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Constrains Theory Explained Trough a Serious Game

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Abstract

Organizations face impediments that affect the normal development of the activities. Managers seek to resolve problems by improving the individual system efficiencies, investing heavily and even making staff layoffs. Sometimes, however, the results remain weak, to the point of ruining the company. In the operation of the processes different obstacles are found, that hinder the achievement of the objectives. This is where the Theory of Constraints (TOC) offers an alternative for managers and leaders of processes to improve results in a logical and systematic way, in many of the cases, without the need of making costly investments, ensuring business continuity and competitiveness. This paper focus on the development of the concepts of Theory of Constrains (TOC), by the design of a serious game that simulates a resembling production process of a plane, in a manufacturing organization. Research shows the serious game design process and an initial application, in which the main purpose is to use the dynamic game as a means for those interested in understand the basic principles of TOC and develop skills to identify and manage restrictive situations in organizations through a systemic approach that leads participants to learn by doing in a simulated scenario.

Keywords: Theory of Constrains, Constraint, Process Efficiency, Serious Games, Instruction.

INTRODUCTION

Initially, the theory of constraints was proposed as an applicable philosophy only to production processes in manufacturing companies. In recent years, the TOC has grown and gained acceptance not only in the initial market (production and management) but in the academic community [1]. The theory of constraints has earned a place alongside other management philosophies such as JIT, TQM, and MRP [2]. Although the theory of constraints can be applied in different areas of the organization, such as finance, project management, accounting, production, marketing, sales, etc.,

In the other hand, the interest in topics related to games and, specifically, in educational games, has evolved in recent years, due to proposals that arise and their applicability in different disciplines. The main objective of educational games is to achieve effective learning, combining concepts with games, which allows learning through experiences.

In games, participants experience for their selves, solves problems and situations, interacts with different variables and plays roles, from perspectives that, otherwise, would be impossible to carry out in real life [3].

Games have been used in various disciplines such as: science, technology, engineering, mathematics, health, business, language, economics, among others, and even games are used in extra-curricular learning contexts such as in education about Substance abuse and healthy eating [4] demonstrating its versatility and applicability in varied educational and social contexts and levels of education.

The structure of the article shows four sections, the first one corresponds to the introduction to the theme of Theory of constrains, in the second the conceptualization of educational games; the next section makes reference to design process of a game focus on TOC, which allows managers review and analyze organizational problems, at the time, that teach participants the principal topics and knowledge of TOC, by simulating a production process in which participants must apply concepts to improve business efficiency and effectiveness. The final section of the article, shows the final game and some results of the initial tests.

THEORY OF CONSTRAINTS *TOC*

"*The Theory of Constraints is a methodology to management service that allows directing the company towards achieving results in a logical and systematic way, helping to ensure business continuity principle"* [5]. The Theory of Constraints is a management methodology to improve operation management systems in organizations [6].

TOC was introduced in 1984 in the book The Goal. It was initially proposed as a theory, only applicable to manufacturing companies. The way Dr. Eliyahu Goldratt conveyed the principles of the theory of constraints is a bit unusual, since it does not present a book structured in a scientific language, as in common to find, but instead, the theory of business management occurs through a novel that features Alex Rogo, a plant manager. Through the story, protagonist faces multiple problems, threatening the continuity of the company. Later we see as the factory begins to rise up from management analysis based on what we now know as theory of constraints, leaving aside the traditional practices of business management [7].

Within the established approach, organizations must be managed as a system, with special recognition of the central role within the same restrictions. A system constraint is anything that limits a system to achieve better performance relative to its goal [8]. *"There are different types of restrictions*

on a company that can limit your progress and profit making, the most common are: manufacturing constraints, market constraints, material constraints, logistical constraints, political constraints" [9].

According to Goldratt, "The Goal" of any industrial system, commercial or services, is "*making money now, as well ensuring continuity in the future*" [10]. In this sense, companies must be careful in using its resources, it means, achieving the objectives by making optimal use of them. In such exercise, organizations may experience problems, some easily solved, others that will demand special care for their detection and solution.

According to Goldratt, the first step is to recognize that the system was created for a purpose. Having identified the purpose of the enterprise, impact of actions against the overall goal, should be evaluate. So, "*any action taken by any level of the company should be judged by its overall impact on the organization's purpose. It means that, before dealing with improvements of any part of the system, we first need to know what the overall goal is and the steps that will allow us to judge the impact of any subsystem and any local action on the overall goal* "[10].

PILLARS OF TOC

The theory of constraints rests on three pillars, which are: (1) the inherent simplicity, (2) win-win solutions, and (3) think that people are good. Here we give a brief description of each.

1. SIMPLICITY INHERENT

In theory of constraints it´s assumed that the reality is simple by nature. No matter how complex a system is, there are very few causes that govern it. Some organizations have the belief that the best way to manage a complex system is to divide it into subsystems. This position is questionable, since the fact of dividing a system into parts requires more coordination efforts and implementation of initiatives within the organization. The reality is that dividing a system generates conflicts between subsystems and the lack of sync.

2. WIN-WIN SOLUTIONS

Any problem can be verbalized as an easy conflict to solve by finding win-win solutions for stakeholders.

3. PEOPLE ARE GOOD

The trend of blaming others is one of the biggest obstacles that exist in organizations for a good organizational climate. The objective of this pillar is to transmit an atmosphere of trust within the production process, which affects work environment in an optimal way, and empowers the achievement of "The Goal".

According to Goldratt [10], there are five steps to improve production processes by applying theory of constraints. These are:

a. Identify the system's constraint.

b. Exploit the system's constraint.

c. Subordinate system to constraint.

d. Raising the system´s constrain.

e. Repeat the above steps finding a new restriction.

GAMES AS A TEACHING TECHNIQUE

Organizations require the development of strategies for learning and strengthening human resource, that allow the improvement of competitiveness in a globalized world. The traditional education and learning methods, have evolved in new ways of teaching, tools and techniques, enabling effective interaction between the teacher, who transmits knowledge and content, and the students or participants that receive information. Games are tools that are used as a mean to present or reinforce a theme or content to a group of participants, in this way *"Games are turning in a new way of interacting content, worth of exploring for learning"* [10].

Games have become an option for business training and a tools for all the teaching- learning process. They are useful during training processes for the development of personal skills such as communication, leadership, teamwork, problem solving, among others, as it allows the concerned person to discover the knowledge together with other participants and with teacher guidance [11].

Games have interactive characteristics and are able to reveal the effects of particular actions, allowing to establish and test new strategies. In addition, they create a safe environment for experimentation, in which the consequences are not transferred to real world [12]. They offer students the opportunity to learn by doing, involving them in a simulated experience of the real world, achieving an immersion in an authentic organizational situation [13], enhances the experience and accumulates memories, leading to agile responses and an accelerated capacity of reaction in daily situations [14]. This helps students achieve technical skills and a problem management perspective.

Games allow to diagnose and improve organizational processes, teach or reinforce concepts in the participants, determine situations of individual and group behavior, through playful activities that make learning a friendly process and at the same time, it allow evaluating skills in individuals and groups [15].

According to Medrano [16] one of the characteristics is that sometimes they require skills that are gained through the knowledge and practice of the game itself; Kebritchi and Hirumi [17] propose that educational games are effective tools for teaching complex procedures and skills, given that:

- They use the action instead of the explanation.
- Create motivation and personal satisfaction.

- Accommodate multiple learning styles and skills.
- They reinforce skills.
- Provide interactive contexts.

METHODOLOGY

The method proposed below is intended to facilitate the learning of Theory of Constraind, and it is based on the methodology proposed by María Clara Gómez [11], which consist on 10 fundamental steps for the design of games for educational purposes. The steps go from the identification of the theme that designer want to developed through the game, to the pilot tests and preparation of the evaluation survey to apply to participants and evaluate the final outcomes.

The proposed steps are:

1) Identify the theme of the game.
2) Establish the purpose of the game.
3) State the instructional objectives of the game.
4) Identify and define general concepts of the subject.
5) Identify candidate techniques.
6) Select the most appropriate technique or techniques according to the characterization of the subject.
7) Incorporate specific knowledge into the game.
8) Develop pilot sessions of the game.
9) Consolidate the final version of the game.
10) Prepare a survey to evaluate the game.

DESIGN OF THE GAME

Based on the proposed methodology, the development of each step is shown, obtaining as final result, the final version of a game to explain constrains theory.

1) Identify the theme of the game

The stablished theme for the game is Theory of constrains (TOC), it is a philosophy of continuous improvement based on a systemic approach to solve problems in organizations [18]. In this sense, TOC seeks to understand and manage systems through a set of knowledge, principles, tools and applications that simplify management, using pure logic or common sense, promoting the achievement of global and not individual results.

The game is proposed as a contribution in the development of management skills that contribute to a cultural change in managers training.

2) Establish the purpose of the game

The purpose of the game is to teach the principles of Theory of constrains, and develop skills that allow managers and process managers to identify problematic situations in organizations.

3) State the instructional objectives of the game

The specific objectives that participants are expected to achieve, are:

- Understand organizations from a systemic approach.
- Know the principal concepts and principles of the theme.
- Identify problematic situations that restrict the functioning of processes in organizations.
- Analyze restrictions in a processes and implement improvements in them, in such a way that the objectives are met.

4) Identify and define general concepts of the subject

Organizations are made up of processes which interact between them, in order to contribute to the achievement of global objectives. In the operation of processes are different restrictions that hinder the achievement of the purposes, these must be analyzed and continuously improved.

The basic concepts that participant will learn during the application of the game, are:

- Process
- Restriction
- Resources
- Efficiency
- Continuous improvement
- Bottleneck processes

5) Select candidate techniques

In this step, an analysis of existing techniques was done, in order to identify games that have methodologies and objectives that could be adapted to proposed game.

In research, two techniques were evaluated, beer distribution game, proposed by a group of professors at MIT in early 1960s, to teach some concepts of supply chain management, and second, role games, in which participants take a specific character, to make decisions and behave in some situations.

6) Select the most appropriate technique or techniques according to the characterization of the subject.

The selected technique was beer distribution game, because it allows to simulate different phases or parts of an entire production process.

Beer distribution game has four phases, in which each participant takes a role: manufacturer, distributor, supplier and retailer, with the objective to simulate a supply chain with a two-week communication gap of orders.

7) Incorporate specific knowledge into the game.

Based on the chosen technique, the new game is developed, simulating an aircraft production system in which the process is divided on six stages and some constrains are introduced. The

principal objective of the game is to produce aircrafts going through the phases of the production system, producing as many aircraft as possible. A prototype of the aircraft is given to participants, to reproduce it, as figure 1.

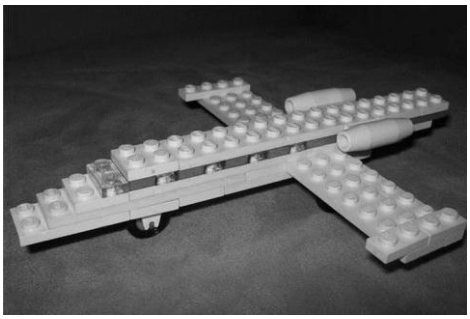

Figure 1. Prototype of the aircraft to be assemble.

The aircraft is built by different types of cheeps, which are storage in the first step of the production system, see figure 2.

Figure 2. Cheeps to build the aircrafts.

The basic conditions and rules for the game are described below:

The game is designed for teams of seven participants, in which some roles are divided:

- One director of the production plant, which is responsible for ensuring the good performance of the production process and decision making depending on the circumstances that arise in the development of the game.
- Two (2) people work as preparers in the process. Its functions are to deliver selected raw material to each stage and collect the finished product after the quality control evaluation, disarm the aircraft and take the chips to the initial stage of the process to initiate again. See Figure 3.

Figure 3. Participants preparing raw material for the game.

- One (1) person is responsible for recording the time of entry at the beginning of the process, and to give participants the orders to the production process.
- Each member of the production stages must read the assigned instruction sheet and comply with the functions described, once the production system starts to work.

Production process has six stages, of which participants are responsible, see figure 4.

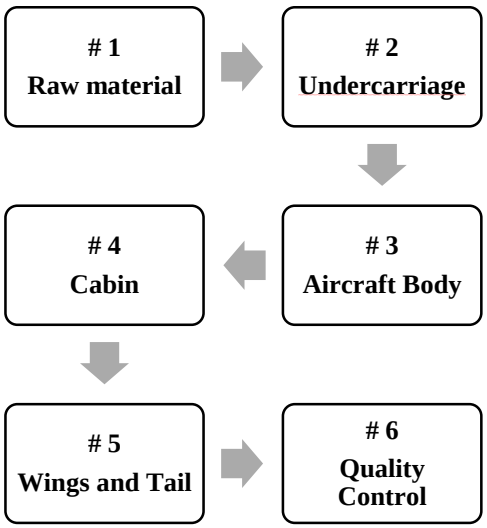

Figure 4. Phases of the game.

During the development of the game three different scenarios are implemented, in which each team have to build the largest number of aircraft possible to meet the orders that arrive at the company. Each scenario needs that participants make decisions and improvements in the production system, following the principles of TOC.

Table 1. shows a description of each of the phases of the production systems.

Table 1. Description of the phases of the production system.

Station	DESCRIPTION
1	**Raw material:** Two participants have to select and classify the raw material given for build aircrafts, and have to send to each phase of the production systems, the exact material they need to complete their work and in the time they required it.
2	**Undercarriage:** This participant is responsible for building the landing gear, according to the technical specifications and then sending the assembly to the next station.
3	**Aircraft Body:** Participant has to build the body of the aircraft according to technical specifications. Also, has to assemble the aircraft body, with landing

	gear from the previous station. Finally, send the assembly to the next station.
4	**Cabin:** Build the cabin and assemble it with the body of the plane. Then send the new assembly to the next station.
5	**Wings and Tail:** This participant has to build the wings and tail of the aircraft according to the technical data sheet. Then assembly them to the aircraft structure. This is the final station of the production systems process. Then, participant has to send the complete aircraft to the final station.
6	**Quality Control:** This person has to make a detailed review of all the aircrafts build by the team, comparing them to the initial prototype, and judging if they meet the manufacturing requirements. Once the aircraft is accepted, participant records the final delivery time of the order.

Figure 5, shows the distribution of participants in all the stations of the game.

Figure 5. Distribution of participants.

Every aircraft built by the team, have to pass through all stages of the production systems, or will not be taken into account for the order.

Once participants complete the first order, the second scenario of the game will start, and participants have some time to plan and stablish strategies to obtain better results and to adapt to the new conditions of the scenario.

APPLICATION AND RESULTS

The next step in the proposed methodology was step number

8) Develop pilot sessions of the game, in which a group of seven persons probed the game and play with all the rules and materials previously described, with the objective to find improvements to the game and validate that in functions in a correct way.

For the consolidation of the game, five (5) pilot tests were carried out, in which four (4) improvements were found, related to the clarity of information, inclusion of some rules during the game, and the inclusion of a moderator, who is the person that makes the quality control, communicates the requirements to the team, measures the time and registers the final results of all the team, this person is in the station number six (6) of the game, and has the roll of supervisor of the production systems.

9) Consolidate the final version of the game.

With the improvements integrated to the designed game, a final application of the game was made, in a group of fourteen (14) persons, divided in two teams of seven (7) each. Figure 6 shows the application of the game.

Figure 6. First application of the game.

The game was developed in three scenarios, whit the objective of manufacture as many aircrafts as possible, during each scenario the following was observed:

Scenario # 1: During this scenario rules and dynamics of the game were explained, and teams had to start manufacturing the aircrafts in the way they consider adequate.

It was common in the participant teams, that could not manufacture a considerable quantity of aircrafts and the quality parameters established at the beginning of the game were not met. The principal observed problem was accumulation of product inventory in process.

Results of each scenario of the game of the participant teams are shown in tables 2 and 3.

Table 2: Results for team # 1.

Scenario	Amount of aircrafts in process	Finished aircrafts	Good quality aircrafts	Bad quality aircrafts
1	10	3	2	1
2	9	4	2	2
3	7	6	5	1

Table 3: Results for team # 2.

Scenario	Amount of aircrafts in process	Finished aircrafts	Good quality aircrafts	Bad quality aircrafts
1	9	2	1	1
2	8	3	2	1
3	6	5	4	1

Scenario # 2: For this scenario participants of each team has the possibility of having a meeting for five minutes to analyze the situation within the production process and make decisions that contribute to improve the performance and the number of manufactured aircrafts.

During the scenario, it was observed that some of the strategies incorporated by the teams contributed to slightly improve the performance of the production process, but still large amounts of product inventory are in process.

Scenario # 3: This is the final scenario of the game, in which all participants of the teams received some indications and characteristics about the implementation of Theory of Constrains in a production system, with the objective of introduce participants to the concepts and give them some tools to apply and improve the aircraft production system.

After showing them the concepts, a new production order of aircrafts was given. In this time, teams significantly improved the performance of the process and the management of the product inventory in process.

Both teams managed to increase production of aircrafts, complying with quality parameters initially established, and reduced the inventory of products in process

10) Prepare a survey to evaluate the game

The survey consists on ten (10) questions about different aspects of the game. The first part of the survey asks participants to evaluated the complete game in aspects such as fun, rules, facility to comprehension and application.

Second part evaluates the performance of the team in which the participant played, in aspects such as efficiency, communication, amount of aircrafts produced in each scenarios and difficulties.

And the final questions evaluate concepts related to TOC, in order to determine if participants understood the principal characteristics and definition of the Theory of constrains and the way they applied it into the game.

CONCLUSIONS

The Theory of restrictions transmitted under the game methodology becomes a managerial alternative for directors, process leaders, mangers and teachers to teach an apply in a didactic way the way it could be implemented, its characteristics, principal concepts and the contribution to improve productive processes of organizations, as a way to obtain profitability and through the proper use of the allocated resources.

The designed game showed to be a fun tool for participants. It allows them simulate a production process, its constrains and interactions between different stations. The game leads participants to learn and know the principal concepts of the Theory of Constrains, even participants who did not have a training in engineering areas or who are not familiar with production systems.

REFERENCES

[1] Davies, J., Mabin, V. J., and Balderstone, S. J., 2005, "The theory of constraints: A methodology apart? - A comparison with selected OR/MS methodologies". Omega, 33 (6), pp. 506-524.

[2] Finch. B., and Luebbe. R., 1995, "Operations management: competing in a changing environment" Constraints management. Fort Worth, Texas: Dryden Publishers.

[3] Ouariachi, T., Gutiérrez-Pérez, J. and Olvera-Lobo, M.-D, 2017, "Criterios de evaluación de juegos en línea sobre cambio climático", Revista mexicana de investigación educativa, 22(73), pp. 445–474.

[4] Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Pereira, J. and Riberio, C., 2015, "An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games", Computers & Education, 94, pp. 178–192.

[5] Aguilera, C., 2000, "Un enfoque gerencial de la teoría de las restricciones" Estudios gerenciales, 16 (77) pp 53-69.

[6] Fernández, A., 2000, "Seminario de habilidades gerenciales", Bogotá: Piénsalo Colombia, Instituto AVraham Goldratt, pp. 200.

[7] Marín, Y., Montes, J., Hernández, H., and López, J., 2010, "Validación de la lúdica como herramienta metodológica complementaria en la enseñanza del método de producción tradicional y del método de producción de la teoría de restricciones (TOC) para el manejo de los entornos multitarea", Ingeniería y Universidad, 14 (1), pp. 97-116.

[8] Goldratt, E., and Cox, J., 1992, "The Goal", New York: North River Press.

[9] Goldratt, E., 1990, "What is this thíng called the Theory of Constraints, and How should it be Implemented", New York: North River Press,. pp. 162.

[10] Bouras, V. et al. 2004, "Juego basado en el aprendizaje utilizando las tecnologías web", Diario de Inteligente y Juegos de Simulación, 3 (2), pp. 67-84.

[11] Gómez, M., 2010, "Definición de un método para el diseño de juegos orientados al desarrollo de

habilidades gerenciales como estrategia de entrenamiento empresarial", [Master Thesis]. Universidad Nacional de Colombia.

[12] Braghirolli, L. F., Ribeiro, J. L. D., Weise, A. D., and Pizzolato, M., 2016, "Benefits of educational games as an introductory activity in industrial engineering education", Computers in Human Behavior, 58, pp. 315–324.

[13] Ben-Zvi, T., 2010, "The efficacy of business simulation games in creating Decision Support Systems: An experimental investigation", Decision Support Systems, 49(1), pp. 61–69. doi: 10.1016/j.dss.2010.01.002.

[14] Lauche, K., Crichton, M. and Bayerl, P. S., 2009, "Tactical decision games: Developing scenario-based training for decision-making in distributed teams", NDM9, Ninth International Conference on Naturalistic Decision Making, London.

[15] Londoño, L. M., 2014, "Diseño de un juego para enseñar y reforzar las relaciones de confianza", [Master Thesis]. Universidad Nacional de Colombia.

[16] Medrano, N., 2005, "El gran libro de los juegos de mesa" Buenos Aires: Ediciones Andrómeda.

[17] Kebritchi, M. and Hirumi, A. (2008) "Examining the pedagogical foundations of modern educational computer games", Computers & Education, 51(4), pp. 1729–1743.

[18] Kim, S., Mabin, V. J., and Davies, J., 2008, "The theory of constraints thinking processes: Retrospect and prospect", International Journal of Operations and Production Management, 28 (2), pp.155-184. https://doi.org/10.1108/01443570810846883