for the player, when comparing his results with the other virtual player, and trying his best to outperform the other assembly line.

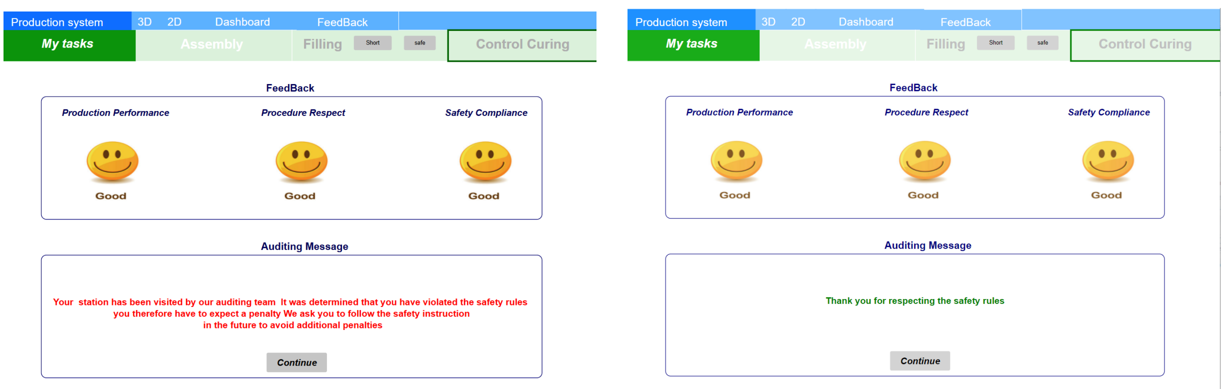
Reward/Penalties: Given that the objective of our game is to elicit the risk-preference, within a context of productivity-safety tension, The player will receive a reward at the end of the game function to his productivity, and a penalization for non-compliance to safety rules.

Realism: Realism is a significant factor that drives players to achieve their objectives in a serious game. Our game is a virtual factory designed based on the real production process of the lead acid batteries, in a 3D environment to make it more realistic. Furthermore, the designed tasks are based on realistic activities.

Feedback: Feedback on performance is displayed during the game in a written and graph form (Figure 6). This feedback serves to strengthen one's perception of progress, thereby sustaining motivation. Additionally, it acts as a reference point for initiating the process of self-reflection.

Time Pressure: The game has a time limit, and the player need to assemble a maximum of battery blocks to meet the demand, which makes the player experience a certain time pressure. This game mechanic will elicit the risk taking behaviour, given that the player will need to make some decisions during the game to achieve the task in the fastest way possible.

Behavioural Momentum: By featuring repetitive decision-making tasks across several levels, and given that these decision will influence the player outcome, the game can cause a shift in behaviour on the part of the player.



(a) (b)

Figure 6: The Feedback

4.2 Learning Mechanics

Action/Task: This mechanic can be linked to a quest system, which prompts the player to complete a particular task for a reward. In our game, the player is asked to complete a set of task, where specific actions are required to get a reward at the end of the game.

Hypothesis Learning Mechanics: The Movements of the Virtual player are manipulated to lead the player to develop hypothesis about productivity/ safety rule compliance. By observing the virtual player, the role-player should develop the hypothesis that making shortcuts can improve his productivity.

Observation: This learning mechanic is related to the social learning theory, and is grounded on the idea that learning takes place by observing, retaining, and imitating the actions of others. Our Role-player will observe the behaviour of the virtual worker which create a social learning effect.

Imitation: This learning mechanism can be associated with Cognitive Apprenticeship, in which the player imitates a more knowledgeable individual. When the Role-player observe the performance of the virtual worker, he is more likely to imitate his behaviour, and start breaking the safety rules.

Plan: This learning mechanism is linked to hypothesis testing, where the player devises a strategy to address a problem. In the context of our game, the player develops hypothesis about productivity/safety rule compliance, and make a plan to improve his productivity.

5 VERIFICATION AND VALIDATION

Verification and validation focuses on ensuring whether the game operates as intended, that it accurately represents the real-world scenario and variables, and that it effectively achieves its intended objectives. Verification ensures technical. Through rigorous testing, verification and validation can help identify and address any issues or deficiencies in the game design, functionality, and content, ultimately improving the overall user experience. Many techniques have been used in the literature for verification and validation. In this study, we provide a preliminary validation by using the following techniques:

Animation: The simulation has been extensively visualized to ensure that the working environment mechanism has been accurately modelled. Previous studies utilized discrete-event simulations for educational purposes, where a visual predictive check was sufficient to showcase the tool's utility. Moreover, animations were deemed as effective as other validation techniques (Sargent 2010). In this serious game, the model's operational behaviour is presented in a graphical format under the "3D" tab, Figure 1. This tab displays the movements of workers and parts through our virtual factory during the game.

Traces: The behaviour of different types of agents in the model are traced (log file) through the model to determine if the model's logic is correct.

Operational Graphics: The dynamical behaviours of key performance indicators (production, accident, and near misses) are visually displayed (Figure 4) as the simulation model runs through time to ensure their accurate behaviour.

6 CONCLUSION AND PERSPECTIVES

The traditional approaches for identifying risk-taking preference have exhibited notable disparities from actual behaviour in real-life scenarios, which could compromise the reliability of the gathered data. To address this issue, this research aims to bridge the gap by developing a Serious Game (SG) that can assess workers' choices to engage in risky behaviours, within an industrial manufacturing setting.

The designed game serves as a tool for conducting incentivized experiments aimed at revealing risk preferences by integrating two critical factors that can influence risk-taking behaviour in an industrial manufacturing context, namely the social learning and the production pressure.

To ensure an entertaining and motivating gaming experience, we adopt the Learning Mechanics-Game Mechanics (LM-GM) framework in designing the game.

The preliminary verification and validation techniques applied to the game are discussed. Although, the implementation phase is ongoing, and the next stage is getting further validation using the so-called "independent verification and validation" which consists of using a third party, knowledgeable in gamification and simulation, to decide whether the game is valid.

Before scaling up, we will conduct user experience evaluation with a small sample of students to investigate how easy the game is to use for the defined purpose, as well as the extent to which the SG is engaging for the target users.

After validation, the developed SG will be used to test the existing hypothesis over the impact of reward/penalty policies on risk-taking behaviour, in the context of conflicting productivity-safety goals.

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AUTHOR BIOGRAPHIES

HANANE EL RAOUI is a Research Associate in the department of Management Science at the University of Strathclyde. Her current research interests include behaviour modelling and simulation, organizational safety, risk management. Her email address is Hanane.el-raoui@strath.ac.uk.

JOHN QUIGLEY is a Professor in the department of Management Science at the University of Strathclyde, and an Industrial Statistician with expertise in developing and applying statistical and stochastic methods to build decision support models. His email address is J.quigley@strath.ac.uk.

AYSE ASLAN is a research fellow in the School of Computing, Engineering and the Built Environment at Edinburgh Napier University. Her email address is A.Aslan@napier.ac.uk.

GOKULA VASANTHA is an Associate Professor in Engineering Design in the School of Computing, Engineering and the Built Environment at Edinburgh Napier University. His interests include engineering design, engineering informatics, design methods, system modelling and analysis, crowdsourcing design and Manufacturing. His email address is G.Vasantha@napier.ac.uk.

JACK HANSON completed an MEng in mechanical engineering at Liverpool John Moores University in England in 2017 before completing a PhD in fluid mechanics at the University of Edinburgh. His current research interest is the quantification and characterization of human movement in industrial settings. His email address is Jack.hanson@ed.ac.uk.

JONATHAN CORNEY is a Professor of Digital Manufacturing at the University of Edinburgh. His interests include manufacturing applications of crowdsourcing; cloud interfaces for manufacturing, the interactive search of digital media and, the creation of "predictive CAD systems" by leveraging data analytics. His email address is J.R.Corney@ed.ac.uk.

ANDREW SHERLOCK is a Director of Data-Driven Manufacturing at National Manufacturing Institute Scotland and a Professor of Practice at the University of Strathclyde.His career has focused on the application of AI, data science and search techniques to design and manufacturing. His email address is A.sherlock@strath.ac.uk.