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A Game-based Approach to Understand Human Factors in Supply Chains and Quality Management

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Abstract

Quality management is an important function for viable production networks. In order to qualify decision makers to understand the fundamental principles of quality management in production networks, a game-based simulation and learning environment is developed, which can furthermore be used to understand how human factors influence the quality of decisions in complex production networks. Previous studies have shown that underlying factors must exist, which predict the players' performance. It is currently unexplored, which factors are contributing to high performance. To deeper investigate which human factors are critical for supply chain success and to further refine the quality management game a series of studies were examined. As expected, expertise had a great impact on performance, however contrary to the expectations cognitive skills had none. The refined decision dashboard, with seamlessly integrated self-adapting visualizations on key performance indicators, had a significant positive impact on game performance. The studies suggest that the developed game is a valuable contribution for the qualification of quality managers, as the quality of decision increased.

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1. Quality management in production networks

Quality management is an interdisciplinary function in industries and organizations. It aims at controlling the complex interplay of heterogeneous processes in a highly dynamic environment. That is, quality management gives a contribution to the decision making process on all entrepreneurial levels from the macroscopic perspective of production networks and supply chains down to the shop floor level, where product and process parameters have to be controlled and adapted in order to maintain stability and capability [1]. Ever since the foundation and successful establishment of the total quality management principle, quality management was directly connected to entrepreneurial success [2]. Hence, quality management offers methods, solutions and tools to support decision making processes in many different functions and fields.

Quality management units are typically in lead, or process owner for several entrepreneurial processes [3]:

1. Quality politics and strategy planning
2. Coordination of quality management methods
3. Standardization of documentation
4. Continuous improvement processes
5. Quality and inspection planning
6. Quality control and assurance
7. Supplier assessment and development
8. Corrective action, change, complaint and defect processes
9. Auditing
10. Surveying customer satisfaction

While all these quality management processes are playing an important role throughout the organization, the processes four to ten can have a direct impact on the value stream; they are not only management or supporting processes, but are

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directly connected to the customer, or the value stream. Hence, quality management eventually has a significant interface to the work and tasks of other entrepreneurial management disciplines in the value stream such as production, logistics and supply chain management and purchasing.

2. Analyzing the interfaces of quality management with direct functions

In order to understand the interface between the management disciplines in supply chains and quality management, the methods and target systems of these disciplines were analyzed and reviewed. Logistics, purchasing and supply chain management are not strictly differentiated in literature. Therefore a process oriented approach was selected, defining the main tasks of these functions which are directly connected to the management of the value stream of production networks:

- Supply chain design
- Demand planning
- Planning of procurement and purchase
- Inventory control and management
- Supply Chain and production planning and control (PPC)

2.1.1. Quality management and supply chain design

Supply chain design covers all tasks connected from the identification via contracting over to the phase-out of suppliers [4] [5]. In order to identify suppliers and possible locations for the production networks various qualitative and quantitative decision methodologies and algorithms especially from operations research can be used. These methods are considering various factors (e.g. price, distance, place, company size), which have to be considered when decisions about the supply chain design are made [5]. Quality management is giving different contributions to these decision factors. Within the process of supplier development and auditing, quality management has the task to assess the system, product and process quality level of suppliers and negotiate quality assurance agreements between the producer and its suppliers. Moreover, quality managers are in charge to run complaint processes to the suppliers using 8D-reports as the state-of the-art methodology [6].

2.1.2. Quality management and demand planning

The demand planning process uses several forecasting methods in order to predict the customer demand for the supply chain. Based on these demands the capacity of the production plants is planned [5]. Especially the processes of quality management which are directly connected to the customer, such as complaint, claim and call-back management are processes which have a significant influence on customer satisfaction and eventually on sales volume [6].

2.1.3. Quality management and procurement planning

Methods such as the ABC/ XYZ analysis are the basis for the decision about the sourcing policy of supply chain management [4] [5]. Sourcing policies are differentiated by the trigger point of the sourcing (reorder-point vs. frequency) and the elaboration of the order quantity (order-up-to-level vs. economic order quantity). Nevertheless modern sourcing policies have to consider the inspection policy and the supplier quality level: A just-in-time delivery with the parts shipped to line would be fatal, if the supplier had issues in process or product quality [5].

2.1.4. Quality management and inventory control

The task of inventory control is to define the necessary level of stock in order to reach the desired service level, while inventory costs should be minimized [4] [5]. Depending on the quality level of production processes and the scrap rate, quality management is giving an important input to the inventory planning process. On shop floor level, quality and inventory control have to establish concepts which guarantee that defect parts, or parts for rework or scrap are not confused with work-in-progress inventory.

2.1.5. Quality management and production planning and control

The Aachen PPC model is a well known regulation framework for the tasks and processes of production management [7]. Quality management processes such as inspection planning, quality control and assurance, and continuous improvement have a significant interdependency with these production management processes. Based on the quality and inspection planning, inspection control work places are designed and integrated in the value stream of the shop floor. Faulty parts and disturbances of machines can cause severe changes and potential turbulences within the production program. Moreover quality management contributes various optimization methods such as the Design-of-Experiments (DoE) for effectiveness and efficiency of machines and processes on shop floor [6].

2.2. Challenges for the integration of the tasks

Nowadays the analyzed interfaces are often implemented in production IT-systems, which support the work flows and decision makers. These systems have a modular structure, meaning that the described processes can be decoupled from each other. To give an example: The purchasing and ordering function of an ERP system does not necessary exchange information with the CAQ or MES module about current scrap and failure rates within the production, but sets the fraction of faulty parts as a constant variable in the system. According to expert interviews, the integration of the methods and interfaces in theory and IT-system can bring a significant benefit for production companies but might also increase the complexity for decision makers in quality, production, logistics and supply chain management. Hence, cause-and-effect chains which were primarily taught within the ITmodules of the functions should be interlinked and connected between the disciplines, without increasing the complexity of the system, perceived by the decision makers. Therefore not only the theory and production concept need to be considered but also the role of the human as the decision maker in complex production systems, when new concepts for quality and production management are designed or connected.

3. Game based learning in quality and production management

In order to train and support human decision making, business games can provide an ideal arena for training and simulation since no penalties or damages resulting from bad decisions have to be feared. Similar to a flight simulator, the decision maker is confronted with a challenging situation recommending fast meaningful decision making.

Production and quality management is facing a long tradition in business gaming in order to support the managers in their daily work and increase decision efficiency. The Beer distribution game is a powerful example for well known games among supply chain managers [8]. Goldratt's game envisions the main idea about the theory of constraints to quality managers.

3.1. Beer distribution game

The Beer distribution game was designed by MIT professors to demonstrate the Bullwhip effect which was discovered and described based on a Pampers production of Proctor and Gamble [8]. The Bullwhip effect describes [9]

- "how small changes in retail sales can lead to large swings in factory reduction,
- how reduced delays may fail to improve management decisions significantly,
- how a factory manager may find himself unable to fill orders although at all times able to produce more goods than are being sold to consumers, and
- how and advertisement policy can have a magnificent effect on production variations."

In the game four players are taking the role of the retailer, wholesale, regional warehouse and factory within one linear supply chain. Each player has to decide about the order quantity for the next game period. The overall target is to operate the supply chain at a minimum cost level. Studies show several measures in order to reduce the amplification of the Bullwhip-effect significantly. Many measures require a collaborative behavior of the supply chain steps such as sharing the information about point-of-sale data.

3.2. Goldratt's game

Goldratt's Game simulates a production line which is imperiled by fluctuations [11]. In this example, the production line consists of two workstations (station 1 and station 2). Fig. 1 illustrates the game set design.

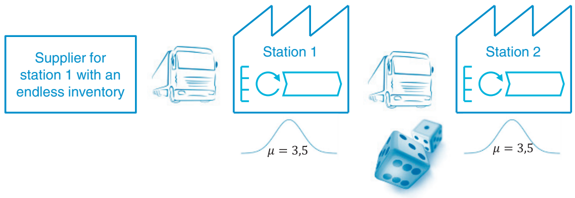

Fig. 1. Goldratt's game

The incoming goods for station 1 arrive from a supplier with an unlimited inventory and the incoming goods for station 2 are produced and delivered by station 1. In order to determine the number of the demanded goods, an ideal dice is tossed in each round once, first for station 1 and then for station 2. A new round starts after the transportation of goods from the supplier to station 1 and from station 1 to station 2 is carried out. If there are not enough goods at station 1 to meet the demand from station 2, then all the goods will be transported. Fluctuations of the production output are caused by dice toss.

3.3. The need for a new Quality Intelligence (QI)-Game

Comparing the concepts of the two games points out that quality managers cannot make decisions in the Goldratt's Game but are reduced to game automats, simply representing different levels of a linear supply chain and rolling the dice in order to simulate variation in part supply. Moreover, the role of the human character and user diversity has hardly been studied for quality management before, as recent research on human behavior in supply chain systems presents. Therefore the next research steps for the quality management in supply chain steps should be

1 – the development of a game and simulation concept for quality management and planning in supply chains (Chapter 4).

2 – the evaluation of the game design and the effect of human behavior and characteristics in the new developed game environment (Chapter 5).

4. Concept and Design of the QI-game

When companies success is measured in profit, quality management has a significant impact according to the total quality management concept [6].

$$Profit = (p - c_v) \cdot n - C_f$$

While the product quality perspective is targeting the maximization of price (p) and sales volume (n), process quality focusses on the minimization of variable costs (c_v)and fixed costs (C_f). Hence the QI-game should consider the described key processes of quality management and simulate their contribution to the overall profit.

4.1. Implementation of the value stream in supply chains

In order to built a game concept for a supply chain the Beer distribution game and Goldratt's game can serve as blueprints. Therefore, the players will take the role of one production unit in the supply chain. For the demonstration of the effects of decisions in quality management processes the ideal abstraction level of the value stream has to be defined. The game should be applicable to a wide range of players with and without expert knowledge in quality or production management. Therefore, the resolution of each process step should not be too detailed, choosing a similar aggregation level to the steps of the Beer distribution game and Goldratt's game. Therefore each player will have to manage a process containing an inventory for incoming goods and a production process. Each supply chain step will receive the incoming goods from a single supplier delivering to just one customer.

4.2. Connecting the key processes of quality management to the value stream

While the game concept of the value stream is only little different to those of the Beer distribution game and Goldratt's game, the player has to get the possibility to make decisions in the most important processes owned by quality management, which again have to be connected to the overall profit. Therefore the earlier discussed processes will be implemented in the game (see also Fig. 2).

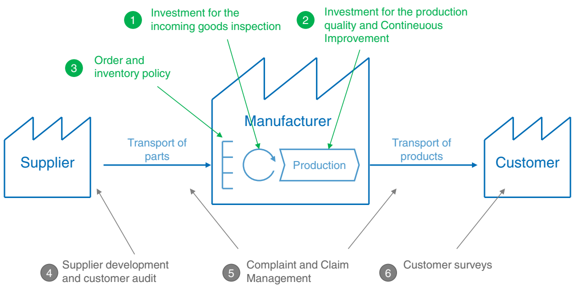

Fig. 2. The QI decision cockpit

4.2.1. Implementation of inspection planning for incoming goods (1)

In order to assure the product quality of incoming goods from the supplier, the player can decide about his inspection policy. When the player increases his invest in inspections, test efforts and sample sizes will be increased and the probability to find faulty goods from the supplier will rise. Faulty supplier parts which enter the production system of a player are more likely to be transformed into faulty products which will cause internal defects or complaints if the product is delivered to the customer. Hence the player has to understand and make decision about the trade-off between higher inspection costs and lower production yields and higher costs for claims due to customer complaints.

4.2.2. Implementation of Continuous Improvement Processes and Production Quality Control (2)

Similar to the decision about the inspection policy, the player will have to decide about his policy for internal processes. Therefore he can invest into the quality level of his own production processes. If invests are low, the yield and final product quality will fall causing higher complaints and claims by the customer, while high invests will compromise the overall profitability. Similar to the decision about the inspection policy, the player is facing another trade-off decision between preventive and corrective quality costs.

4.2.3. Order and inventory policy (3)

In addition the player has to decide about his inventory and order policy, considering the scraped products of the supplier and faulty products from his own production. While the parameters for the management of orders are similar to the Beer game, rapid changes in demand will not occur, leaving the focus on the decisions of the game on the quality policies. Nevertheless the player has to consider scrapped parts due to low production quality or blocked parts due to poor supplier product quality, when he makes the ordering decisions.

4.2.4. Implementation of problem management and claim and complaint processes (5)

Faulty supplier parts identified by the incoming goods inspection will be complained at the supplier. Hence, the player will get credit for the complained parts. Moreover, the supplier will learn from the complainted parts. That is, a supplier receiving no complaints due to low inspection policy of his customer will deteriorate his product quality level in order to reduce his own costs.

Furthermore, the player will receive complaints from the customer. The complaints will increase quality costs and decrease overall profits. Furthermore, lower customer satisfaction can lead to decreasing customer demand.

These processes will run automatically as consequences of the players inspection and production quality policy.

4.2.5. Supplier development, auditing and customer satisfaction studies (4,6)

In supply chain management the supplier development will use audits, supplier development and customer surveys to assess and enhance the quality level of the supplier and measure customer satisfaction. These measures are usually used in order to decrease the need for costly in-line inspections (4.2.1) and adapt production quality control (4.2.2). In order to reduce the complexity of the game for the player, he will not get to decide about the assessment, but will play two games with and without the additional information about supplier quality level and customer satisfaction. These information could be compared to the information about point-of-sales data in the beer game.

4.3. Implementation of the QI-game

Fig. 2 shows the implemented decision cockpit for one player of the QI-game. The upper half is showing the described information and key performance indicators for the inspection at goods receipt, inventory and logistics, and production and sales planning. The player can shift the slider in the quality management decision board in order to adapt inspection and production quality policies and decide on the orders. The implemented traffic lights are optional features which could serve as early indicators for the true state of the supplier quality level and customer satisfaction, while the internal measured quality depends on the policy decisions of the players and might contain systematic bias.

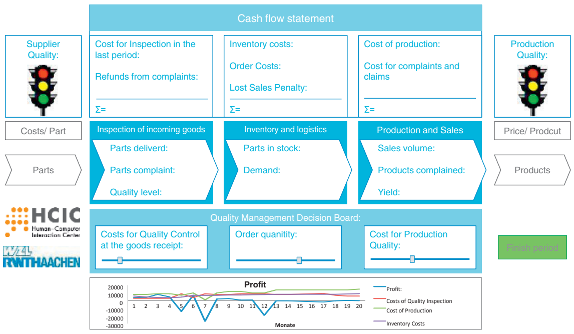

Fig. 2. The QI decision cockpit

Similar to the Beer distribution game, the next step was to find the right parameters for the functions and cause-and-effect chains. While the functions can be deduced using an analytical approach, the parameter level will have a huge effect on the sensitivity of the model. In order to define the level of the parameters pre-studies were conducted. As for the Beer game, the player will be challenged with a disruptive change of the supplier product quality and or his production quality. Therefore, it can be trained to adapt the inspection and production quality policies to severe changes in the supply chain or the production system.

5. Evaluation

After the implementation of the QI-game as a publicly available web application a formal user study was conducted. The goal of this study was to evaluate the game model, to understand how players interact with the game, how different settings within the game model effect the company's performance and to investigate whether player profiles also have an influence on the performance of the simulated company. In the following a highly focused review of the results is given; an in-depth presentation of this and a series of accompanying sub-studies can be found in [12], [13]. The evaluation of the game was guided by four formal hypotheses:

H1: The game is useable in the sense that the players can achieve reliable results.

H2: The company's performance is influenced by the simulated quality of the supplier (drop vs. no drop) and the quality of the own production (drop vs. no drop).

H3: The presentation of indicators for the supplier's quality and for the internal production quality increases the company's performance.

H4: The player profile influences the performance of the simulated company.

5.1. Experimental Setup

To validate the hypotheses, we designed a formal experiment, in which participants played two consecutive rounds of the QI-Game under different experimental conditions. Before the game a pre-survey assessed the subjects' demographic data (age, gender, vocational background) and various personality traits. After the game a post-survey captured the player's strategy, perceived difficulty, as well as an overall evaluation of the game.

5.1.1. Independent Variables

As independent variable a characterization of the player's personality was used. It was modeled by the Five Factor Model (FFM), which describes the human personality by the five dimensions openness, conscientiousness, extraversion, agreeableness, and neuroticism. To assess the participants' personality traits a 20-item questionnaire by Rammstedt [14] was used. Furthermore, self-efficacy in interacting with technology (SET) was measured, as it was found to have a substantial impact on user's efficiency, effectivity and satisfaction within a wide range of domains, in which users interact with technology [15]–[17].

5.1.2. Experimental Variables

The complexity of the simulation was controlled by two between-subjects repeated-measures factors: First, a factor indicating a drop or the absence of a drop of the supplier's product quality by 30% after the 10^{th} round. Second, a factor indicating a drop or the absence of a drop of the internal production quality by 30% after the 10^{th} round.

The visibility of indicators for the supplier's quality and the internal production quality was controlled as a within-subject variable. Either both indicators or no indicator were visible. If displayed, the indicators were represented as traffic lights within the game environment.

5.1.3. Depended Variables

As the dependent variable the cumulated profit after each round was evaluated. Note that the parameterization of the in-game costs and profits is reasonable, but still arbitrary. Hence, the values presented below should not be interpreted as absolute values, but as indicators for relative complexity of the game. Furthermore, the total playing time for each round and the number of changes of the company's controls was measured.

5.1.4. Sample description

Participants were recruited on social networks, by email or posters in lecture halls. In total 127 participants completed the experiment, of which 97 are male (23.6%) and 30 are female (23.6%). The sample is rather young with a mean age of 27.7 years (σ=7.2 years). Over half (58.6%) of the participants reported a university degree as their highest educational attainment, followed by a high school diploma (39.7%). A third of the participants reported previous knowledge in quality management (67.7%) or business management (65.9%). Regarding the Five Factor Model the sample is comparable to the reference sample of Rammstedt.

5.2. Results

The data was analyzed with uni- and multivariate analyses of variance (M/ANOVA) and bivariate correlations. Pillai's trace values (V) were used for the significance in multivariate tests. The level of significance was set to p < .05. The remainder of the section is structured as follows: First, the commonalities of both rounds are presented. Second, the impact of the drops in supply and production quality is shown. Third, the influence of visible quality indicators is quantified. At last, the influence of human factors on game performance is revealed.

5.2.1. Effect of Repetition

There is a strong correlation between the player's profits in first and second round of the game (r=.730, p<.01). Hence, players who achieved a high/low profit in the first round of the game, also achieved a high/low profit in the second round of the game. Furthermore, the average profit increases significantly in the second round of the game (F(1, 126) = 36.6, p<.01). In the first round the average profit was M=-19.0 (σ=258.5) money units and it increased to M=76.6 (σ=218.3) money units in the second round.

5.2.2. Effect of game complexity

The experimentally controlled game complexity had a significant effect on the company's profits, although only the drop of the internal production quality is significant (F(1, 122) = 12.342, p=.001<.05), while the drop of the supplier's quality is not. As expected, the highest profits were achieved under stable conditions were no drops in the supplier's quality and the internal production quality occurred (M=148.5, σ=128.). If the supplier's quality drops, the result is slightly worse (M=132.9, σ=81.2). A drop of the internal production quality led to drastically reduced profits of M=-1.3 (σ=316.4) if the supplier's quality stayed constant and M=11.5 (σ=236.8) if the supplier's quality also droped (see Table 1).

Table 1. Average profits for each of the four game complexity conditions.

		Supplier's quality	
		no drop	drop
Internal production quality	no drop	M=148.5, σ=128-0	M=132.9, σ=81.2
	drop	M=-1.3, σ=316.4	M=11.5, σ=236.8

5.2.3. Effect of presentation of quality indicators

The availability of quality indicators for the supplier's quality and the internal production quality had no significant impact on the average profits (p=.537, n.s.).

5.2.4. Effect of personality traits

None of the personality traits from the Five Factor Model had a significant impact on game performance. Furthermore, self-efficacy in interaction with technology (SET) only marginally influences the average profits (r=.163, p=.084 <.1), which contradicts the previous study on Forrester's Beer Distribution Game [17]. Also, prior expertise and domain knowledge in either quality management or business administration had no significant impact on game performance. As the average results are higher for high SET values and high domain knowledge, one can assume, that significant difference might occur with larger sample sizes or when the large variance of the average profits it reduced by optimizing the game model.

Regarding the player's interaction with the game environment, two observations were made. First, the time spent in the first round correlated with the average profit made (r=.301, p=.001 < .05). However, this effect fades for the second round of the game (r=.142, p=.112>.05). Second, the number of adjustments on the company's investments had a significant impact on the company's profit (r=.303, p =.001<.05). Also, different interaction patterns – specifically an efficient reaction to changing quality levels – between high and low achievers were discovered. Those are presented in detail in [13].

The player's strategy (assessed after playing the game) had a significant impact on performance (r=.370, p<.01), with players with a high quality orientation achieving higher results (M=136.1, σ=96.3) than players with a low orientation towards quality (M=21.1, σ=280.4).

6. Discussion

The high correlation between the profits in the first and second round of the game reveal two important findings: First, the player's performance is relatively stable, meaning that there are players who perform better and players who perform worse. This indicates that underlying human factors that explain player's performance. Second, the stability of the results furthermore suggests, that the game model itself yields stable results. In summary, this result alone is a strong evidence for both hypothesis H1 and H4. However, the current study failed at constructing a model for explaining the human factors behind differences in game performance.

The randomly assigned game complexity had an impact on the average profit of the company, indicating that hypothesis

H2 holds true. Still, we suspected that the condition with quality drops on both sides (supplier and internal) would be the most difficult condition, which was not the case within this study. We learned, that the impact of a drop of the supplier's quality is easier to identify and to react on than a drop of the internal production quality, which frequently remained unnoticed, reducing the overall profits.

To our surprise the traffic lights indicating the supplier's quality and the internal production quality did not influence the player's performance. Hence, this study suggests that hypothesis H3 has to be rejected. However, informal interviews conducted after the experiment suggest, that many players had well understood the indicator for the supplier's quality, but did not sufficiently understood the concept of internal production quality and were misguided by its visual indicator. Further studies will need to investigate this issue by providing a better explanation of the indicator's functioning which will then probably also lead to significant positive effects of the availability of quality indicators.

Using games as a tool to facilitate learning is getting increasingly popular, also in professional domains [18]. Within this study the participants gained expertise and learned to control the simulated company more efficiently and increased the average profits between both rounds of the game. Furthermore, they post survey revealed, that the participants' awareness for quality management increased and that the attention shifted towards quality management techniques within the game.

Summarizing, the study reveals that the QI-Game is both, a valuable tool to investigate human decision making in complex logistic scenarios and also a fun and highly effective tool that can be used in vocational training for quality managers and supply chain managers.

7. Limitations, Summary and Outlook

We observed that the key depended variable "average profit" features large variance, hence many of the non-significant results may yield significant results if the sample size is increased, if the game model is optimized and if more rigid statistical methods are applied.

To our surprise, the availability of quality indicators did not increase the player's performance in the game, although they were conceptualized as an instrument to quickly identify the source of changing product quality. As argued in the results section, this should be addressed in a refined briefing before the game and then the effect of quality indicators should be reevaluated.

The current game model is reduced to the control of one sort of products. In reality quality managers and supply chain managers have to overview a large and more diverse set of products and materials with varying replacement times. Therefore, further studies will need to address this increased complexity with a more realistic test environment.

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