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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
John Quigley

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

Ayse Aslan
Gokula Vasantha

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

Jack Hanson
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

Conventional methods used to elicit risk-taking preferences have demonstrated significant disparities with real-world behaviors, compromising the validity of the data collected. Serious gaming (SG) provides a high potential to bridge this gap. This paper presents a serious game as a novel approach to elicit risk-preference in an industrial manufacturing context, focusing on the game-design and implementation using hybrid simulation modelling. The developed SG serves as a tool for conducting incentivized experiments aimed at assessing human behavior towards risk, to inform policy recommendations. The game incorporates two influential factors in shaping risk-taking behavior in a manufacturing environment, namely the social learning and production pressure and use a variety of game mechanics to promote the players' motivation and engagement. A usability study was conducted with 10 participants using the Usability Scale System (SUS) to identify problems in the usability of the game. Results have shown that our game has a good usability.

1 INTRODUCTION

Understanding the risk-taking behavior of workers in manufacturing sites can inform decision-making, help organizations to select the best strategies for improving the safety, and correct the deviant behavior. This highlights the need for data on human decisions to engage in a risk-taking behavior.

Economists and psychologists have developed a variety of experimental methodologies to elicit individual's attitudes towards risk. The existing elicitation methods differs in their level of complexity. Simple elicitation methods such as Balloon Analogue Risk Task (BART) (Lejuez et al. 2002) has also been used in investigating risk attitudes across various domains (Fecteau et al. 2007; Hunt et al. 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. Although, questionnaires are commonly not directly incentivized, raising doubts

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about accurately reflecting genuine risk attitudes. Complex methods for eliciting risk preferences often involve presenting individuals with a sequence of choices between gambles. One such method, is the multiple price lists (MPL) (Kahneman et al. 1990). Although, despite its popularity, Anderson et al. (2011) discovered that the risk preferences obtained through MPL had limited predictive ability regarding economic variables, and non-economic behaviors. A promising approach to overcome the limited predictive power of classical methods for eliciting risk preferences is Serious Gaming (SG). SG is a tool that gained popularity in the last few years in various fields (Abt 1987). The explicit purpose of serious games can range from analysing human behavior, enhancing player skills through training (Rüppel and Schatz 2011), to fostering a deeper understanding and awareness of complex issues and interdependencies within complex systems (Lukosch et al. 2018). Using a serious gaming role-play experiment as a method of data collection could serve as a valuable addition to reported elicitation 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.

The aim of this paper is to address the gap of the conventional elicitation methods by designing a SG as a tool to understand the workers decisions to engage in a risk-taking behavior, in an industrial manufacturing context. The game includes two effects that can shape human behavior towards risk-taking in a manufacturing context: social learning and production pressure effect.

Social learning theory (Bandura and Walters 1977) suggests that when individuals repeatedly observe their colleagues engaging in unsafe actions, they may consider deviating from safety rules as acceptable and may be more inclined to imitate these behaviors.

Tension between productivity and safety can have a significant impact on human behavior towards safety in the workplace (Clarke 2006; Morrow et al. 2010). 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, which can sometimes lead to cutting corners or taking risks that compromise safety. In this game, we create a goal conflict between productivity and safety 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.

The reminder of this paper is organized as follows: Section 2 provides the related work highlighting the relevance of serious gaming, Section 3 details the design elements, Section 4 introduces the didactics of the game, the usability study conducted is presented in Section 5, and we provide concluding remarks and some perspectives.

2 RELATED WORK

SG are games that are 'designed and/or used for non-entertainment purposes' (Bakhanova et al. 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 a diversity of SG types: simulation games, quizzes, sandbox games, and video games, among others (Stanitsas et al. 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 et al. 2017). The benefits of SG in various industries have been widely discussed. Authors in Kogler and Rauch (2020a), Kogler and Rauch (2020b) explore the use of game-based workshops to facilitate knowledge transfer between science, industry and education in the wood supply chain. The workshops involve interactive games that simulate supply chain processes using Discrete Event Simulation (DES), to enhance the understanding and retention of information. Results highlight the potential of the designed game in improving decision-making and collaboration among participants. SG's have also been utilized for safety training, Sitzmann (2011) presents a meta-analytic review to evaluate the effectiveness of SG's for safety training across multiple industries. The authors found that SG's can improve safety knowledge and behavior, as well as increase engagement and motivation. Martín-Gutiérrez et al. (2017) reviewed the use of virtual technologies, including SG's, in education and training. They found that SG's can enhance the effectiveness of safety training by providing realistic and interactive simulations, immediate feedback, and engagement. SG's 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.

A SG using agent-based modelling is presented in Di Ferdinando et al. (2015). The authors propose an approach to create a game called "Learn to Lead," which aims to teach leadership skills to young people. Zhang et al. (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 DES approach to teach medical professionals how to manage patient flow and resource allocation. Besides the primary training purposes SG's offers the opportunity to study and analyse players behavior (Rüppel and Schatz 2011). SG's have been recognized by Solinska-Nowak et al. (2018) as a valuable research tool due to their ability to provide controlled and safe environments. These environments enable researchers to explore and observe stakeholder behavior and decision-making processes. Lovreglio et al. (2017) discuss the relevance of SG in investigating human behavior during earthquake evacuations. SG have also been used as an emotion elicitation tool. Ahmed et al. (2023) designed a SG that incorporates multiple socio-economic game theory paradigms to elicit emotional response and decision-making patterns in the wild. Nevertheless, we are unaware of any implementation of a SG that incorporates the productivity/ safety dilemma for the purpose of elicitation of risk preferences in an industrial context. Consequently, there are no existing studies directly comparable to the research conducted in this article.

3 SERIOUS GAME DESIGN

In the present work, we design a serious game based on hybrid simulation modelling combining DES and Agent Based Modelling (ABM), using the AnyLogic simulation aoftware. The potential from DES and ABM are combined to create realistic scenarios that reflect complex industrial systems and real-world situations. The implementation details are provided in the following subsections; Figure 1 demonstrates the user interface (UI).

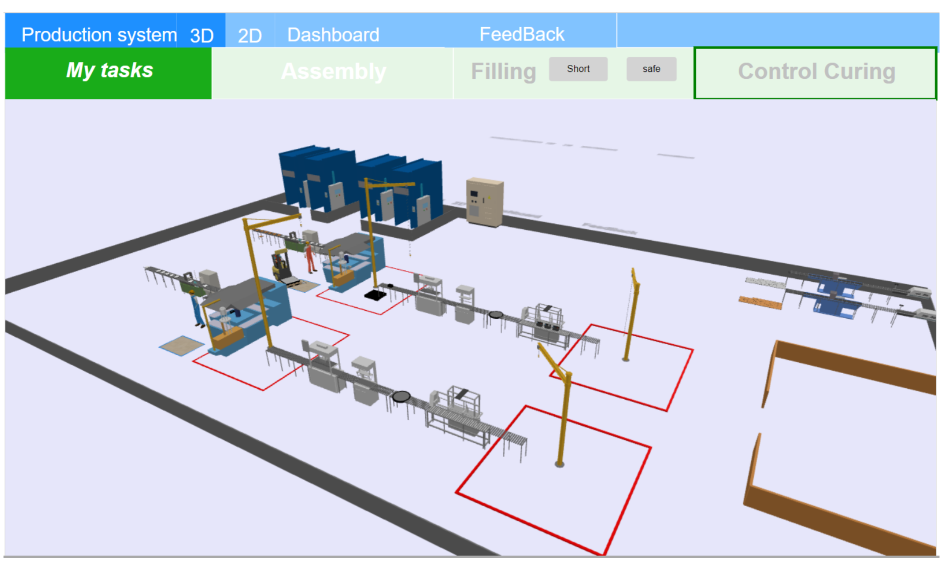

Figure 1: The serious game UI.

3.1 Discrete Event Simulation

DES is used to model the lead acid battery production process. Given that the focus of our game is not on the production process, but rather on creating a more realistic environment to the player, we have chosen a high abstraction level for simulation. The logic of the DES model is based on a tutorial published by Anylogic (2023), and is composed of two sub-processes, namely the production of electrodes and the assembly of battery. The electrode production process starts by receiving metal to create the lead grates, which are then covered with a special paste to become active. The electrodes are grouped into batches. These batches are transferred to the curing oven using forklifts to extract any moisture. Cured electrodes are transferred to a pre-wrapping buffer area where they are unbatched. The assembly process starts by wrapping each in isolating envelopes to form electrodes groups, followed by the subsequent assembly stage where the electrode groups 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. The acid-filled batteries are finally transported to the designated area for the charging process.

To facilitate the association between the production process and the simulation building blocks, we use a standardized process modelling language to construct the framework (Kogler and Rauch 2018). Business Process Modelling Notation (BPMN) is chosen to describe the model logic (see Figure 2). The key input parameters used in the DES model are presented in Table 1.

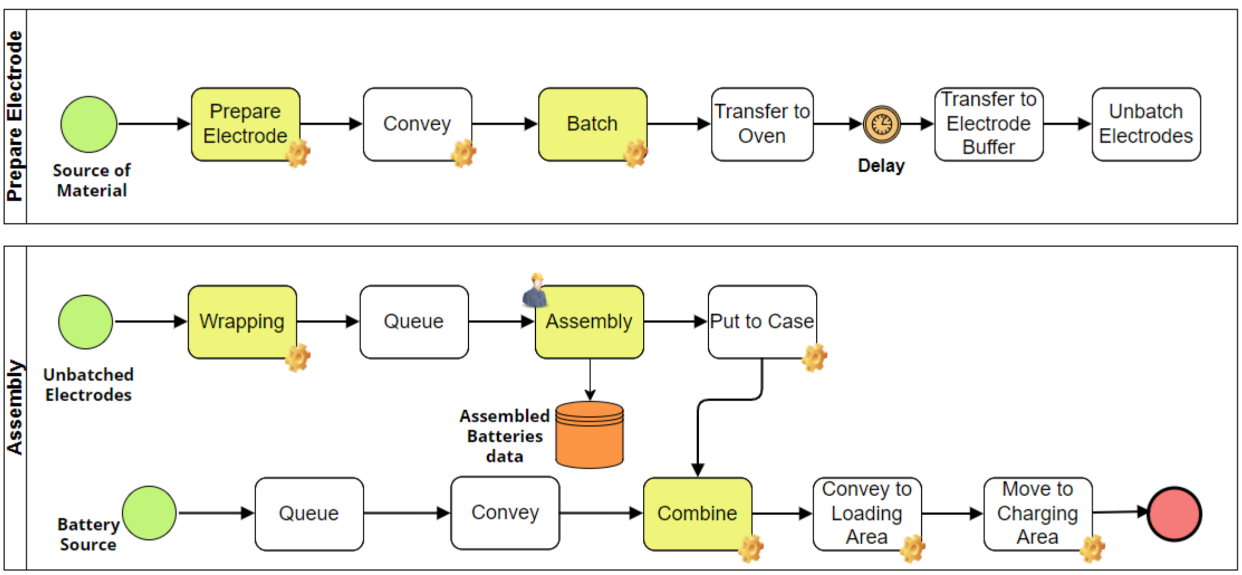

Figure 2: BPMN model of lead acid battery production process.

Table 1: Input parameters for the DES model.

Input Parameters	Value
Metal arrival rate	5 cubic meters/s
Battery case arrival rate	20/h
Electrode batch size	100
Curing time	5 min

3.2 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 et al. 2018a; El Raoui et al. 2018b; El Raoui et al. 2020; El Raoui et al. 2023). ABM models the actions and interactions of individual agents.

In this game, ABM 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, identification with one's avatar makes the game more enjoyable.

The main player and virtual worker are both working on an assembly line. The purpose of integrating a virtual worker with the same activity is to create a social learning effect on the player and elicit their risk taking preferences. The behavior of the virtual worker is governed by a predefined set of rules to trigger risk-taking and risk-aversion behavior of the player. Indeed, the virtual worker is monitored using a Unified Modelling Language (UML) state chart to break the safety rules with a certain frequency by taking shortcuts through the danger zones indicated with a red rectangle in Figure 1. The virtual worker can get injured while moving on a danger zone with a certain probability. In such cases, his assembly line will stop producing for an amount of time, which decreases productivity. This event is expected to change the player's perception of risk. The extent to which the player adjusts their risk-related beliefs based on other virtual workers' experience will be influenced by various factors, including their prior beliefs and individual traits such as risk tolerance. In other words, whether the player is prone to taking risks or being risk-averse will shape their reaction to the event.

The player is given three tasks to perform during the game. These tasks are controlled using the UML state chart in Figure 3a. The primary task involves operating an assembly machine while s/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 (see Figure 1), which 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 may result in injury, causing a game pause and leading to reduced productivity and missed rewards.

The third task consists of controlling the curing oven. This task doesn't include any risk taking decision, but serves to maintain a cognitive effort by the player in the game. Furthermore, it comprises specific

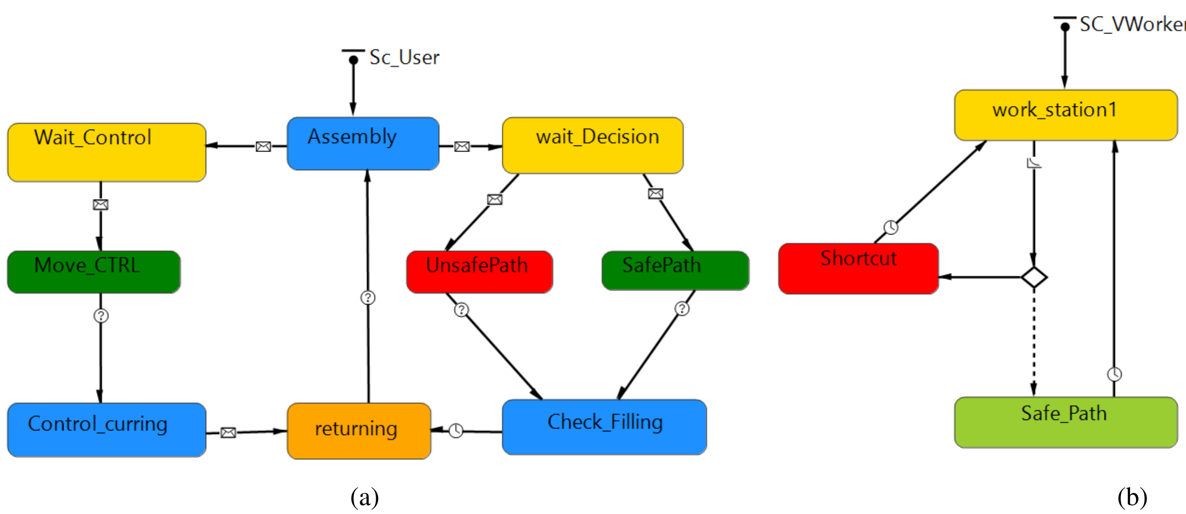

Figure 3: UML state-chart of the Role Player (a), and the virtual worker (b).

procedures that are explained in subsection 4.1, and the software has the capability to identify any skipped steps. These violations are part of the assessment of the player performance.

3.3 Verification and Validation

The presented SG is designed using hybrid simulation modelling. To ensure the validity of the DES and the ABM, we use the following validation and verification techniques (Kogler and Rauch 2018):

Animation: The simulation has been extensively visualised to ensure that the working environment mechanism has been accurately modelled.

Traces: The behavior 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: Dynamical behaviors of key performance indicators (production, accident, and near misses) are displayed (see Figures 4 and 5) as the model runs through time to ensure accurate behavior.

Additional validation techniques will be applied in the extended work, such as the degenerate tests, and sensitivity analysis (Sargent 2010).

4 DIDACTICS

4.1 The Tasks of the Role-Player

The role-players' 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: the player monitors the filling machine, where s/he makes manual adjustments to the machine when changing the battery model and s/he sets 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

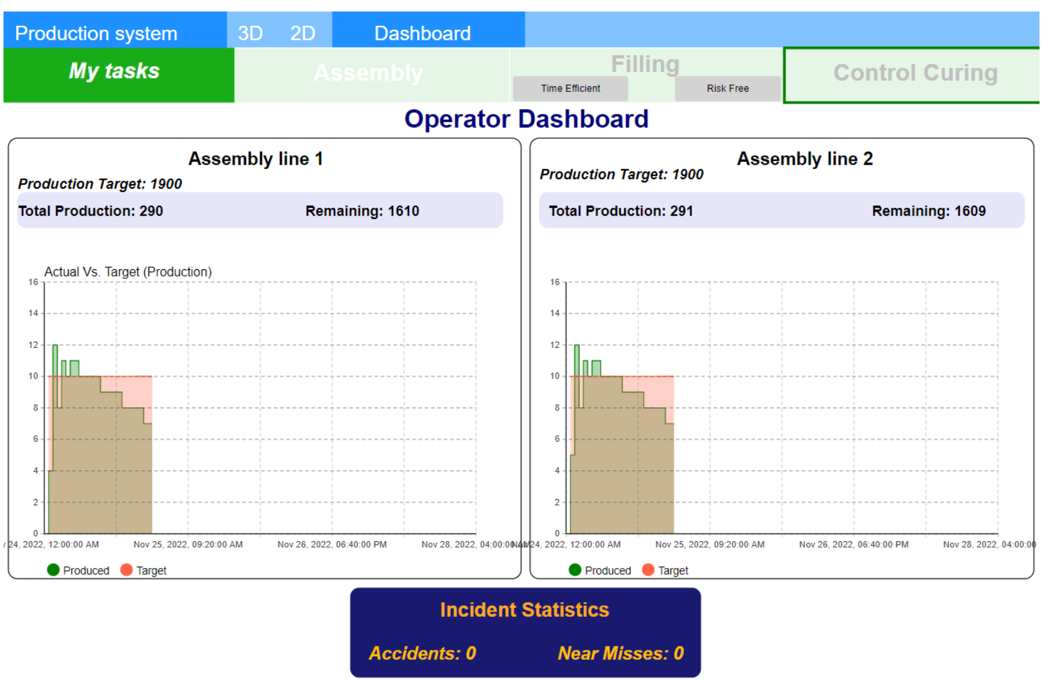

Figure 4: Role-player performance measure.

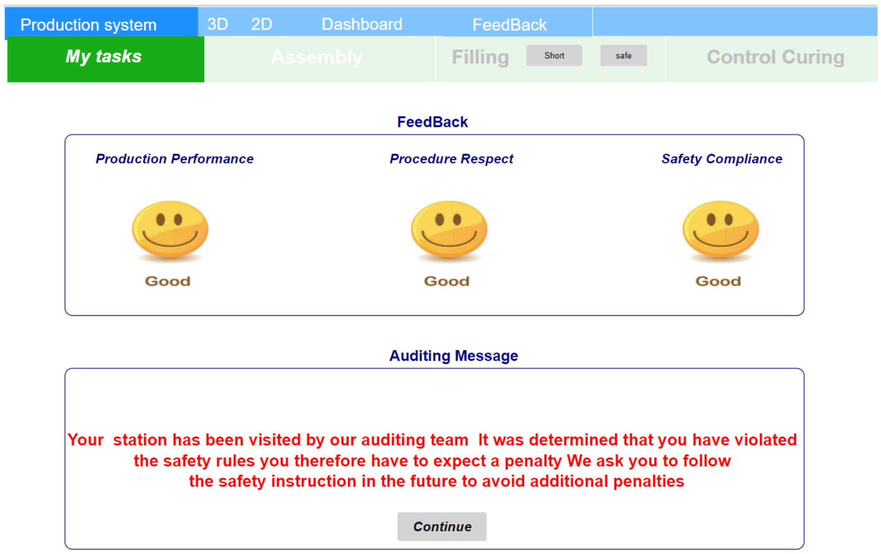

Figure 5: The feedback.

and humidity levels is critical. Manufacturers typically safeguard the details regarding the specifics of this step, such as temperature, and humidity. The third task of the operator is to monitor the temperature and humidity in the curing oven and adjust if necessary. The process involves 3 stages, where each stage requires the oven to be set to a specific temperature and humidity as follows:

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

4.2 Learning Mechanics-Game Mechanics Framework

The Learning Mechanics-Game Mechanics (LM-GM) model (Arnab et al. 2015) is a framework that facilitates serious game mapping by emphasising the primary game and learning mechanics involved in each game scenario, thus supporting the identification and analysis of SG's.

LM refer to the fundamental mechanisms and processes that put into action the learning objectives. On the other hand, GM are focused on defining regulations, interactions and arrangements that aim to produce enjoyable and motivating gaming experiences. GM and LM within our game are presented in Table 2.

4.3 Data Collection

The game will be used in a workshop setting with master's students. The workshop consists of three main phases: an introductory phase, the gameplay session and the evaluation questionnaire phase. An instruction video explaining the game rules and how it works will be provided to the players in the first phase. During the game, Anylogic creates a log file by default to 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 variables:

- The number of safety violations by taking a short-risky path: the software detects 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.

Table 2: Game Mechanics-Learning Mechanics.

GM	Implementation	LM	Description
Role-Play	The player takes a role of an assembly worker	Action/Task	The player is asked to complete a set of tasks, where specific actions are required to get a reward at the end of the game
Movement	Navigate the player in a 3D environment	Hypothesis Learning	The virtual player's guide the role-player to develop a hypothesis about productivity /safety rule compliance. Observing the virtual player, the role-player may hypothesize that taking shortcuts can enhance productivity
Competition	Display the achievement of both assembly lines (See Figure 4)	Competition	The "Dashboard" allows the player to compare his achievement with the other virtual player
Reward Penalties	Receive a reward at the end for productivity, and a penalization for non-compliance to safety rules	Imitation	This mechanism can be associated with Cognitive Apprenticeship. When the Role-player observe The performance of the virtual worker, she/he is more likely to imitate their , and start breaking the safety rules.
Realism	-virtual factory designed based on the real production process. -3D environment - Tasks are based on realistic activities	Plan	This mechanism is linked to hypothesis testing. The player develops hypothesis about productivity/safety Rule compliance, and plan to improve his productivity
Time Pressure	Assemble a maximum number of battery blocks in a time limit	Feedback	Displaying feedback during the game. serves to strengthen player's perception of progress, thereby Sustaining motivation. Additionally, it acts as a reference point for initiating the process of self-reflection.
Behavioral Momentum	Through repetitive decision-making at different levels, the game induces a shift in player behavior by emphasizing the impact of these decisions on his outcome.	Observation	This mechanism is related to the social learning theory. Our role-player will observe the behavior of the virtual worker which create a social learning effect.

- 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.
- Then near misses: used to inform on the extent of safety rule compliance. We display this indicator to the player on the tab 'dashboard' (see Figure 4) dynamically during the game, to change his beliefs on the probability of getting injured, and cause a shift of their risk-taking behavior.

A feedback survey will be conducted at the end of the game to evaluate the students' perception of the game and workshop.

5 USABILITY STUDY

A usability study was conducted to assess the game. According to Nielson's theory (Nielsen and Landauer 1993), 3 to 5 users can identify 85% of the most relevant usability problems. To ensure a comprehensive testing of various game features, it was decided to conduct the study with 10 participants. The System Usability Scale (SUS) questionnaire was used to measure usability (Brooke et al. 1996). It consists of 10 statements that are scored on a 5-point Likert scale. In the original survey, the questions pertained to general "system", we adapted the original version by replacing the term "system" with "game" (Table 3).

The SUS evaluation uses a scale of 0 to 4, where odd statements (positive) are scored by subtracting a point from the participant's response, and even statements (negative) are scored by subtracting the response from 5. The total score is then multiplied by 2.5 to get a percentage evaluation. This percentage is interpreted as not acceptable (<50%), marginal (50-70%), or acceptable (>70%). Participants' scores for each statement are shown in Figure 6. The results show that all the statement have a positive rating, with an average rating higher than average score. Although, participants tend to give lower rating to statement 1, which can be explained by the seriousness of the game. The average SUS score obtained is 77.7% (SD=10), which is considered as "acceptable" according to the evaluation scale. Therefore, users evaluate the SG favourably which meets the usability criteria.

Table 3: Questions for System Usability Scale(SUS)(adapted from Brooke et al. (1996)).

SUS 01	I think that I would like to use this game frequently
SUS 02	I found the game was unnecessarily complex
SUS 03	I thought the game was easy to use
SUS 04	I think that I would need the support of a technical person to be able to use this game
SUS 05	I found that the various functions in the game were well integrated
SUS 06	I thought that there was too much inconsistency in this game
SUS 07	I would imagine that most people would learn to use this game very quickly
SUS 08	I found this game awkward to use
SUS 09	I felt very confident using the game
SUS 10	I needed to learn a lot of things before I could get going with this game

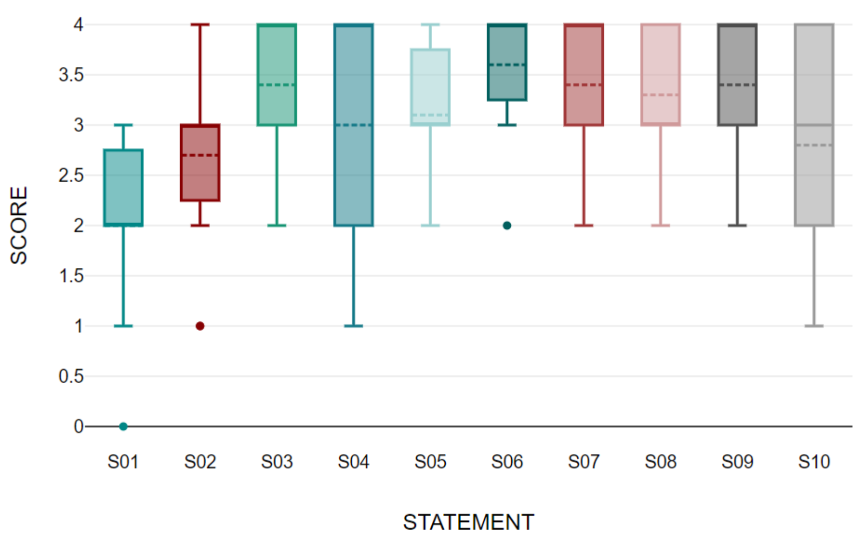

Figure 6: Participants' scores for each statement.

6 CONCLUSION AND PERSPECTIVES

The conventional methods used for elicitation of risk preference have exhibited notable disparities from actual behavior in real-life scenarios, which could compromise the reliability of the gathered data. This paper bridges this gap by introducing a SG as a novel approach to assess workers' choices to engage in risky behaviors, within an industrial manufacturing setting. The designed game serves as a tool for conducting incentivised experiments in a realistic and controlled environment with a primary objective to enhance the accuracy and reliability of risk preference measurements. This aspect holds great significance for researchers, policymakers, and industry practitioners.

The SG tool acknowledges the contextual intricacies that influence risk-taking behaviors within the industrial manufacturing setting by incorporating elements of social learning and production pressure into the game's design, which holds promise as a tool for understanding human behavior towards risk and shaping policy recommendations to correct deviant behaviors.

The present work is an introduction on the design and implementation of a SG as a tool to elicit risk preference within the industrial manufacturing sector. A fully-fledged study to test the existing hypothesis over the impact of reward/penalty policies on risk-taking behavior, providing valuable insights into the dynamics of risk management within the industrial manufacturing domain is our next step.

This study opens various other research opportunities. For instance, the validity of behavioral data gathered can be increased by coupling SG with virtual reality technologies. It is of interest to incorporate other mechanics in the game design to elicit emotions, which are crucial determinants of human behavior.

While the SG provides potential for risk assessment, it has limitations. For instance, it's difficult to infer behavioral preferences towards risk using only social learning and production pressure. Others factors can influence human behavior such as stress and past experience with trauma. However, risk-taking behavior can be strongly influenced by peer pressure, which this game attempts to include through social impact using virtual avatars, although, it cannot emulate real social effects that can be experienced while interacting with co-workers.

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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 behavior 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.