IMPROVING THE RESULTS OF THE PROJECT's PORTFOLIO OF AN AIRCRAFT MANUFACTURER USING THE THEORY OF CONSTRAINTS TOOLS (ToC)

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Abstract. Aircraft manufacturers have a large number of customers spread all over the planet and their products, the airplanes, are highly controlled equipment. Therefore, all the needs of corrections or improvements generated by the clients generate projects for correction or product improvements, directly to the manufacturer. The large volume of open projects (WIP), plus the high cost of such skilled resources imposes a high dispute for resources during the execution of the projects (multi-tasking). This ultimately reduces the speed with which projects are been executed and often prevent projects from being delivered within the agreed deadlines. This case study will describe how the company succeeded in using ToC thinking processes tools and Critical Chain method, to reduce the project delivery cycle and increasing the volume of deliveries, without increasing the size of the team responsible for the projects execution.

Keywords: Theory of constraints, critical chain, cycle reduction, Throughput increase.

1. INTRODUCTION

The company focus of this case study is an aircraft manufacturer and therefore, it is inserted in an extremely regulated environment. During the development of a new aircraft, the manufacturer must submit its new product to thousands of hours of flight or ground test, in order to demonstrate compliance with all the requirements of the three main aeronautical agencies: National Civil Aviation Agency (ANAC), Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA). Once the aircraft is certified, it receives a TC (Type Certificate) from each authority, which is a document attesting that the product meets all the safety requirements of that country or region. Since this document covers the entire product tree (BOM) and its production process, any modification in this process or in the product will require a new, even partial, approval process. This modification is done through a document called DCA (Design Change Approval), which will need to describe what is the modification, its impacts in terms of affected requirements and the show compliance plan. This document will be issued together with the test results that shows all the requirement compliance, and must be approved by the aeronautical authorities before it can be carried out on the plane. In addition to the authorities, there are several suppliers involved in the development of the aircraft, spread all over the world, responsible for the development of various systems that remain responsible for it throughout the life of the aircraft. If a particular improvement affects a vendor's system, the vendor company cannot perform the change on the vendor's system. The manufacturer should involve you and ensure that the customer's request is fully enforced.

The fact described above make customers, here called operators, to rely on the manufacturer for most of the modifications and improvements that, from their point of view, are mandatory to operate that aircraft. To make the environment even more chaotic, the aircraft manufacturer has hundreds of customers spread around the world and each of them are operating in different climatic, economic and cultural conditions, which ends up generating needs of the most varied types. Just as an illustration, we can say that the kind of improvements or modifications requested by a Saudi operator whose climate is hot and desert, will be very different from the type of requests generated by a Canadian operator who has a cold climate and many times, operating on ice and snow. The aircraft manufacturer then has portfolio of projects, consisting of hundreds of projects, of the most varied types and requested by different operators, but all with a common need: "Everyone needs their projects to be prioritized and delivered as soon as possible".

The case study described here will discuss how this aircraft manufacturer used the Critical Chain method, others Theory of Constraint (ToC) tools, to understand the root cause of the problem, propose a plan to solve it and then, increase the number of projects delivered reducing the average cycle time for the delivered projects.

The objective of this paper is to explore the application of ToC tools to identify the root problem ("What changes?"), determination of the new goals ("For what to change?") and to create a step to the implementation of change ("How to promote change?").

2. LITERATURE REVIEW

2.1. The thinking process of the Theory of Constraints (ToC)

According to Goldratt (1990), the (ToC) usually tends to be applied in environments, where the constraints are more obvious, that is, where constraints are physical. However, as the improvement in these areas occurs very fast and constant, this ends up leading the factory to an over-production, without any increase in profit. Now, the constraint is not inside the company, it was pushed to the market or even to a political constraint.

Goldratt (2002) says managers need to be able to answer three questions to deal with constraints:
1. "What to change?";
2. "For what to change?";
3. "How to promote change?"

The roles played by the tools are represented in the so-called "Trees" or "Logic Diagrams". In addition, each of the three questions for a logical structure is used.

Table 1 shows the association between these structures, the questions to be answered and the objectives in the ToC thinking process.

Table 1. Questions to Handle Restrictions, Logic Structure and Objectives.

Questions	Logical structure used	Objectives
What to change?	Current Reality Tree (CRT)	To promote the bases for the understanding of complex systems; Identify undesirable effects (UDEs); To relate UDEs to root causes (RCs) through logical cause and effect chains; Identify where possible a root problem (RP) that is eventually responsible for 70% or more of the mapped EDUs.
For what to change	Conflict Resolution Tree (CRT)	Confirm that the conflict actually exists. Identify the conflict that perpetuates the larger problem; Resolve the conflict; Create solutions for both sides to win; Create new and breakthrough solutions to problems; Explain why a problem exists; Identify all the assumptions that have a connection with problems and conflicts;
	Future Reality Tree (FRT)	Lets you effectively test new ideas before committing time, money, and people to implementation; Determines whether the proposed system of changes will in fact produce the desired effects without creating other devastating new effects; Reveals, by the negative branches, whether (and where) the proposed changes will create new or collateral problems; Serves as an initial planning tool to change the future course.
How to promote change?	Prerequisite Tree (PT)	Identify obstacles that hinder a certain course of action; Identifying remedies or conditions necessary to overcome or neutralize obstacles to a particular course of action, purpose or injection; Identify a sequence of actions required for a given course; Serve as a link between the FRT proposal, which presents future solutions with the transition tree, which presents the step-by-step, time-sequenced action plan.
	Trees Of Transition (TOT);	Demonstrate a step-by-step method for implementation; Communicate to others the reasons for action; Execute injections developed in the CRT or in the FRT; To meet the intermediate objectives in PT; Prevent the occurrence of undesirable UDEs during implementation.

On the other hand, Figure 1 presents in simplified form the main elements of each of the trees or diagrams and the relations between them.

The Current Reality Tree (CRT) shows the links and effects in the ongoing operation revealing the causes of the problem. As Cogan (2007) comments, it is not a simple task, but when completed successfully, one will know "What to change?".

This logical structure uses the proposition of cause and effect, or "If ... then ..." and describes the current state of things, which is created from top to bottom, intended to identify the constraint of the system: the root problem (RP). The entity at the top of the structure is usually the goal to be achieved.

From there, the web of Cause and Effect is mapped, identifying the main "undesirable effects" (UDE's) or symptoms, and we arrive at the causes of these effects. Once the (RP) has been identified and the "What to change?" question has been answered, the next question becomes "For what to change?"

The Conflict Resolution Tree (CRT) or Conflict Resolution Diagram (CRD) is a diagram used to identify the main conflict that is limiting the organization. For Cogan (2007), it is composed by: the objective (the opposite of the root problem), the needs (conditions essential for obtaining the objective) and the prerequisites (conditions that define the needs of the conflict). According to Noreen et al. (1996), the key is to identify the assumptions that lead to a lack of possibility of a visual solution. Thus, this is the specific technique to identify the underlying assumptions of apparent conflict and to end the dispute.

Already in the Future Reality Tree (FRT), once the underlying assumptions of the conflict have been identified, the possible solutions, new ideas of cause and effect (CRT) relationships for future events are tested. After identifying an injection (proposed solution), the (FRT) is used to verify that the successful application of this injection will eliminate

the symptoms. It can also be used to identify possible negative consequences. Having negative consequences, the solution must be changed or even make a new CRT.

According to Moss (2007), the Transition Tree (TT) and the Prerequisite Tree (PRT) are used to identify the necessary conditions to cause the changes and implement the application of the thinking process tool.

These tools complete the phrase "How to promote change?" and are used to identify and overcome obstacles to achieving a goal or implementing a solution. The (PRT) provides a bridge between (FRT) and (TT). As such, the (PRT) has a time sequence.

Thus, according to Noreen et al. (1996) all obstacles imaginable to the injection application are placed in the (PRT). The final tool, (TT), identifies the specific actions that must be taken to overcome the obstacles identified in the (PRT).

Considering that at this stage of the ToC application process in a company or institution, people are already less resistant to change, they can help with the project. The idea is to engage the people who will execute the changes.
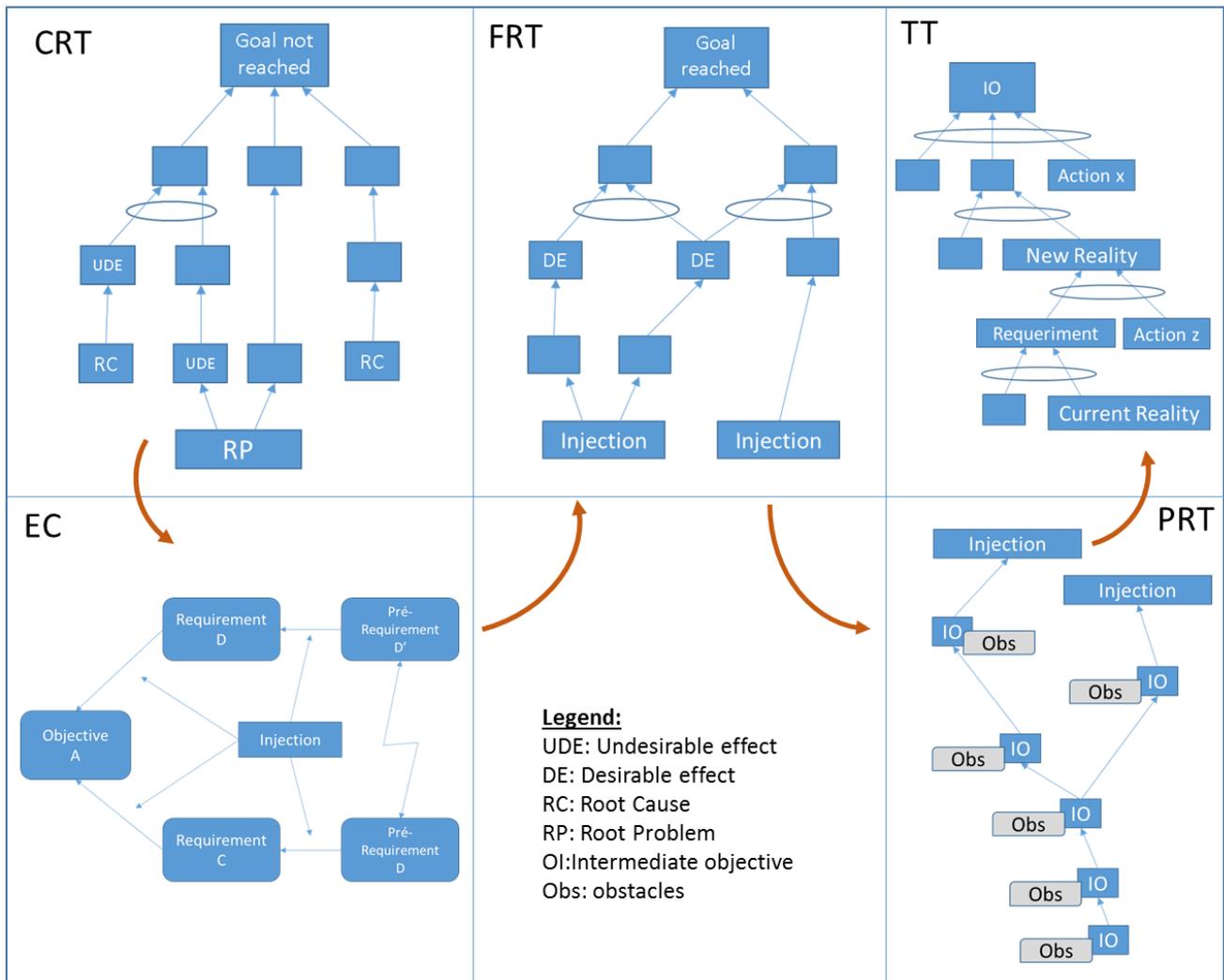

Figure 1. Model of application of the thinking process Tools (ToC)

2.2. Introduction to Critical Chain

Project management is an activity that, despite all the efforts, continues to be implemented without much success in achieving deadlines, budgeted cost, requirements or even expected quality, as evidenced by the most recent benchmark survey organized by PMSURVEY.ORG (2014).

A typical behavior in project management is that when pressed by the delivery date of activities, people protect themselves, adding security to their activities and by doing this, they could be adding time to the critical path and will negatively affect the project deadline, due to longer lead time.

Another very common effect in project environments is the existence of many in progress projects at the same time. There is a widespread perception that "Start Before is synonymous with Ending Before". Many of who argue for the

above sentence rely on the fact that the sooner we start an activity, sooner we will know if the risks mapped out for it will prove to be true or not, and if these risks prove to be true, we will have more time for implementing the contingency plans.

According to Goldratt (1991), the fact ignored by them is that the excess of projects in progress, negatively affect the flow of information on each project.

Working on an overloaded environment, where every task is very important and urgent, the teams are aimed to deal with a large number of activities in parallel, apparently doing everything at the same time. This is called Multi-task.

For Leach (2000), the evident constraint of a unique project is the chain of activities that takes the longest to complete. In environments with multiple projects, assuming these projects are carried out at the same time, the resources (persons) have to be shared among the projects creating multi-tasking and thus reducing the possibility to finish the task in the scheduled time. Evidently, at least one of these resources should be the capacity constraint of the system, so, the company constraint resource (persons) becomes the drum for multiple projects scheduling.

Critical Chain is a project management method, which focuses primarily on the management of time and activities, considering the allocation of resources, and is based on the Theory of Constraints (ToC) as it was initially proposed by Goldratt (1998) and later detailed by others (Leach, 2000; Steyn, 2000; Peng and Jin, 2009; Jianmim, 2011).

The method is simple, but it requires a great change of paradigms and to follows all the steps of the logic described in this work.

3. CASE STUDY

This chapter describes the case study itself and the applied ToC tools: Current Reality Tree (CRT); Conflict Resolution Diagram (CRD); Future Reality Tree (FRT) and Prerequisite Tree (PRT).

3.1. Application of the Current Reality Tree (CRT)

As can be seen in Figure 2, the elaboration of (CRT) started with the problem: "low customer satisfaction regarding project deadlines". The root cause for the problem was identified and is decomposed in three items: 1. lack of information about the company's priorities; 2. lack of an activity distribution system and; 3. Several entrances (the possibility of the areas generating demands directly for the engineering). It was realized that together, these three (UDEs) s made the delivery performance of the company heavily degraded.

For years, the due-date performance indicator shows that the number of projects delivered on time is decreasing. People react adding more "security time" to their estimates, preserving the default behavior: "The answer to delays is add more time to next estimates". They forget that this action eventually increases the total project cycle, which already was perceived as long by customers.

3.2 Application of the Conflict Resolution Tree (CRT) or Conflict Resolution Diagram (CRD)

This structure proposes to answer the question: "For what to change?" For the construction of the (CRD), we followed the objectives as listed previously in Table 1.

As demonstrated in Figure 3, the (CRD) identifies the conflict that prevents the resolution of the root problem exposed by (CRT).

On the first side, the assumption behind the need to "have a stable queue of projects" and that should be challenged in this case was:

- Since there is no tool, one system, which allows reprioritization of activities in an integrated way, it was necessary to have a stable queue of projects, thus reducing the chance of areas being working with different priorities.
- The injection to overturn this assumption was the creation of a system to act as unique source of activities. A system that contain all the tasks addressed to the engineering teams, that must be ordered by the project priority defined by the company, ensuring that all the activities are there, into the same report, ordered from higher priority to lower ones.

On the other hand, the assumption behind the need "constantly change the priority of projects" and what needed to be challenged in this case was this:

- Since the Project completion dates were not reliable, the company would only knows the "expected project end date" when it has actually ended. It was not possible to schedule a new urgent project after it, as this date was not clearly known, so, the "as earlier I start, early I finish" behavior was enhanced.
- The injection to overturn this assumption was to use Critical Chain in order to have reliable projected end dates.

- With best end dates forecast, and the ability to make scenarios simulation, the board is able to decide based on a clear vision of the impacts generated by the approval of the new project.

3.3 Application of the Future Reality Tree (FRT)

This structure proposes to answer the question: "For what to change?" However, in the (FRT) the solution, the injection is tested to see if the change in the management process will occur. Thus, according to the objectives of Table 1, the (FRT) is intended to prevent obstacles that are currently preventing a certain course of action; identify remedies or necessary conditions to overcome or neutralize obstacles to a particular course of action, purpose or injection; identify a sequence of actions required for a particular course; and serve as a link with the transition tree that presents the step-by-step action plan, sequenced in time. The logical structure found can be verified in Figure 4.

With the construction of the (FRT) it is possible to validate the solutions proposed in (CRD), that is, the injections worked, becoming both undesirable effects, as in desirable effects, one soon knows "For what to change?".

3.4 Application of the Prerequisite Tree (PRT)

This structure proposes to answer the question: "How to promote change?". This phase refers to the implementation plan for the proposed changes. Its main objectives are: 1. to visualize possible obstacles to be overcome and; 2. to serve as a link between the "FRT proposal" and the Transition Tree. Thus, the structure can be verified in Figure 5.

The first obstacle refers to the lack of knowledge of the company priorities by the areas responsible for the execution of the activities.

According to the analysis, the main reason for this undesirable effect (UDE) was the lack of a system to distribute prioritized list of activities for all areas.

Another important factor for this undesirable effect (UDE) is that there was no single input source. To have several input sources for the engineering areas, force people to choose which one is the real next one. Then, in order to deal with root causes listed above, the injection was defined: Create an activity distribution system, that will be only source for the areas to receive their to-do lists. Any activity addressed to engineering must be planned into this system and the prioritization criteria would be unique regardless of the type of activity.

Another undesirable effect that heavily affected performance is the fact that the planned cycles of the activities are much longer than the time expected to complete the task. The remaining time are there to address uncertainties of the task, it is protection, a kind of buffer.

As an injection for this undesired effect (UDE), the company implemented a project planning and control process (and system), based on the critical chain method. This action ended up generating schedules with smaller cycles and contributed significantly to the improvement in project delivery rates in the term as will be demonstrated later in the results chapter.

3.5 Application of Transition Trees (TT)

This structure also proposes to answer the question: "How to promote change?", thus, the tool (TT) is used to implement the change. It is proposed to execute the selected injections to meet the intermediate objectives and to prevent the occurrence of possible undesirable effects, according to Figure 1.

As already described, the application of the transition tree for this case study will not be addressed in this article, since it would describe in detail the changes that were made in the company's processes, which for reasons of confidentiality could not be described here.
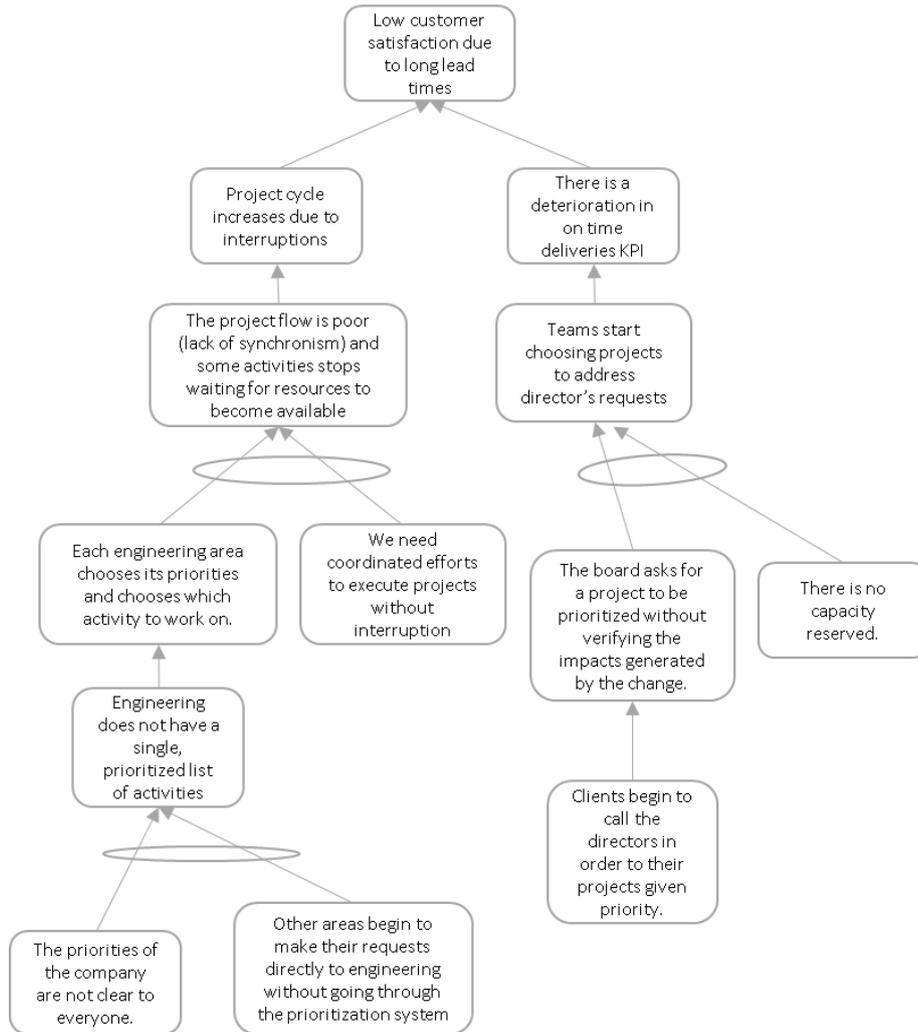
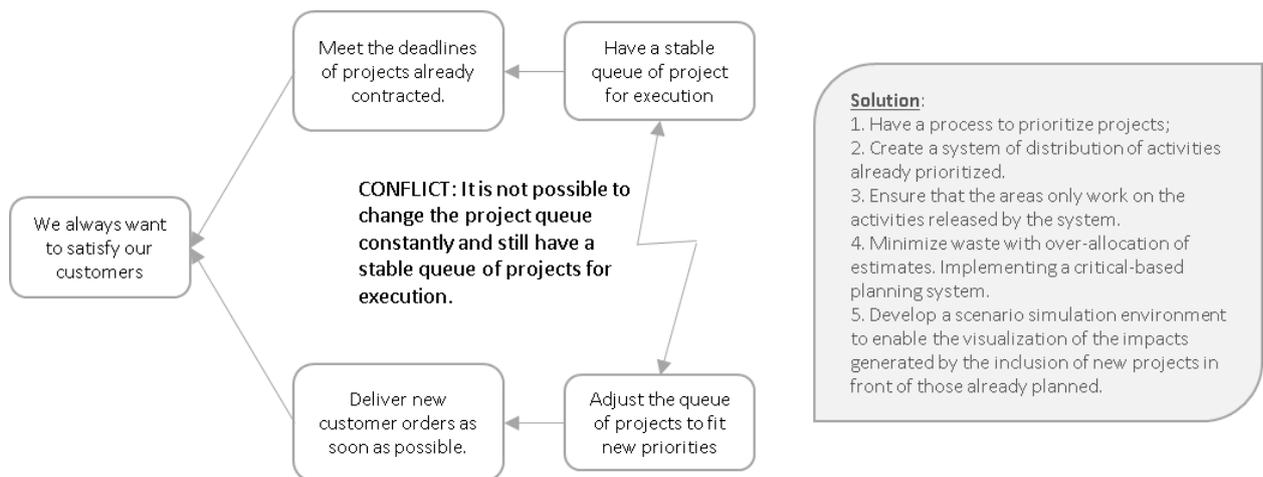**Figure 2. Current Reality Tree (CRT) for the analyzed Company**

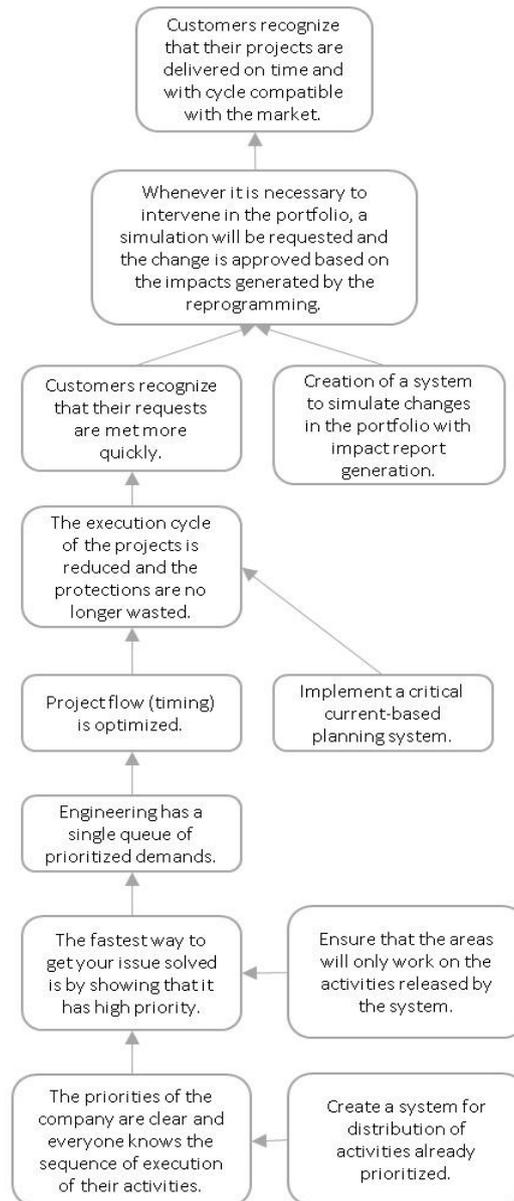**Figure 3. Conflict Resolution Diagram (CRD) for the analyzed Company**

Figure 4. Future Reality Tree (FRT) for the analyzed Company

3.6 Achieved Results

Some indicators are selected to measure the improvements generated by the processes changes. Are they: Project execution cycle (average) and number of delivered projects per year.

The project execution cycle (average), a monthly indicator, is based on the list of projects that were completed in that month and the time that they were in execution. With these two information, the average execution cycle for the month is calculated. Figure 6, shows that, the company achieved a reduction of (21%) in the average of execution cycle of its projects.

In the case of the indicator of number of projects delivered, it was expected that with the flow improvement of activities within each project, caused by the existence of an integrated and critical-based system, responsible for the distribution of activities on a synchronized way for all engineering areas, in addition to the reduction in the execution cycle of the projects, there would be a noticeable increase in the number of projects delivered in the same period of time and with the same number of human resources allocated to the execution of these projects. Regarding this item, after 12 months, there was an increase of 39% in the number of projects delivered, as can be seen in Figure 7.

The system go-live happens on Mar/2010, (left bar of figure 7 shows the number of projects delivered on the 12 months prior to the go-live and the right bar, shows the number of projects delivered on the 12 months after the go-live).

Figure 8 shows the cumulative delivery curves for the years 2009 (reference year), 2010 and 2011.
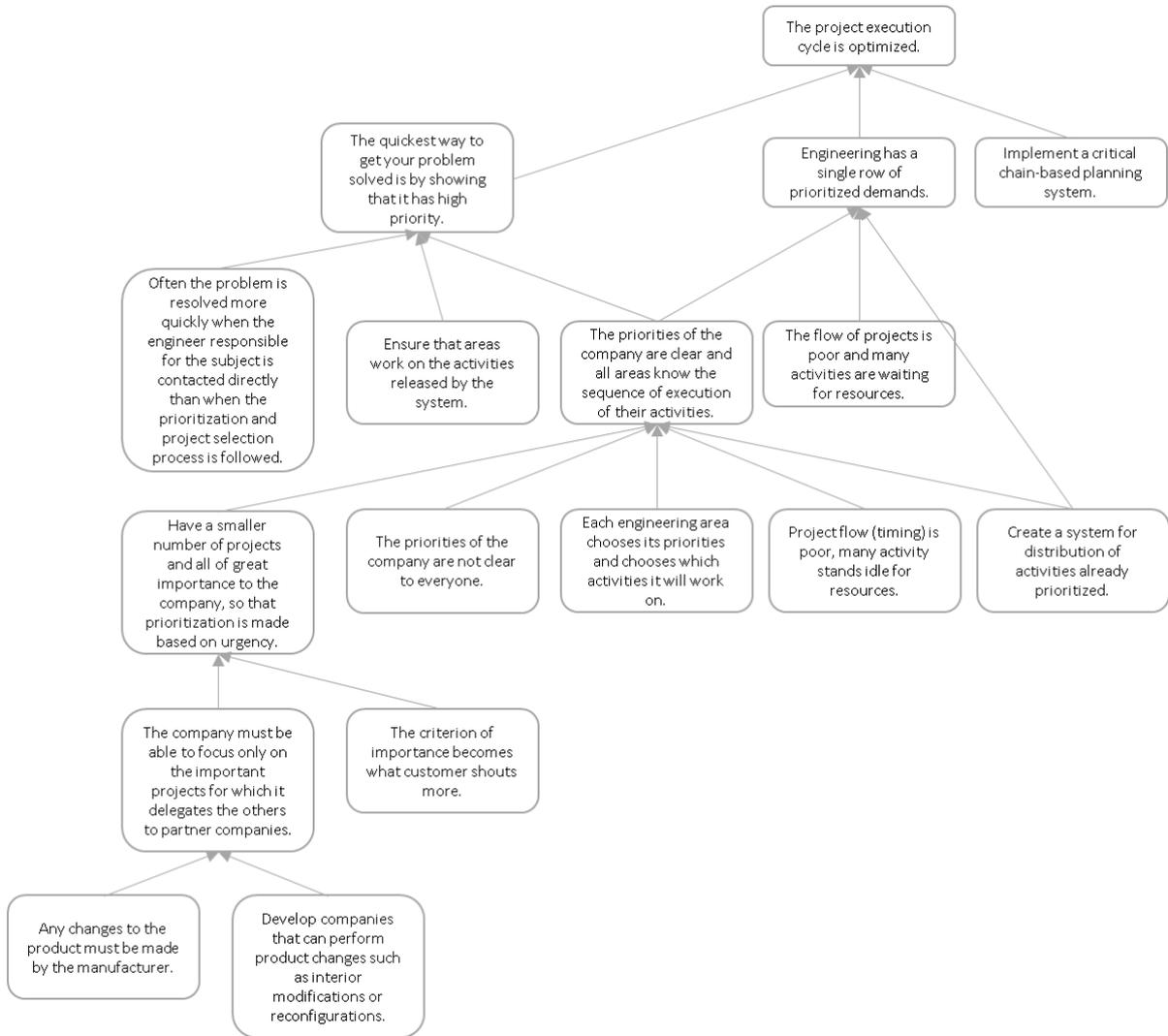
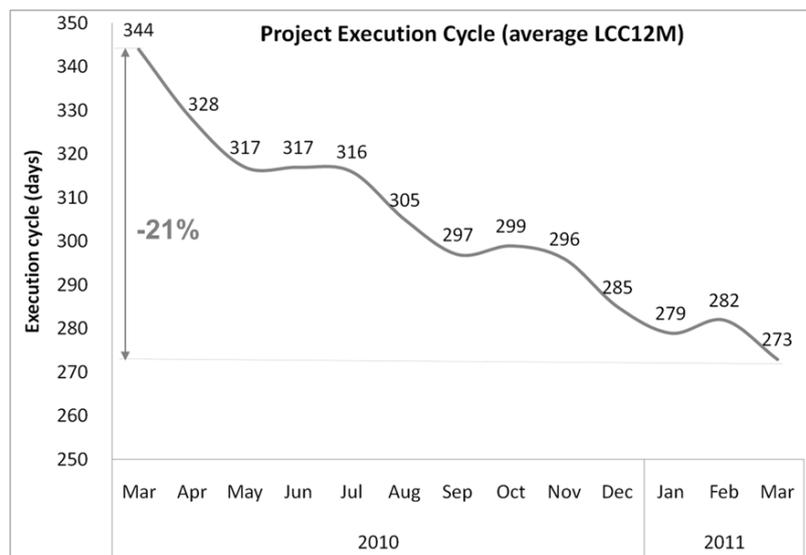**Figure 5. Prerequisite Tree (PRT) for the analyzed Company.**

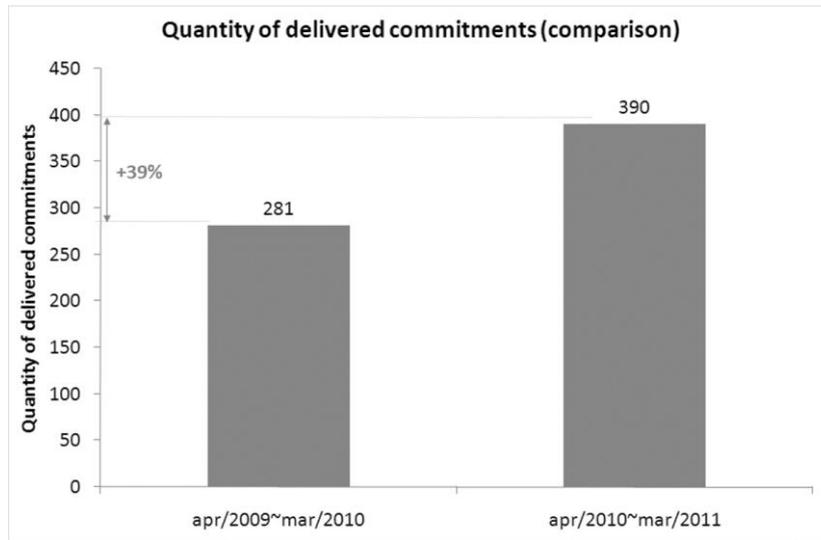**Figure 6. Average project execution cycle: reduction of (21%).**

Figure 7. Quantity of projects delivered: increase of (39%) after 12 months of key turn.
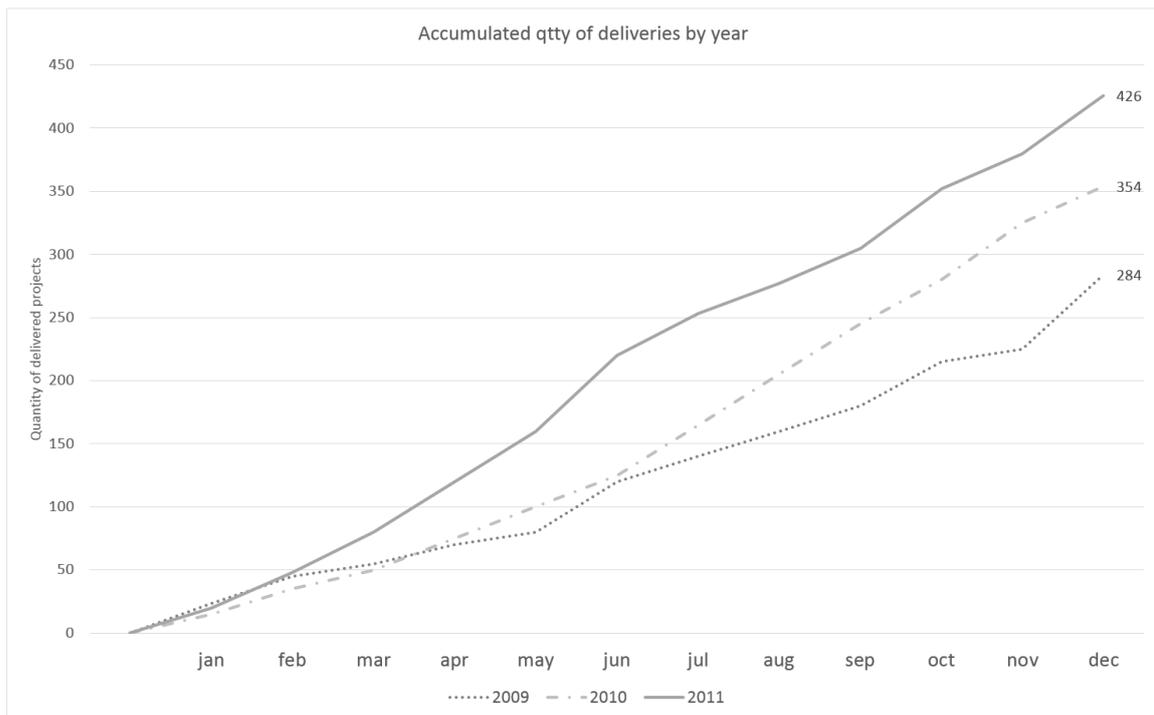

Figure 8. Evolution of the number of delivered projects between 2009 and 2011.

4. CONCLUSIONS

The tools of ToC were of great value for identification of the restriction of the system. The low delivery performance on time, which would normally be solved by hiring more resource (traditional solution), was eventually solved by creating a software tool, used to aggregate all the demands to the areas and with clear priorities. This system not only managed to reduce the cycle of the projects but also to increase the number of projects delivered, besides being able to keep the quantity of deliveries at a higher level, releasing engineering resources to other areas of the company.

The results for the first structure, the Current Reality Tree, whose objective was to find the system constraint by identifying the root problem and answering the question "What changed?" Indicated that the root problem a priori is the lack of a clear vision for the functional areas on which the company's priorities were.

The results of the second structure, the Conflict Resolution Diagram, confirmed the existence of a conflict. Through the (CDR), it was observed that the prerequisite for the accomplishment of the change, that is, for the effectiveness of the injection, is the need to create an integrated tool to distribute activities already prioritized for the areas.

The third structure, the Future Reality Tree, sought to sketch how the change will occur, and answer the question "For what to change?". Thus, it was possible to validate the proposed solutions in the Conflict Resolution Tree, that is, the injections functioned making the undesirable effects into desirable effects.

Finally, the construction of the fourth structure, the Prerequisite Tree, aimed to plan the implementation of the methodology, visualizing the main obstacles and answering the question "How to promote change?". Thus, for each imagined obstacle, specific intermediate objectives were found, guaranteeing the effectiveness of the proposed injections.

It is concluded that, through the application of the four logical structures of the ToC Thinking Process (CRT, CDR, FRT and PRT), it is feasible to use the technique in a company that develops projects, being feasible to diagnose the main problems and propose Injections to solve them.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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