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Improving a game-based education tool for quality management in production networks

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Abstract

Managing the quality of a product and a company within a production network is a challenging task for decision makers, as the impact of actions is often time-delayed and can lead to the famous bullwhip effect in a multi stage supply chain. In order to qualify decision makers to understand the fundamental principles of quality management in production networks and thus enable them to effectively use it to optimize quality within his or her company, a game based simulation similar to Goldratt's game, called Q-I-Game, has been developed and tested in a previous research project. Within the game, one player acts as a factory between a supplier and a customer and states his desired invest into quality, the quantity of parts to be ordered and the investment into an inspection of incoming parts. The game uses simple, artificial functions to model effects between the investment into quality and the resulting quality of produced parts. To improve the learning effect of the game in regards to inspection planning as well as to promote understanding of the mechanics, the functionality of the game was expanded and a more realistic model of production is being developed and shown in this paper. The added functionality allows to simulate an extended supply chain with multiple players all acting as customer and supplier within the game. Thus, the game has evolved from simple single player to a complex multi-player game, taking the fact into consideration, that the bullwhip effect increases downstream of the supply chain. In addition, players will have the opportunity to make decisions on defect parts coming from a supplier (e.g. reject them and accept a new supply date). The extensions of the game which are already realised will be presented within the paper and future developments will be discussed.

Keywords: Quality assuranc; Production; Decision making

1. Introduction

Production companies in high-wage countries today are challenged by the ever increasing competition of markets. Upcoming companies from low-wage countries are not only challenging established companies by offering substitute products at aggressive prices. Furthermore, the technological know-how of companies from low-wage countries is increasing rapidly. Thus established companies are required to justify higher product prices through an exceptionally high product quality and at the same time reduce the costs related to their products by reducing their own sourcing and production costs and making their processes more efficient. [2]

Assuring the right quality for both supplied parts and the finished product, is a challenging task in this regard, especially due to the increase of global sourcing to save costs.[3]. Not surprisingly, quality management is generally regarded to be closely connected to both supply chain coordination and supply chain management [4]. A competent quality manager has to be able to control the quality throughout the entire production network, in order to assure that the output of his own company meets customer specifications and to keep all costs related to insufficient quality at a minimum. To do so, tools and methods from various disciplines such as simulation based forecasting from supply chain management [5] and Weibull- and risk-analysis from quality management and inspection planning [6] have to be put to effective use. In this sense, decision makers in supply chain management have to be familiar with the various tools provided for supply chain management. However they

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should have a profound understanding of the causes and effects of their decisions within the production network [7, 8].

2. Game-based learning approach

The approach of game-based learning using so called “serious games” can be used to educate quality managers about the consequences of their decisions in production networks. Besides its use of training managers and thus supporting them in their decision making processes, game-based learning also generates valuable information and data which can provide a better understanding of human behaviour in complex and stressful situations. This is especially important as similar information usually remains hidden in real world scenarios and thus cannot be used to reflect decisions [9, 10].

The first approach which can be seen as a predecessor of today’s business games is dated back to 1932, when Mary Birshstein developed a simulation to support management decisions in a production plant of typewriters. The American Management Association developed in 1956 the first commonly known business game called Top Management Decision Simulation. To support supply chain managers in their decisions, simulations such as the Beer Distribution Game [11] have been developed. The Beer Game simulates the relation between stocks and order quantities among different players in a supply chain. The aim of the game is to visualize the so called bullwhip effect, which has later been proven to be existent by Lee [12]. The bullwhip effect describes the phenomenon that a simple increase of the customers product demand leads to an amplification and oscillation in other stages of the supply chain (see Fig. 1).[1, 13]
Another game-based learning approach is Goldratt’s Game. Similar to the Beer Game, players step into different roles within the supply chain or a production process. This turn-

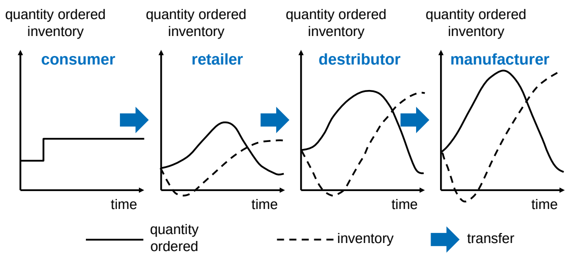

Fig. 1. Visualisation of the bullwhip effect in a supply chain[1]

based game shows how simple variances in each process step can amplify and thus influence the whole process quality. Empirical studies have shown that game-based learning approaches are more effective than traditional learning by studying [14].[15–17]

3. Educational game for quality management in supply chains

To provide decision makers in supply chain management a better understanding of the principles and interdependencies of quality and costs within a production network, a simulation based game (Quality-Intelligence-Game, or Q-I-Game) has been developed in a cooperation of the Chair for Metrology and Quality Management and the Human Computer Interaction Center at the RWTH Aachen University. The game is designed as a one player game, who acts as a manufacturer in a three stage production system consisting of a supplier, manufacturer and customer. The other two functions are realized through simulation models. Within a Java based graphical surface, the player makes certain decisions which then count for a one month production period, aiming at maximizing profit at the end of a given game period (e.g. after 2 years or 24 periods). The player is able to decide on the investment into quality inspections for incoming goods. A higher investment leading to a lower number of faulty parts entering his manufacturing system. Every detected faulty part directly leads to a penalty for the supplier, whereas the model behaviour is changed depending on the amount of penalties the supplier has to pay for faulty parts. Furthermore, the player is able to invest into the quality of manufacturing processes, higher investment leading to lower variances of the fault rates, lower fault rates in general and thus, lower penalties for customer complaints of faulty products. The player has to decide on the amount of procured parts from the supplier for the next round, whereas high stocks lead to warehouse costs and inability to deliver products and this to profit loss. [17]

4. Motivation for further development of the game

This section focusses on the current game structure, identified constraints and possible improvements of the model behind the game. Following the discussion of these constraints, necessary extensions to the game will be presented.

4.1. Constraints of the current development state

Within the current development state, three major constraints are present which affect the realism of the game’s behaviour, as well as the complexity of strategies which can be used to play the game.

Constraints regarding the quality of procurement
Within the current state of the game, the single possibility of the player to influence the quality of delivered parts is through the value of investment into incoming inspections, which influences the detection rate of defect goods following a simple linear function. This presents a constraint to the strategic options available to control the quality of delivered goods from a supplier.

Constraints regarding the quality of manufacturing
In terms of product quality the player is able to decide on the investments into the manufacturing process quality which directly influences the rate of defect-free manufactured products, when using defect-free input parts. The connection between investments and rejection rate follows a simple linear function. However whether a linear function is really able to reflect the reality of quality investments in manufacturing

companies is unknown. Holweg and Bicheno indicate that realism in supply chain simulation games is an essential factor for the credibility of the game [18]. Another constraint in regard to the quality of manufacturing in the game is the fact, that product quality is modeled as a simple ratio of good and faulty products at the end of the manufacturing process. The ratio of good to defect parts depends on the investment into the production quality via the linear function. The fact that the current game only models a product to be good or faulty also does not enable the player to strategically work towards optimizing his own process reliability, following the theory of Taguchi´s loss function. [19]

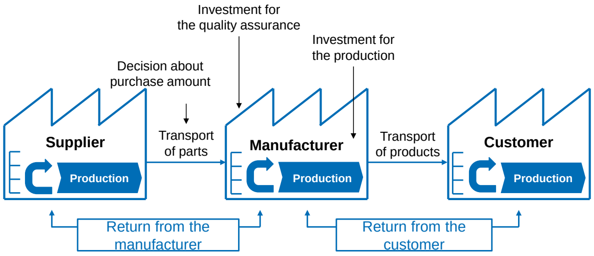

Fig. 2. Concept of the Q-I-game

Constraints regarding the possible game modes

The Q-I-Games supply chain allows one player to play the game as a manufacturer, in the middle position of a simple three stage supply chain. This presents a significant educational constraint of the game as players cannot experience, how the bullwhip effect amplifies along a multi (more than three) stage supply chain from the customer to the supplier [12]. For this reason, the initial Beer-game consisted of four stages and during its evaluation, the same amplification of order variance accounted to the bullwhip effect has been observed [11].

The mentioned limits served as motivation to develop a new game for quality management in supply chains which will be discussed in the following subsequent sections.

4.2. Necessary extensions of the game

The current constraints offer several new developmental directions for the game. The possibilities how to address these constraints through extensions of the game are presented consequently.

4.2.1. Extensions to control the quality of procurement

Quality penalties and rewards

Besides the investment into the inspection policy, manufacturers can in reality use penalties and rewards to motivate suppliers to deliver higher quality and thus reduce the cost of low-quality for the manufacturer itself [20]. A necessary extension would therefore be to give players the possibility to define penalties and rewards for his/her supplier. Penalties could also include the possibility to reject entire deliveries if the ratio of faulty parts is above a specific limit. Giving players the opportunity to experience how the interplay between inspection rate (i.e. invest into inspection), penalties and rewards can be used to control the quality of supplied parts, should be beneficial to the educational value of the game. Especially in contract negotiations with suppliers, managers could use this knowledge to motivate the supplier to deliver the desired quality.

Supplier selection

Supplier selection is a major task within quality management and is critical to the success of production networks [16]. A more realistic approach of the supplier interaction should include the possibility of the selection between different suppliers or even the choice of multiple suppliers at the same time [21]. Hence, the long-term influences of different sourcing and supplier strategies (low price vs. high quality) could be analysed.

Connection between supplier quality invest and cost of his products

Because of the described possibility for the player to reject an entire delivery from the supplier, depending on a certain ratio of faulty parts, the supplier must be able to improve his product quality due to higher investments. To be more realistic and to hold the player from just always demanding deliveries without any faulty parts, the model should include a connection between these higher investments and the price of the supplier’s product. In the end a lower acceptance ratio for faulty parts results in higher procurement costs for the manufacturer.

4.2.2. Extensions to control the quality of manufacturing

Manufacturing model uses real-world parameters

A model function, based on a real production scenario could benefit the game through enhanced realism in terms of game behaviour. In real production scenarios, quality problems occur which may require more difficile strategies towards procurement and inventory optimization than using the simple model of the current development state.

Modeling product quality individually and continuously

Realisation of a specific degree for the quality, instead of products being categorised into defect and defect-free. Of course, depending on the customer requirements, this categorization still has to be made afterwards in order to decide, whether the produced quality is sufficient or not. The second improvement then would be the implementation of a realistic function, describing the connection between investments and production quality better than the current assumed linear connection (as described in section 4.1).

4.2.3. Extensions to the game modes

Horizontal extension of the production network

Allowing a more complex production network, consisting of more than one factory, i.e. an arbitrary number of consequent factories could benefit the game by enabling players to experience different amplifications of the bullwhip effect and develop individual strategies to counter this effect at their respective position.

Multi-player gaming

Enabling multiple players to act as factories within a multi-stage supply chain would enable comparison of the players at different stages within the supply chain. In addition, different communication strategies could be explored, to determine what the minimum amount of information is which has to be passed on from player to player, in order to keep the production network stable and prevent the bullwhip effect from occurring.

Multiple suppliers and customers per factory

Enabling multiple vertical connections from and to each factory would bring aspects of supplier selection and competition into the game´s strategic focus. This vertical extension in combination with the other extensions could lead to complex game situations with competing manufacturers with different strategies and multiple customers with different requirements regarding the product quality.

Intelligent computer players

Following an extension of the game towards multiplayer gaming, it could also be beneficial to create an artificial intelligence (AI) for the factories, which could be used to artificially increase the size of the production network and thus enable more complex game scenarios without the need for more human players. These AI players could also be used to examine different pre-defined strategies in terms of their effectiveness for different game situations and modes. Realizing such an AI is the most challenging of the presented possible extensions, as specific algorithms would have to be developed to fit the game mechanics.

4.3. Summary

Whether the extensions which were presented can bring an actual benefit to the educational value of the game and to the understanding of human behavior in complex supply chains remains to be examined. The extensions which were derived from the current constraints of the game were taken as motivation to develop a new game as a re-development of the Q-I-Game which will be presented consequently.

5. LogisticsSim – A new educational quality game

To differentiate the new game from the Q-I-Game, it is titled "LogisticsSim" and is currently under development at the Chair for Metrology and Quality Management of the RWTH Aachen University. It is also being developed in Java. The new game realizes the player factories as instances from a generic factory class. An arbitrary number of instances can be generated for a certain game with every instance being played by a different human player. Thus, the game becomes a multiplayer endeavor with variable complexity of the supply chain. The game can be played without communication between players to encourage the development of individual strategies in order to counter the varying amplitude of the bullwhip effect at different positions within the supply chain. Bringing multiple players into one game, different level of information transfer can be realised, in which e.g. players are allowed to share their inspection policies or their invest into production quality to a certain degree. This modality enables players to experience the extensively analyzed advantages of information sharing in supply chains. [12, 22]

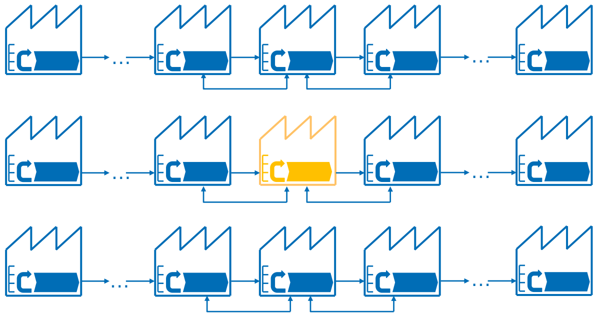

Fig. 3. Multiplayer game realisation with horizontal extension and three parallel supply chains

The game thus allows for a far more complex simulation of the actual bullwhip effect, as demand and supply control are now placed into human hands. Players can still influence the detection of faulty parts through investments. However a new element is introduced into the game which allows the player to reject an entire delivery of parts if the detected ratio of faulty parts is above a certain pre-defined limit and to once receive a new delivery within the same round of the game. In the prior version of the game every part which was detected to be faulty simply leads to a fixed penalty for the supplier. Following a rejection of the entire delivery, the supplier then has to re-inspect the entire delivery. If the ratio of faulty parts for the entire shipment is indeed above the pre-defined limit, the supplier has to cover all costs related to the scrapping of faulty parts. Otherwise the customer has to cover these costs. After sorting out the faulty products the supplier fills up the difference in the shipment with products from his stock. If he is unable to do so a penalty for the incomplete delivery has to be paid by the supplier.

This requires the player to consider various different information and aftereffects when deciding about his factories inspection policy. For example, if a delivery from the manufacturer contains too many faulty parts, as described he has the possibility to reject the entire delivery and to receive a new one during the same round. If the second delivery also contains an unacceptable high number of faulty parts, the player is again allowed to reject the delivery in the next round. This may result in the situation that the manufacturer is unable to produce the number of parts ordered by the customer leading to a loss of profit .

This example should give an impression on how this new game element can increase the complexity of the game and the different strategies which can be pursued by the player.

6. Conclusions and Outlook

In this paper the constraints of the Q-I-Game, an educational game for supply chain quality managers have been presented. These fall into three main categories: Constraints regarding the possibilities to modify the inspection policy of incoming parts, constraints regarding the possibility to control the quality of manufactured products and regarding the constraints regarding possible game modes. In order to overcome these limitations, a new game called LogisticsSim has been presented which presents a development of the Q-I-Game. The new LogisticsSim game addresses several of the constraints of the Q-I-Game in its current development state. Especially the possibility to have multiple players participate in one instance of the game and the possibility of declining a shipment following a bad sample inspection make completely new strategies possible. However not every possible extension has been realized within the software at the current development state and concepts have to be developed to realize these extensions. In addition, a new graphical surface will have to be developed which enables the user to effectively control the new decisions the game allows.

Possible elements of the LogisticsSim which were derived from the constraints of the Q-I-Game now have to be implemented step by step and a behavioral analysis has to be conducted, whether these new elements are accepted by the players and whether they lead to new strategies within the game.

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