An Exploratory Research on Adaptability and Flexibility of a Serious Game in Operations and Supply Chain Management

https://doi.org/10.3991/ijoe.v18i14.35083

Giovanni Romagnoli[1(✉)], Matteo Galli[2], Davide Mezzogori[2], Francesco Zammori[1]
[1]University of Parma, Parma, Italy
[2]University of Modena and Reggio Emilia, Modena, Italy
giovanni.romagnoli@unipr.it

Abstract—Serious games (SGs) in industrial engineering education are an established topic, whose implementations are continuously growing. In particular, they are recognized as effective tools to teach and learn subjects like Operations and Supply Chain Management. The research on SGs, however, is primarily focused on displaying applications and teaching results of particular games to achieve given purposes. In this paper, we provide an exploratory research on the flexibility and adaptability of a specific SG to different target groups and students' needs in the field of operations and supply chain management. We first provide an overview of the SG and introduce its mechanics. Next, we explain how the mechanics has been implemented, by means of a set of parameters and indicators. We report the results of two different game sessions, played by a class of bachelor's degree students at different levels of difficulty, which were achieved by altering some specific game parameters. By comparing the Key Performance Indicators (KPIs) in the two sessions, we report and discuss the consequences of the modified game parameters, in terms of impact on the difficulty level of the SG measured by the indicators. Experimental results match with our hypothesis, since the increased level of difficulty of sourcing and delivery times only deteriorates the related subset of indicators in the harder game session, without altering the remaining KPIs.

Keywords—serious game, operations management, supply chain management, flexibility, adaptability

1 Introduction

A Serious Games (SG) is a game whose primary function is teaching and learning, instead of entertaining, that is an artifact with the main aims of learning and behavior change [1], [2]. SGs in engineering education are not a recent topic: SG have already been proposed and implemented in engineering education more than 50 years ago [3], [4], although they have not always been taken very seriously, especially in the first years [5]. More recently, thanks to the rise of non-traditional labs and lab networks [6], [7], and to the improvements in distance learning and online services for education [8], SGs have seen a new wave of interest as they are more and more perceived as immersive and entertaining learning tools [9]. This reconsideration is also accelerated by the fact that many teachers consider learning by doing as an effective teaching style to close the gap between theory and practice [10], and SGs give learners the opportunity to explore and understand a simulated context by reflecting everyday practical processes, without exposing learners to most the risks that these processes include [11]. For these reasons, SGs are effective tools to teach and learn subjects like Operations and Supply Chain Management, among others.

In the last few years, the number of SGs focused on these subjects has increased dramatically [12], [13]. The research on SGs, however, is mostly focused on presenting applicability and results of specific artifacts to achieve given purposes. The flexibility and adaptability of SGs to different target groups and students' needs is, on the contrary, a rather underinvestigated topic [14], [15]. At the University of Parma, in the frame of the project 'Open Digital Lab for You' (DigiLab4U), a project funded by the German Federal Ministry of Education and Research (BMBF) with the goal of creating an integrated and hybrid learning and research environment providing different types of labs to different kinds of users, we developed a SG, nicknamed Op&SCM (Opescm). The SG is aimed at students in Operations and Supply Chain Management, and at practitioners and company staff. Due to the wide range of learners that the game targets, with different skills and backgrounds, the game must be easily reconfigurable to align its difficulty with the starting level of knowledge and experience of the players, so as to offer an appealing and challenging gaming experience. In this study, we present a wide set of parameters of the SG, that the teacher can modify at his or her will to create the most suitable and motivating 'universe' for the teams to play in. Each parameter directly impacts on specific educational elements of the game, and their setting allows the teacher to adapt and customize the game.

We also present a set of Key Performance Indicators (KPIs) that can be used to evaluate players' progresses, but also to measure if and how much a change in the above-mentioned parameters makes the game's dynamic harder. To validate this assumption, although in an explorative way, we report the results of a class of bachelor's degree students, who played two game sessions at an increasing level of difficulty, obtained by altering a sub-set of parameters, which only influence specific aspects of the game. Our hypothesis here is that increasing the difficulty level of some game parameters affecting the total throughput time (namely sourcing and delivery times, and machine performance) will only impact on related KPIs (i.e., sourcing and delivery performance, and the cash flow). By comparing the KPIs in the two game sessions, the consequences of the modified parameters will be measured and discussed.

The remainder of the paper is organized as follows: Section 2 provides a literature overview on gamification and SGs in Operations and Supply Chain Management. Section 3 presents the overview of Op&SCM, and it explains its mechanics, whereas Section 4 reports the implementation of the game, which is the list of parameters that directly impact on the game complexity, as well as the KPIs that can be used to measure it. Section 5 presents the results of a preliminary evaluation on the connection between parameters and indicators, and Section 6 draws conclusions and suggests possible future directions of research.

2 Literature review

2.1 Gamification in education

Despite the research interest on the topic of gamification has significantly risen in the last two decades [1], [16], games and simulations have been used in education long before [17] and the trend is accelerating [18]. The concept of gamification, however, is not unanimously interpreted in the literature: some different definitions exist, and these definitions also allow for subjective interpretation (see for example [19], [20]). Also, gamification aspects might be addressed either in a 'superficial', or in a 'deeper' way, but these aspects still differ from the concept of 'game-based' learning. According to [21], **'superficial gamification'** includes simple game elements, such as points, badges, avatars, and leaderboards to increase students' interest and motivation to engage with the course content. In these cases, game elements are commonly implemented through a learning management system with the typical intent of creating competition between students or, more unlikely, non-digital game elements are also used. So far, superficial gamification has proved its utility in motivating and engaging students [22], and in increasing time spent on project work and improving student performance [23].

Deeper gamification, on the contrary, inserts in the learning activities both simple game elements and more complex game mechanics and dynamics. Thus, in this case, gamification is used as a tool to facilitate the learning process, even if activities are still not presented as, and do not feel like, games [21]. Deeper gamification can also be implemented in both digital and non-digital form. We note, however, that, albeit the differentiation among different gamification levels is important, the boundaries of these levels are quite unclear.

Finally, we talk of **'game-based learning'** when a game, or simulation, often referred to as 'serious game', is fully implemented to achieve determined learning outcomes. Serious Games (SGs) typically comprehend all the game elements, mechanics and dynamics of the previous gamification levels, and other explicit game aspects, such as roles, scenarios, and game instruments (e.g., game engine, board, and cards). As such, the learning activity is also presented as a game to the learners, whose playful behavior is encouraged. SGs are generally considered as safe environment for exploration and experimentation of students' behaviors and ideas, as well as tools that might help students to experience and apply learned theory in a timely and cost-effective way. With appropriate design, SGs can provide a meaningful experience with the subject matter, even if post-game reflection, and possibly a supervised one, is required to translate this experience into effective learning outcomes. As [9] reports, games can encourage and sustain the learning of both academic and non-academic skills, and especially soft skills, by promoting intrinsic motivation, motivating learners to collaborate and share information effectively.

2.2 SGs in operations and supply chain management

The recent and continuous rise of research interest on gamification is also evident from the growing popularity of its applications, and especially on the use of SGs, in operations and supply chain management. Engineering education, which has traditionally focused on technical skills and knowledge, is recently struggling to surpass core engineering topics and provide modern curricula with up-to-date knowledge and wider professional skills [24], with an emphasis on soft skills such as team building, leadership, collaboration, and communication, which are often associated to active and experiential learning [25], [26]. In this subsection, we report a broad range of SGs, whether they are analog, digital, or mixed media, in a chronological order, to explain different practical examples in which SGs could be implemented, and to trace their evolution over the years.

It is generally recognized that one of the earliest and most popular multiplayer SGs on supply chain management is the Beer Game [27], where players represent different tiers of a beer distribution supply chain (hence, its name), and interact with each other to fulfill customer's demand, and by experiencing supply chain dynamics, such as the well-known bullwhip effect [28]. Digital games and simulations have also been deployed in this field: as early as 1977, [17] presented a discrete-event simulation aiming at teaching and illustrating inventory management concepts by allowing the learner to take a set of decisions to direct and control flow of materials through a given supply chain, and receiving feedback on the economic consequences of their decisions. More recently, other games have also covered these technical topics and improved simulations and games on internal and external logistics, operations and SCM. To report a few examples, AUSUM [29] is a SCM serious game that focuses on the dynamics of an automobile supply chain, aiming to investigate the interconnections and dependencies among players' decisions, and their consequences. Reference [30] introduces a computer-based dice game that provides a learning exercise on line balancing and production flow. By operating in a simulated production line with workstations characterized by significantly different coefficients of variation, students learn about the various impacts of variability, the importance of inventory and work-in-process, they experience the Little's Law and wider supply chain implications. The Fresh Connection [31] covers the concept of value chain, by allowing players to experience cross-functional alignment, collaboration, and coordination, both at internal and external level, and in terms of strategy and operations. In this way, players can understand the importance of maximizing shared objectives, such as the Return on Investments of the whole supply chain, to the detriment of personal objectives, such as maximizing the performance of a single function.

An interesting example of SG in the field of operations management is Learn2Work [32]. This SG delivers three different scenarios, all of which, although starting from different points, have been designed to support the player to undertake the journey of an entrepreneur trying to bring his or her company to success. To accomplish this mission, the player must deal with a variety of entrepreneurial challenges, such as: customer relations, workforce and resources acquisition, and capacity management. Finally, Practice operations [9] is a single-player 3D SG that challenges the player with the managing of a clothing company plant. To achieve success, the player must deal with different roles and tasks, such as placing and winning bids, managing procurement and resources, transforming raw materials in end products, and organizing outbound shipping to final customers.

3 Game overview and mechanics

Op&SCM is principally aimed at bachelor students of supply chain and operation management courses, with the intent of motivating learners and of addressing different learning habits (e.g., Self-Directed Learning). Op&SCM has been designed by following the ARCS (acronym for Attention, Relevance, Confidence, and Satisfaction) model, a known method to improve the appeal of instruction and learning material [33], as ARCS is commonly used to address effective learner motivation, especially in SGs design (see for example [34]). Upon completion of a minimum game session of 16 hours of Op&SCM, gamers/learners will be able to (**learning objectives**):

– given the accelerated time and the generated events, examine the characteristics of the simulated universe of the game, distinguish the different actions available for each company role and their consequences;
– combine a strategy to successfully address a specific market niche;
– assess the results achieved by the selected strategy and possibly generate a new strategy that is more effective in addressing the target market niche.

In each match, players are grouped into teams (of two or three students), and each team represents an Original Equipment Manufacturer (OEM) company. Thus, players experience the daily operativity of a manufacturing firm, namely an OEM, specialized in producing and selling e-bikes. Players teams compete in the same market niche of a fictitious universe, which means that each OEM, operated by a single group of learners, competes to satisfy the same customers, and shares the same set of suppliers. All teams, in fact, live in a single-echelon supply chain, and they have to manage their relationships with direct suppliers, and compete for direct customer demand. Suppliers' and customers' agents are simulated by artificial intelligence models that shape the overall market supply and demand dynamics, in terms of quantities, quality levels, due dates, and price. To this aim, players must define a strategy to understand the market and target its best segmentation, because all teams share the same product catalogue (which can be extended or modified during the gameplay, if the players within the same company agree to do so). An example of the Bill of Materials of the 'City Bike premium' is reported in Figure 1, while Figure 2 illustrate the dashboard of general statistics of Op&SCM, which is available to and visible from all roles. The game is implemented as a multiplayer discrete-event simulation, and the interaction of player with the game is in response to events, both generated by the game engine, and generated by other players of the same team (i.e. company), in an environment where the passage of time is accelerated, in order to allow for a rapid interaction, and so for an efficient and effective learning.

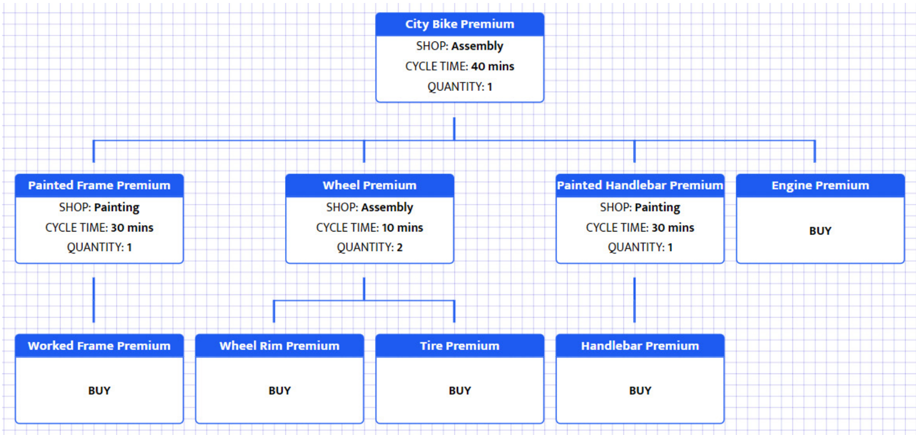

Fig. 1. The bill of materials of the city bike premium product in Op&SCM

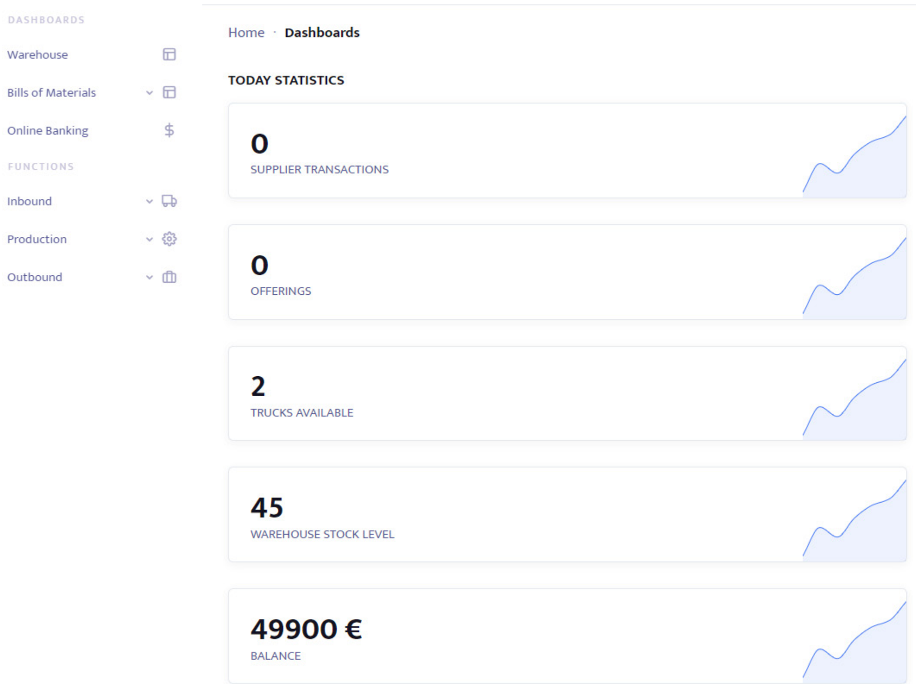

Fig. 2. The dashboard of general statistics in Op&SCM

Finally, the game is accessible as a web application, which mimics a simplified Enterprise Resource Planning (ERP) system. Thus, it can be enjoyed in a classroom, or remotely, with the only requirement of having a computer/tablet/smartphone equipped with a web browsing software and an internet connection. We also note that, without significant changes to the market segment where the OEM company operates, the game could be adapted to different products and different supply chains (e.g., frozen foods production, production of machinery, and the like). Each player has a specific role within the simulated OEM company, and the three roles are: purchasing manager (PM), operations manager (OM), and sales manager (SM). Each role has a given scope, and a certain set of tasks to be performed. In case of a two players team, the same player will play both PM and SM roles, as these roles are easier than OM.

The PM is responsible of the procurement of raw materials and assemblies, by controlling stock levels and selecting the best combination of materials and suppliers, to be managed with respect of cost, quantity, quality, and due date. The OM is in charge of the effective and efficient scheduling of production orders, with the aim of utilizing the available workcenters and equipment to meet demand, which could either be customers' orders or sales forecasts. The SM is in charge of acquiring customers' orders and managing shipments. As it emerges, while the game is running, players must face and, possibly, solve operational and daily issues, ranging from the supplier management to the production scheduling, to the customer demand management as well. A typical flow of activities is described in [9] and it is limited to the Make-To-Order (MTO) logic, where the SM places offers to existing customer requests and, when an offer is accepted by a customer, production planning is triggered. The OM then receives the offer details and tries to plan production, according to the bill of materials and quality levels of the offered product. Should raw materials and/or subassemblies be missing, the PM must act accordingly, by submitting purchase offers to suppliers, receiving and controlling the quality of incoming materials, and making them available for production. Eventually, after completion, the product is shipped to the final customer, who will correspond the due payment, if his or her expectations have been adequately met. A successful application of this strategy requires that the SM learns how to effectively negotiate with customers, and to manage outbound logistics, the OM learns and applies classical scheduling methodologies by considering the overall productive capacity, time and cost constraints, and the PM learns how to handle inventories and how to effectively purchase from suppliers.

The MTO approach is the most common starting point of players we experienced so far; however, other possible approaches to the game are the Make-To-Stock (MTS) or Assemble-To-Order (ATO) ones, and players typically consider them after a few hours of playing the game. In these cases, the production of end products (in the MTS case), and also the purchase of incoming materials (in the ATO case) are based on forecasts and start before customers' order are accepted. These approaches, however, increase inventory levels, to the benefit of delivery times, and time-pressure on procurement and/or production planning. Thus, in order to effectively adopt these logics, players must perform a preliminary market segmentation analysis, and decide which type of product and quality level they want to target. The demand dynamics of the game have been modeled to leave room for multiple market segments, according to the level of difficulty. Therefore, players are expected to discover these segments, and tailor their activities and strategy to meet the needs and expectations of the customer segment they agreed to serve. Also, quality management is another important issue of the game. Whenever a customer's request is received, the SM should also consider its quality requirements. As these values can be negotiated with the customer, an adequate trade-off between quality, sale price, and due date is crucial for success. Hence, since this decision impacts on the whole team, the OM should decide whether it is economical convenient to plan detailed quality controls in one or more points of the production process and, similarly, the PM should evaluate quality aspects when submitting purchase orders to suppliers. Finally, the game is designed to convey the importance of communication, as an essential method for coordinating different departments and/or corporate functions. To this aim, the game interface has been designed to reproduce a simplified ERP system that does not provides the players full visibility of the decisions made by their teammates. In detail, the interface only reports partial and aggregated information about the actions taken by other players within the same team, so that players are strongly encouraged, or rather forced, to effectively communicate among them for better coordination.

Also, any time a new game is configured, a certain in number of *breaks* can be scheduled at precise instants of time; when a break takes place the game-time is paused, new events cannot be issued by the game engine and the game can only be accessed in a read-only mode. During these so-called *strategic* pauses, which are commonly triggered by a supervisor instructor, players of the same team confront each other, discuss their experiences, analyze their operations, and refine or define their strategies, to coordinate future operations. These strategies may concern coordination and organizational aspects, cross-company aspects, such as make-or-buy policies on some of their components, expansion of the product portfolio, or concern more specific aspects, such as purchase of new machines or improvements in the offer strategy. Thus, players must cooperate amongst them and coordinate their activities to achieve results and compete against other OEM teams. Also, they are required to take consensual decisions, concerning the strategy they want to pursue and the market segment they are targeting. Indeed, teamwork, collaboration, cross-functional understanding and leadership are key topics to direct the company toward success.

4 Technical implementation of the game mechanics

4.1 Game parameters

To foster and sediment learning, each player should play the game three times, changing his or her role (PM, OM, SM) each time. In this way, all areas of the company are covered and a more precise understanding of how the company works and on the importance of communication between different departments is obtained.

Apart from that, the game can also be repeated at increasing levels of difficulty; in this way it is possible to check how well the main managerial principles have been learned, keeping the game experience challenging and engaging. Specifically, as the difficulty increases, decisions have to be made faster, the stress of timely and accurate decisions increases, a careful coordination and information sharing among players becomes more and more essential, and it becomes harder to understand the key market drivers that can lead to the company's success. Operatively speaking, any time a new *universe* is created, its difficulty level can be defined by the teacher by tuning a set of parameters that are reported and described in Table 1. For each one of them, the table provides: (i) the name, (ii) a description, (iii) the way in which it was modelled, (iv) the affected roles and (v) the reason why the players perceive the game as more challenging.

Table 1. Technical parameters and their effect on the game's difficulty

Parameter	Description	Modeled as	Effect on	Impact on Perceived Difficulty
Simulation clock	The speed at which the simulation time flows	Discrete time interval	All roles	The faster the simulation time, the harder and more stressful to take appropriate decisions
Inter arrival time of customers' requests	The time between two consecutive customers' requests	Poisson process	SM	The longer the inter arrival time, the less frequent the customer requests, and the more competitive the market
Customers' requests expiration date	The duration of the customer requests; that is the time windows within which an order can be placed	Uniform distribution	SM	The shorter the time window, the harder and more stressful to make appropriate offers
Threshold limits on bidding parameters**	Upper and lower bounds of delivery date, price, quality, and quantity that might cause offer rejection	Percentage (± a%) of requested values	SM	The tighter the threshold, the greater the difficulty
Offering Cost*	A fixed cost incurred any time a new offer is issued	Fixed cost	SM	The higher this cost, the more players must be careful to place bids, to avoid extra costs
Maximum number of offers	The maximum number of offers that the player is allowed to issue per day	Fixed number	SM	The lower this value, the more player must be careful to select customers and place bids
Stock Evaluation interval*	How often the inventory level is recorded, to generate the time series from which the average inventory level and the corresponding stockholding cost is computed	Fixed time	All roles	The shorter the interval, the more stock peaks affect the stockholding cost, and the higher the need to limit inventory
Warehouse capacity	The number of pallets that can be accommodated in the warehouse	Fixed value	All roles	The lower the capacity, the greater need to keep the limit the inventory
Daily unitary cost of extra inventory capacity*	Any time the inventory capacity is violated, additional storage space must be leased at a fixed daily unit cost	Fixed cost	PM	The higher the unit cost, the greater the need to keep the inventory low
Material stockholding cost*	Daily stock holding cost per unit of material or Work-In-Progress (WIP) in the plant	Fixed cost	PM	The higher the unit cost, the greater the need to keep the raw materials and WIP inventory low
Product stock cost*	Like the previous cost, but relative to the end products	Fixed cost	OM & SM	The higher the unit cost, the greater the need to keep the finished goods inventory low

(Continued)

Table 1. Technical parameters and their effect on the game's difficulty *(Continued)*

Parameter	Description	Modeled as	Effect on	Impact on Perceived Difficulty
Production Order Cost*	The fixed cost sustained for each confirmed production order	Fixed cost	OM	The higher the cost, the more production is pushed towards higher batches
Shipment Setup Time	The time it takes to prepare and load a truck before a delivery can be made	Uniformly distributed	SM	The higher this value, the longer the delivery Lead Time
Number of trucks	The number of trucks available for shipping	Fixed value	SM	The lower this value, the more complex it is to plan shipments
Quality Inspection Standard	The quality control policy, i.e., the probability that quality control is performed by the customer	Binomial distribution	OM & SM	The higher the expected probability, the greater the need to comply with quality requirements
Customer Request Factor, per product**	The number of items requested by a customer in an order line. A different value is set for each customer-product combination	Uniform distribution	SM	This parameter differentiates the customers and segments the market
Customer request probability, per product**	Every customer regularly generates a purchase request, but only a subset of requests is selected, according to this probability value	Binomial distribution	All roles	This parameter differentiates the customers and segments the market
Market Machine Price*	The purchase price of a new machine is defined for every kind of machine available on the market	Fixed price	All roles, OM in particular	This value affects the revenue, the depreciation, and the strategic decision on acquiring new assets
Machine performance rate	*An index which decreases the nominal yield (or productivity) of the machines*	*Fixed value*	*OM*	*The lower this index, the less performing machines are*
Machine Availability	*An index determining the percentage of time a machine is available for production (i.e., not faulty)*	*Fixed value*	*OM*	*The lower this index, the more time is needed to complete a production batch*
Machine Quality Rate	*The percentage of products that are not affected by quality problems*	*Fixed value*	*OM*	*The lower this value, the higher the number of defects or the need to rework items*
Production orders' batch size range	Minimum and maximum quantity of a production order of a machine or department	Fixed value	OM	The stricter this range, the less production flexibility is available to players
Machine setup time	Time required for changeover or machine setup	Fixed value	OM	The higher this value, the more time is needed to complete a production batch

(Continued)

Table 1. Technical parameters and their effect on the game's difficulty *(Continued)*

Parameter	Description	Modeled as	Effect on	Impact on Perceived Difficulty
Supplier shipping time	Time needed to complete a shipment, calculated as a function of the distance	Fixed value	PM	The higher this value, the more accurate the planning must be
Supplier Approval Time	Time taken by the supplier to answer to the order requests from players	Uniform distribution	PM	The higher this value, the more accurate the planning must be
Supplier Discount Allowance	The discount rate above which the supplier rejects an order request	Fixed value	PM	The higher this value, the less room for discount
Supplier Batch size, per product	Minimum and maximum quantity that can be ordered at once	Fixed value	PM	The stricter this range, the less purchasing flexibility is available to players
Supplier quality range, per product	*Minimum and maximum quality level that can be obtained from a supplier*	*Fixed value*	*PM & OM*	*The higher this value, the more variable the supplier's quality. Players know the average value, but not the range*
Supplier production lead time	Extra time required for production if the ordered products are not available from stock at the supplier's	Fixed value	PM	The higher this value, the higher the probability to experience extra rimes in supplier's delivery

Notes: *parameters that immediately translate in a positive or negative cash flow; **parameters that generate different market clusters; *In italics* parameters that cannot be easily calculated and are expected to be unknown to players.

4.2 Key performance indicators (KPI)

To verify that the above-mentioned technical parameters truly have an impact on the perceived difficulty, especially in the areas indicated, a set of KPIs was defined. Noticeably, each KPI has been conceived to measure the performance of the players in one or more areas of the company, so that if two players with the same initial skills play the game at different levels of difficulty, the KPIs should deteriorate, accordingly. The main KPIs of Op&SCM, which will also be reported afterwards in the experimental test of section 5, are described in the following subsections.

Cash flow – CF_t. When the game starts, all the teams have at their disposal the same amount of money or cash. Next, as the game proceeds, the players make transactions, either of operational or tactical nature, which correspond to incoming or outgoing economic flows, which is revenues or costs. Some examples of operational transactions are bidding costs, purchasing costs, and transportation costs. Example of tactical costs are purchase of new machines, hiring of people, and expansion of the warehouse capacity. Due to these transactions, the cash balance, or instantaneous cash flow, continuously changes, and its values (immediately) reflect the (short time) correctness of the players' actions. In this sense, the cash flow can be considered as the main synthetic KPI to assess the performance of a team, by considering all roles altogether (PM, OM and SM).

The computation of the cash flow at a certain time t is thus straightforward, as it is obtained as the cumulative sum (with sign) of all the transaction occurred until t, as it is reported in Equation 1. Please note that some transactions are not explicitly generated by the players but are implicitly generated by the systems. Examples are: stock holding costs, penalties, depreciations, and the like.

$$CF_t = F_0 - \sum_{\tau < t} f_\tau \tag{1}$$

Where F_0 is the initial cash, and f_τ is a generic transaction (either positive or negative) at time τ. Similarly, its main representation is an x-y plot where the x-axis reports time and the y-axis reports the current cash level, as in the example of Figure 3.

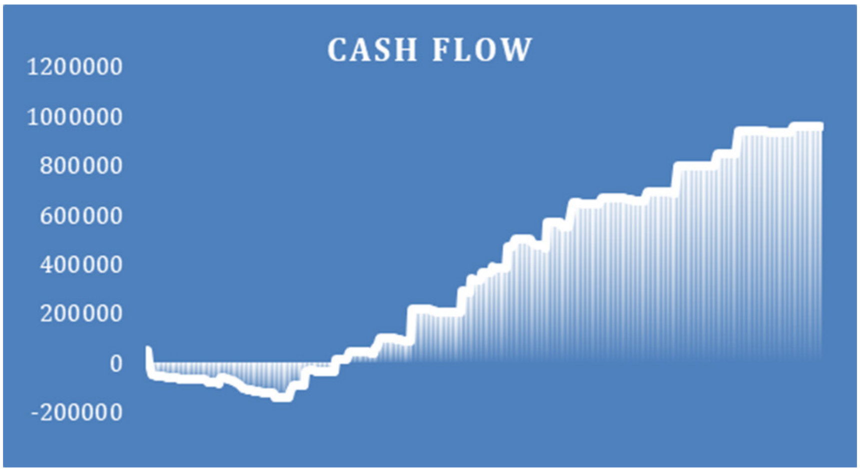

Fig. 3. An example of the trend of the cash flow over time

Sourcing performance: unsuccessful purchase requests per cause and motivation – $\bar{P}_k$. This metric is the main KPI used to assess the performance of the PM. It provides the failure rate of the purchase requests (i.e., the number of requests that were not accepted by the suppliers), grouped in terms of the root cause that led to the rejection of the offer. Specifically, three main causes are considered: (i) due date is too tight, (ii) quality level is too high (with respect to the price), and (iii) price is too low.

Please note that, in this sense, the subscript $k \in \{d, q, p\}$ denotes the failure's root cause, where d, q and p indicates 'due date', 'quality' and 'price', respectively. For instance, in case of requests rejected due to an unfeasible due date, P_d is computed as in Equation 2.

$$\bar{P}_d = \frac{\sum \bar{r}_d}{R} \tag{2}$$

Where $\bar{r}_d$ is a rejected request and R is the total number of issued requests. It goes without saying that the percentage of successful requests P, obtained as in Equation 3.

$$P = \frac{\sum r}{R} = 1 - (\bar{P}_d + \bar{P}_q + \bar{P}_p) \quad (3)$$

Where r is an accepted purchase request.

Being a percentage value, D_f is generally displayed as a pie chart, as it is summarized by Figure 4.

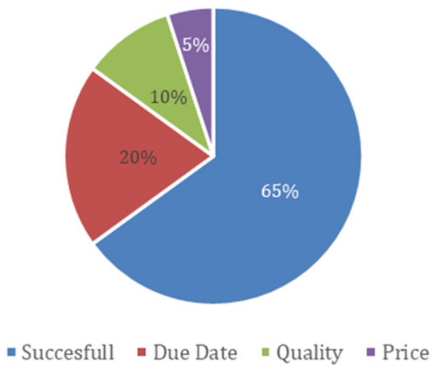

Fig. 4. An example of the pie chart on successful and unsuccessful purchase offers

Production orders performance – O_k. This metric is used to evaluate the effectiveness of production planning and scheduling; hence, it is the main KPI to assess the performance of the OM. More precisely, the metric shows the percentage of orders that ended in each one of the following states:

- Fulfilled, the order was terminated smoothly; all materials and WIP (in terms of both quality and quantity) were available, and there were no problems with the quality and/or availability of the machines;
- Fulfilled with warning, the order was terminated but during the production cycle, some warnings were issued. Typical examples are warning relative to the quality of the input materials (too low, or even too high) and or to the actual quality level detected after quality checks are performed. These warning can be ignored by the player, but in this case the generated batch will not have the exact characteristics as defined in the original production orders;
- Suspended, the order was terminated before completion. Major problems (such as unavailability of materials, major fault of the machine, etc.) occurred and the production batch could not be completed.

Please note that, at a certain time t, the state of an order can also be ‘ongoing’. This means that, until t, the production of the batch has proceeded smoothly; nonetheless, before its completion some warning and major problems could still occur. Therefore, these orders are not considered when computing O_k (i.e., only the orders that were completed or suspended are accounted).

Also note that, the subscript $k \in \{f, w, s\}$ denotes the ending state of the order, where f, w and s indicate 'fulfilled', 'warnings' and 'suspended', respectively. For instance, in case of fulfilled orders is computed as in Eq. 4.

$$O_f = \frac{\sum o_f}{O} \quad (4)$$

Where o_f is a fulfilled production and O is the total number or issued orders. Being a percentage value, O_k is displayed as a pie chart; as in the example of Figure 5.

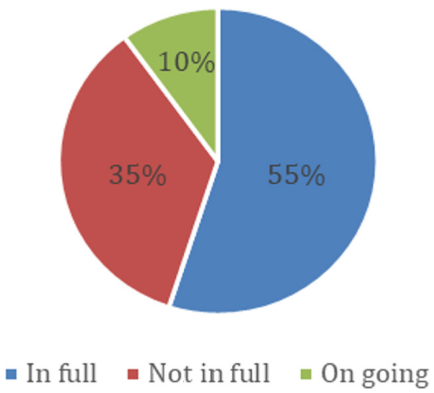

Fig. 5. An example of the pie chart on successful and unsuccessful production orders

Offerings performance: successful bidding per product type – B_p. This metric is the main KPI used to judge the performance of the SM, as it gives the percentage of offers won by the team (i.e., accepted by the end customer), grouped by product type. It is computed as in Eq. 5, where p is a specific product type, w_p is a won offer, and N_p is the total number of offers for product p. Concerning its representation, B_p can be displayed in the form of a summary table, as in Figure 6; a pie chart can also be added to synthesize the overall percentage of offers won.

$$B_p = \frac{\sum w_p}{N_p} \quad (5)$$

Delivery performance – D_k. This is the second KPI used to judge the performance of the SM. Whereas O_p quantifies effectiveness in formulating offers, D_k is more focused on shipments and deliveries to the end customers. This KPI provides the percentage of orders that were:

– delivered in full (i.e., with the right time, quantity, and quality rate),
– delivered late, or 'not in full',
– ongoing (i.e., still on the road).

Please note that, in this sense, the subscript $k \in \{f,l,g\}$ denotes the delivery type or state, where f, l and g indicates 'full', 'late' and 'on going', respectively. For instance, in case of orders delivered in full, D_f is computed as in Eq. 6.

$$D_f = \frac{\sum d_f}{W} \quad (6)$$

Where d_f is an order delivered in full and W is the total number or orders won. Being a percentage value, D_f is generally displayed as a pie chart, as in the example of Figure 5 (although in this case we refer to shipping orders, instead of production orders). Lastly, we note that since the capability to delivery in full, also depend on the quality and availability of the input materials, and on the efficiency of the manufacturing process (and of its schedule) D_k can also be used to judge the performance of all the players competing in the same team.

City Bike Basic	
Won	20
Lost	39
% Won	34%

City Bike Premium	
Won	15
Lost	14
% Won	52%

Total	
Won	35
Lost	53
% Won	40%

Fig. 6. An example of the table on successful bidding per product type

5 Experimental tests and discussion of results

The main use of the KPIs introduced in Section 4 is to objectively quantify the improvement of the players and the achievement of their didactical goals. Nonetheless, in this paper, the focus is not on the didactic aspects, but on the technical features that allows one to change the level of difficulty of the game. Hence KPIs are used to empirically verify if a change in the parameters truly entails a higher level of difficulty felt by the players and, consequently, a worsening of the KPIs. In detail, we hypothesize that by increasing the difficulty level of sourcing and delivery times, and by decreasing machine performance, the related KPIs of sourcing and delivery performance will be worsened, together with the overall cash flow indicator.

To this aim, a preliminary study was made using nine B.Sc. students in Industrial Engineering, enrolled in a course of Operation Management held at the University of San Marino. These nine students, who volunteered to cooperate for the research, were divided into three teams of three players each (T1 to T3), who played an easy level game (i.e., all parameters were set to their basic level) with two kinds of bicycle 'basic' and 'premium', respectively. This game session was labelled as *Easy Game*. Next, the students were shuffled into three new teams (always T1 to T3) and played a second game at a higher level of difficulty, labelled as *Hard Game*. Specifically, the following parameters, which affect the total throughput time (from order receipt to order delivery) were raised to a higher level of difficulty:

- Inbound (PM)
  - Supplier shipping time (all suppliers)
  - Supplier approval time (all suppliers)
  - Supplier production lead time (all suppliers)
- Production (OM)
  - Machine performance rate (all machines)
- Outbound (SM)
  - Shipment setup time (all teams)
  - Number of trucks (all teams)

Table 2. Sourcing performance

Sourcing Success and Failure Causes									
Easy Game	**Won Offers**	**Lost (time)**	**Lost (price)**	**Lost (quality)**	**Hard Game**	**Won Offers**	**Lost (time)**	**Lost (price)**	**Lost (quality)**
T1	70.0%	14.0%	6.0%	10.0%	T1	69.8%	20.9%	2.3%	7.0%
T2	81.5%	14.8%	3.7%	0.0%	T2	75.0%	19.4%	0.0%	5.6%
T3	83.3%	5.6%	1.9%	9.3%	T3	50.0%	15.5%	25.9%	8.6%
Avg.	**78.3%**	**11.5%**	**3.9%**	**6.4%**	**Avg.**	**64.9%**	**18.6%**	**9.4%**	**7.1%**

Table 3. Productions orders' performance

Production Orders Performance									
Easy Game	**Completed**	**Ongoing**	**Warning**	**Error**	**Hard Game**	**Completed**	**Ongoing**	**Warning**	**Error**
T1	91.4%	2.3%	3.1%	3.1%	T1	84.8%	0.9%	11.7%	2.7%
T2	85.9%	4.7%	2.4%	7.1%	T2	95.0%	0.8%	2.5%	1.7%
T3	84.2%	1.3%	7.2%	7.2%	T3	92.3%	0.0%	2.1%	5.6%
Avg.	**87.2%**	**2.8%**	**4.2%**	**5.8%**	**Avg.**	**90.7%**	**0.6%**	**5.4%**	**3.3%**

Table 4. Offerings performance

Successful Offerings Per Product							
Easy Game	**Basic**	**Premium**	**Total**	**Hard Game**	**Basic**	**Premium**	**Total**
T1	50.0%	41.3%	44.0%	T1	27.1%	21.1%	25.2%
T2	62.8%	30.0%	45.2%	T2	56.1%	40.0%	48.7%
T3	33.9%	51.7%	39.8%	T3	66.7%	60.5%	62.1%
Avg.	**48.9%**	**41.0%**	**43.0%**	**Avg.**	**49.9%**	**40.5%**	**45.3%**

Table 5. Delivery performance

Delivery Performance							
Easy Game	**In Full**	**Non in Full**	**Not Delivered**	**Hard Game**	**In Full**	**Not in Full**	**Not Delivered**
T1	23.1%	76.9%	0.0%	T1	73.1%	23.1%	3.8%
T2	73.3%	16.7%	10.0%	T2	25.0%	60.0%	15.0%
T3	80.8%	15.4%	3.8%	T3	36.8%	52.6%	10.5%
Avg.	**59.1%**	**36.3%**	**4.6%**	**Avg.**	**45.0%**	**45.2%**	**9.8%**

Table 6. Cash flow

Cash Flow Over Time							
Easy Game	**Cumulative Cash Flow**	**No. of Days**	**Average Cash Flow per Day**	**Hard Game**	**Cumulative Cash Flow**	**No. of Days**	**Average Cash Flow Per Day**
T1	€ 1,142,880	72.07	€ 15,857.27	T1	€ 665,715	61.02	€ 10,910.26
T2	€ 527,372	72.75	€ 7,249.10	T2	€ 660,635	61.51	€ 10,739.61
T3	€ 905,006	72.97	€ 12,403.24	T3	€ 624,246	62.33	€ 10,014.64
Avg.			**€ 11,836.54**	**Avg.**			**€ 10,554.83**

With the same aim, which is to make it harder to meet the due dates, also the threshold limits of the bidding parameters were taken to a higher level of difficulty. Conversely, no other modifications were made concerning the production area, as this is already the most difficult role to play. Hence, we considered that increasing the difficulty of this role could have introduced a bias in the overall results.

In this respect, we also note that teams were reshuffled accordingly to the following constraints: (i) each team was formed by players who were not in the same team in the previous round and (ii) each player had to change role. By doing so, although each player participated to two game sessions, the learning effect is minimized and its impact on the KPI results can be considered negligible. Obtained results are summarized in Tables 2–6, which show the effect of the increased difficulty on the KPIs described in Section 4.

As it can be seen, in alignment with the expected effects of the parameters that were changed:

- the sourcing success dropped from 78.3% to 64.9%;
- the delivery performance dropped from 59.1% to 45%.

Conversely the other KPI (linked to the bidding process and to production planning and scheduling) did not change significantly; rather a very slight increase was observed, probably due to the past experience maturated in the previous round of the game. These results, which certify the correctness of our choices, are also confirmed by the Cash Flow at the end of the game that, as previously explained, can be considered as the main summary indicators. Specifically, a reduction of around 11% was observed, as it is shown by Table 6. Please note that since round 1 and round 2 had a different simulated length (and also the teams played for a similar, yet different amount of time), the cash flow is expressed as per unit of time in the table.

To conclude we observe that, at this level, nothing more than a simple comparison of the average values of the KPIs (unsupported by statistical tests, given the small sample size available) can be done. As previously noted, only two games were played, using the same nine players, with different roles and shuffled to for new teams. Hence, obtained results, are to be considered preliminary and only indicative; yet they appear to be promising as they are perfectly aligned with our expectations. Further tests are scheduled in the next future.

6 Conclusions and future perspectives

In this paper we presented Op&SCM, a SG in the field of operations and supply chain management. In the game, players are divided into teams, each one representing an OEM manufacturing company, which compete on the same market with the overall objective to maximize the generated cash flow. To do so, teams must collaborate and take operational and tactical decisions concerning inbound, production and outbound processes, respectively played by 2 or 3 players operating as manager of 3 different functions (PM, OM and SM, respectively). Also, and perhaps most important, decision must be taken in real time. The game, in fact, does not follow a turn-based approach, since the events requiring a decision, such as a customer's request, the arrival of a freight, and the like, do occur at any time. Furthermore, as the simulation time runs faster than the real time, decision must not only be correct, but also quick. In this way, in addition to basic managerial principles, players also learn how to manage stress and understand the importance of collaboration and information sharing. Hence, by playing, they can improve both their hard and soft skills, and this aspect certainly is one of the distinguish features of Op&SCM.

The serious game is aimed at a wide range of users, such as bachelor and master students of supply chain and operation management, and practitioners and industrial personnel. For this reason, the level of difficulty must be readjusted from time to time, according to the initial level of knowledge and experience of the players. Similarly, an adjustable difficulty level could also be useful to emphasize specific educational themes, which could and will be made more difficult that other ones. To this aim, we presented more than 30 parameters of the game that can be parameterized by the teacher to customize the SG, and/or to make it harder. In addition to the game's parameters, we also presented five KPIs that are automatically calculated as the game runs. Although the main goal of these KPIs is to check and measure the progresses and improvements of the players, in the present paper we used these KPIs to check whether or not an appropriate parameters' setting has a measurable impact on the difficulty level of the SG. To empirically validate this assumption, we had teams composed of bachelor's degree students play two games at a different level of difficulty. To keep things simple and to see that the parameters do only affect certain aspects of the game, we modified only the parameters linked to supplier management and to the total throughput time (i.e., time from order acceptance to delivery). Results of the experiments perfectly matched our hypothesis, as only the KPIs that measure the goodness of bidding offers and the fulfilment of delivery dates deteriorate in the second and harder game, while all the other ones remained almost unaltered. It is worth noting that, at present, conclusions are based on the straight comparison of the average values of the KPIs. Only two games were played and so, given the small sample size, the analysis cannot be supported by any statistic techniques. Consequently, although promising, the outcomes are to be considered preliminary and only indicative. Additional tests are being implemented, both to increase the sample and to test the effect of the other parameters that were not used in the present study.

7 Acknowledgments

This research project was funded by the German Federal Ministry of Education and Research BMBF, grant number 16DHB2116 (Digilab4U – https://digilab4u.com/).

8 References

[1] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games," *Comput. Educ.*, vol. 59, no. 2, pp. 661–686, 2012. https://doi.org/10.1016/j.compedu.2012.03.004

[2] S. Deterding, D. Dixon, R. Khaled, and L. Nacke, "From Game Design Elements to Gamefulness," in *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments – MindTrek' 11*, 2011, p. 9. https://doi.org/10.1145/2181037.2181040

[3] D. Meadows, "Gaming to Implement System Dynamics Models," in *Computer-Based Management of Complex Systems*, Berlin, Heidelberg: Springer Berlin Heidelberg, 1989, pp. 635–640. https://doi.org/10.1007/978-3-642-74946-9_69

[4] J. M. Leonard and R. L. Wing, "Advantages of Using a Computer in Some Kinds of Educational Games," *IEEE Trans. Hum. Factors Electron.*, vol. HFE-8, no. 2, pp. 75–81, Jun. 1967. https://doi.org/10.1109/THFE.1967.233315

[5] J. M. B. Hauge, B. Pourabdollahian, and J. C. K. H. Riedel, "The Use of Serious Games in the Education of Engineers," 2013, pp. 622–629. https://doi.org/10.1007/978-3-642-40352-1_78

[6] G. Esposito, D. Mezzogori, D. Reverberi, G. Romagnoli, M. Ustenko, and F. Zammori, "Non-Traditional Labs and Lab Network Initiatives: A Review," *Int. J. Online Biomed. Eng.*, vol. 17, no. 05, p. 4, May 2021. https://doi.org/10.3991/ijoe.v17i05.20991

[7] G. Romagnoli, G. Esposito, A. Rizzi, F. Zammori, M. Bertolini, and D. Uckelmann, "Lab Networks in Engineering Education: A Proposed Structure for Organizing Information," *Int. J. Online Biomed. Eng.*, vol. 16, no. 05, pp. 41–70, May 2020. https://doi.org/10.3991/ijoe.v16i05.11891

[8] M. Burghardt, P. Ferdinand, A. Pfeiffer, D. Reverberi, and G. Romagnoli, "Integration of New Technologies and Alternative Methods in Laboratory-Based Scenarios," in *Advances in Intelligent Systems and Computing, Volume 1231 AISC*, 2021, pp. 488–507. https://doi.org/10.1007/978-3-030-52575-0_40

[9] M. Galli, D. Mezzogori, D. Reverberi, G. Romagnoli, and F. Zammori, "Experiencing the Role of Cooperation and Competition in Operations and Supply Chain Management with a Multiplayer Serious Game," *IFIP Adv. Inf. Commun. Technol.*, vol. 633 IFIP, pp. 491–499, 2021. https://doi.org/10.1007/978-3-030-85910-7_52

[10] E. Bottani, D. Reverberi, G. Romagnoli, M. Ustenko, and A. Volpi, "Batch Experiment: A Fruitful Way of Combining Hands-On Laboratory and E-Learning," *Lect. Notes Networks Syst.*, vol. 298, pp. 244–255, 2022. https://doi.org/10.1007/978-3-030-82529-4_24
[11] H. W. Reese, "The Learning-by-Doing Principle," *Behav. Dev. Bull.*, vol. 17, no. 1, pp. 1–19, 2011. https://doi.org/10.1037/h0100597
[12] E. Pacheco and J. Palma-Mendoza, "Using Serious Games in Logistics Education," in *2021 The 2nd International Conference on Industrial Engineering and Industrial Management*, 2021, pp. 51–55. https://doi.org/10.1145/3447432.3447438
[13] V. Delke, W. Buchholz, and H. Schiele, "Assessing Serious Games within Purchasing and Supply Management Education: An In-Class Experiment," *Proc. Eur. Conf. Games-Based Learn.*, vol. 2021-Septe, pp. 178–187, 2021.
[14] D. Hansen, E. Bonsignore, M. Ruppel, A. Visconti, and K. Kraus, "Designing Reusable Alternate Reality Games," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 1529–1538. https://doi.org/10.1145/2470654.2466203
[15] A. Streicher and J. D. Smeddinck, "Personalized and Adaptive Serious Games," 2016, pp. 332–377. https://doi.org/10.1007/978-3-319-46152-6_14
[16] C. Dichev and D. Dicheva, "Gamifying Education: What is Known, What is Believed and What Remains Uncertain: A Critical Review," *Int. J. Educ. Technol. High. Educ.*, vol. 14, no. 1, p. 9, Dec. 2017. https://doi.org/10.1186/s41239-017-0042-5
[17] J. L. Showers, "An Inventory Management Simulation Game," in *Winter Simulation Conference*, 1977, pp. 279–284.
[18] A. Mittal, M. P. Gupta, M. Chaturvedi, S. R. Chansarkar, and S. Gupta, "Cybersecurity Enhancement through Blockchain Training (CEBT) – A Serious Game Approach," *Int. J. Inf. Manag. Data Insights*, vol. 1, no. 1, p. 100001, Apr. 2021. https://doi.org/10.1016/j.jjimei.2020.100001
[19] S. Deterding, M. Sicart, L. Nacke, K. O'Hara, and D. Dixon, "Gamification. using Game-Design Elements in Non-Gaming Contexts," in *Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems – CHI EA '11*, 2011, p. 2425. https://doi.org/10.1145/1979742.1979575
[20] K. Werbach, "(Re)Defining Gamification: A Process Approach," in *Persuasive Technology*, A. Spagnolli, L. Chittaro, and L. Gamberini, Eds. Springer, Cham, 2014, pp. 266–272. https://doi.org/10.1007/978-3-319-07127-5_23
[21] M. Despeisse, "Games and Simulations in Industrial Engineering Education: A Review of the Cognitive and Affective Learning Outcomes," in *2018 Winter Simulation Conference (WSC)*, 2018, vol. 1, no. 1, pp. 4046–4057. https://doi.org/10.1109/WSC.2018.8632285
[22] J. B. Holmes and E. R. Gee, "A Framework for Understanding Game-Based Teaching and Learning," *Horiz.*, vol. 24, no. 1, pp. 1–16, Feb. 2016. https://doi.org/10.1108/OTH-11-2015-0069
[23] R. N. Landers and A. K. Landers, "An Empirical Test of the Theory of Gamified Learning," *Simul. Gaming*, vol. 45, no. 6, pp. 769–785, Dec. 2014. https://doi.org/10.1177/1046878114563662
[24] N. Buyurgan and C. Kiassat, "Developing a New Industrial Engineering Curriculum using a Systems Engineering Approach," *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 1263–1276, Nov. 2017. https://doi.org/10.1080/03043797.2017.1287665
[25] D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*. FT press, 2014.
[26] A. Pfeiffer, V. Lukarov, G. Romagnoli, D. Uckelmann, and U. Schroeder, "Experiential Learning in Labs and Multimodal Learning Analytics," in *Adoption of Data Analytics in Higher Education Learning and Teaching*, 2020, pp. 349–373. https://doi.org/10.1007/978-3-030-47392-1_18

[27] J. D. Sterman, "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment," *Manage. Sci.*, vol. 35, no. 3, pp. 321–339, Mar. 1989. https://doi.org/10.1287/mnsc.35.3.321

[28] X. Wang and S. M. Disney, "The Bullwhip Effect: Progress, Trends and Directions," *Eur. J. Oper. Res.*, vol. 250, no. 3, pp. 691–701, May 2016. https://doi.org/10.1016/j.ejor.2015.07.022

[29] A. Tobail, J. Crowe, and A. Arisha, "Learning by Gaming: Supply Chain Application," *Proc. – Winter Simul. Conf.*, pp. 3935–3946, 2011. https://doi.org/10.1109/WSC.2011.6148084

[30] M. Lambrecht, S. Creemers, R. Boute, and R. Leus, "Extending the Production Dice Game," *Int. J. Oper. Prod. Manag.*, vol. 32, no. 12, pp. 1460–1472, Nov. 2012. https://doi.org/10.1108/01443571211284197

[31] S. De Leeuw, M. C. Schippers, and S. J. Hoogervorst, "The Fresh Connection," in *The Handbook of Behavioral Operations Management*, Oxford University Press, 2015, pp. 359–377. https://doi.org/10.1093/acprof:oso/9780199357215.003.0017

[32] S. Göbel, "Serious Games Application Examples," in *Serious Games*, Cham: Springer International Publishing, 2016, pp. 319–405. https://doi.org/10.1007/978-3-319-40612-1_12

[33] J. M. Keller and T. W. Kopp, "Application of the ARCS Model to Motivational Design," in *Instructional Theories in Action: Lessons Illustrating Selected Theories*, C. M. Reigeluth, Ed. New York (NY), USA: Lawrence Erlbaum, 1987, pp. 289–320.

[34] G. A. Gunter, P. D, and R. F. Kenny, "A Case for a Formal Design Paradigm for Serious Games," *J. Int. Digit. Media Arts Assoc.*, vol. 3, no. 2004, pp. 1–19, 2006.

9 Authors

Giovanni Romagnoli is a lecturer in Operations and Project Management at the Department of Engineering and Architecture of the University of Parma. Since December 2019, he is the local scientific coordinator of the project DigiLab4U (http://digilab4u.com/). His research interests include virtual and remote lab network initiatives, RFID and supply chain management, production planning & control systems. He has published more than 50 contributions on International Journals or Conference proceedings, some of which have been awarded with prizes. His ORCID iD is: https://orcid.org/0000-0002-9891-0314 (email: giovanni.romagnoli@unipr.it).

Matteo Galli was born in 1987 in Piacenza (Italy). He obtained his Master Degree in Computer Engineering at the Politecnico di Milano (2013). After his studies, he worked in the private sector as an entrepreneur in a company offering management systems to SMEs; during this time he consolidated his knowledge of industrial processes with multiple projects and dozens of customers. In 2020, at the University of Parma, he has been involved in the DigiLab4U project. Since 2022, he started a Ph.D. at the University of Modena e Reggio Emilia with the goal of optimizing large-scale waste management. He is currently co-author of five scientific publications.

Davide Mezzogori has received his Ph.D. on Industrial Engineering at the University of Parma. He is now research fellow at University of Modena and Reggio Emilia. He is coauthor of more than 20 international scientific publications. He has published articles on the application of Machine Learning and Deep Learning algorithms to Industrial problems, such as demand forecast in the fashion industry, the application of neural networks to WLC systems, as well as articles on optimization

algorithms (i.e. metaheuristics) applied to engineering operations management, such as scheduling problems and warehouse allocation problems. Currently, his research effort is towards Green Advanced Planning and Scheduling systems. He has been involved in the DigiLab4U project for the development of the serious game Op&SCM.

Francesco Zammori graduated with distinction in 2004 in Management Engineering and completed his post-graduate studies in 2009, when he received a Ph.D. in Industrial Engineering from the University of Pisa. From 2012 he has been working at the University of Parma with the role of Assistant Professor. Since 2021, he is Associate Professor at the same University, where he teaches Management Accounting Systems, Information Science, Data Bases and Information Systems. His research interests mainly concern: (i) Lean Thinking, (ii) Hybrid Production Planning and Control Systems, (iii) Modeling and Simulation (v) Machine Learning and (iv) Project Management. His research activities led to the publication of more than 50 works, most of which accepted on prestigious International Journals. His ORCID iD is: https://orcid.org/0000-0003-4931-5540 (email: francesco.zammori@unipr.it).

Article submitted 2022-09-05. Resubmitted 2022-10-11. Final acceptance 2022-10-15. Final version published as submitted by the authors.