Collaborative Networks Management from a Theory of Constraints Perspective

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Abstract. Collaborative networks are organizational structures that, instead of expressing market behavior, their formation and operation are based on **principles of collaboration**, where trust, reliability, and commitment between partners prevail. These principles allow collaborative networks to share risks and become more competitive. **Collaboration-based strategies** are increasingly important in the face of a growing demand for new and more sophisticated services and products, posing significant challenges for companies that must struggle to fulfill. In this sense, companies need to adapt their business strategies, so they can react and keep up with the pace of change. In this work, we propose a new perspective from the **Theory of Constraints** in Collaborative Networks Management. The adaptation of the **TOC's Five Focusing Steps** and **TOC Thinking Process,** combined with the **Critical Chain Project Management** (CCPM) approach, are proposed to improve Collaborative Networks Management. CCPM is brought into a collaboration context to deal with project network uncertainty. A preliminary motivation example is shown in this position paper, aiming at illustrating this prospective approach in Collaborative Networks Management.

Keywords: Collaborative networks · Theory of Constraints · Critical Chain Project Management

1 Introduction

The increasing level of market globalization is requiring the creation and development of ever more innovative products and services. Competitiveness, innovation, risk, sustainability, resilience, and flexibility are such terms that are increasingly being considered when reflecting on the general state of organizations, countries' economies and even nations, whose results are grounded on the performance of their productive systems. While, in many sectors of activity, increased competitiveness may be related to the modernization of processes associated with technological advances, in others, success may be related, above all, to how companies organize themselves and manage their productive systems.

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In this context, Project Management and Innovation can contribute to the success of organizations, providing a contribution to increasing performance and improving countries' economies. Innovation projects, if well managed, will allow technological and organizational development and increasingly sustainable solutions which can be obtained through Collaborative Networks (CN) with high added value efficiently using available resources, skills or competencies in ever shorter development cycles.

As a result, the intrinsic characteristics of projects (by definition, unique and temporary), along with the dynamics of organizations and markets, contribute to the fact that change and uncertainty is inevitable. This happens both at project level (e.g. variations in programmed durations, unavailability of resources or materials) and at organizational level (e.g. by limitations of appropriate mechanisms for decision support or sharing information or competences). Considering these aspects, the application of the Theory of Constraints (TOC) in Collaborative Networks Management (CNM) is proposed in this position paper.

Assuming this TOC-based perspective into CNM, we could stipulate that there is always at least one constraint affecting the performance of a CN. Therefore, identifying and exploring this constraint will eventually make possible to subordinate it to the set of CN partners that are most capable of mitigating the mentioned constraint. In this way, the hypothesis that is being explored is that CNM can be improved by applying the principles of TOC into CNs.

In next chapter, a brief introduction to the Theory of Constraints, their corresponding POOGI, and TOC Process Thinking for problem resolution, as well as the Critical Chain Project Management for project and change implementation. In chapter 3, a few directions on how TOC could be used in Collaborative Networks Management are then addressed. Finally, the main conclusions and some points to be addressed in the future work are proposed.

2 Introducing the Theory of Constraints

In this section, we will begin by introducing fundamentals concepts and approaches of the Theory of Constraints, bounding the scopeto the main aspects that can contribute to its application in Collaborative Networks.

2.1 The TOC Core Concepts

The Theory of Constraints, as presented by Goldratt in 1990 [1], has evolved methodologically as well as in its implementation domains [2] since its first publication [3]. Along their evolution, TOC has presented several designations over time. Initially, it was associated to the "Optimized Production Timetable" (OPT) scheduling, but "Timetable" was later replaced by "Technology" [2]. It was also associated with other designations, such as Synchronous Production or Constraints Management (CM), which should be used in their specific domains [4]. TOC is nowadays used as a management paradigm, theory or philosophy, as it includes their own concepts, principles, methods and tools [5–7].

The TOC assumes that in any system, there is always at least one constraint affecting its performance, and that eliminating or attenuating this constraint will increase the system performance. The rationale for this “at least one constraint hypothesis” is that if a system had no constraints, then its performance could increase indefinitely, but this is not possible [1]. The focal point of the TOC thus resembles Liebig’s law, when he states that the growth of a system is not controlled by all available resources, but by the less abundant resource, which is intended as a limiting factor [8].

Therefore, in the TOC perspective, contrary to what is commonly assumed, the existence of constraints should not be seen as negative, but rather an opportunity for focusing management actions and decisions on system improvement. As a constraint establishes the maximum performance of a system, its reduction translates directly into improved system performance.

According to the TOC, any organization can be considered a system, i.e. aggregation of interrelated elements, with defined purposes and objectives to support value creation: typically, more profit for stakeholders and more sustainable service level for organizations. A system can also be viewed as a network of interacting processes, not just a set of processes, in which the performance and survival of a system depends mostly on how its processes interact rather than their individual and local capacity or performance. Once the purpose of each system’s component has been defined, the TOC concentrates all its efforts on promoting improvements that directly translate into system purposes or objectives and, inevitably, into increasing overall performance. These advantages may even increase, when TOC is combined with other management paradigms [9].

In TOC, several types of constraints can be identified [10–13], typically classified into: (a) physical (resources unavailability, as an example) and (b) strategic, political and organizational constraints (such as rules, regulations, procedures, lack of information, etc.). The physical constraints are the easiest to identify, as their effects can be seen through direct observation. On the other hand, the identification of non-physical constraints can be more difficult to distinguish and manage. In addition, aspects like human skills, behaviors, and attitudes, whether individual or collective, can also be included in this non-physical category.

These constraints may also be considered internal or external to the system. A typical external constraint is the market itself. As such, when a production system has more capacity than the required by market, the constraint becomes external. Whenever corresponding balancing and changes are done, the improvements allow reviewing market share and to look for new opportunities. Organizations should concentrate on capitalizing on these new competitive advantages, instead of focusing on continuous improvement in their internal operations.

Furthermore, it is commonly assumed that in service organizations physical constraints are less relevant than organizational ones [10]. As highlighted in [14], it is usually necessary a full elimination of organizational constraints to boost organization results.

2.2 The TOC Thinking Process Logic

From the TOC perspective, any system performance improvement is based on Five Focusing steps known as the Process Of On Going Improvement (POOGI), which can be synthesized as: (1) identify, (2) explore the constraint, (3) subordinate, (4) elevate the constraint, i.e. improve performance and (5) evaluate the changes made and overcome inertia.

The framework is implemented using TOC specific tools, such as TOC Thinking Processes as designated in [15] (TOC TP), performed in a closed loop of continuous improvement, as shown in Fig. 1.

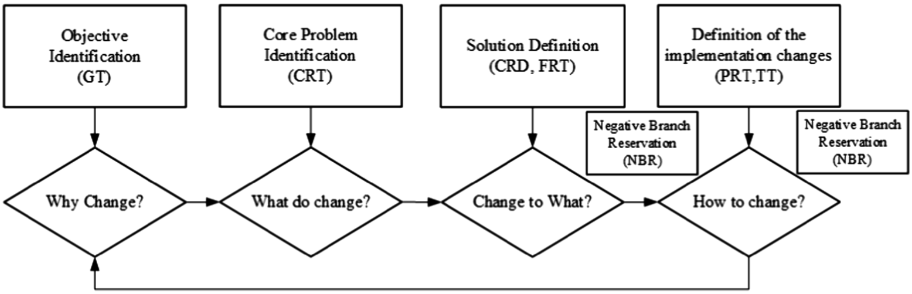

Fig. 1. The TOC Basic Questions and TOC TP tools

As shown in Fig. 1, the TOC TP six logical tools, is used according to a specific set of objectives, namely:

- Goal Tree (GT): clarification and identification of the objective to be achieved under analysis.
- Current Reality Tree (CRT): identification and analysis of system core problems and existing related Undesired Effects (UDE).
- Conflict Resolution Diagram (CRD): identification and resolution of conflicts; also called Evaporating Cloud (EC).
- Future Reality Tree (FRT): search for alternative solutions, characterizing the entities and foreseeable interconnections in the future system, converting the UDEs into desired effects (DE).
- Negative Branch Reservation (NBR): used to identify possible risks of the future solutions and corresponding implementation plan, checking the new system solution against the identified UDEs.
- Prerequisites Tree (PRT): used to ensure the coherence of the solution.
- Transition Tree (TT): to determine the main actions to be taken during the implementation of the solution.

Organizations can be seen as dynamic systems, which undergo changes for their improvement and survival [16]. Although TOC TP is not in the literature traditionally associated with change management, it may support it providing new business perspectives, increasing the managers' sense of control, and allowing more proactive actions [17]. Therefore, the TOC TP presents itself as one of the TOC features with the greatest potential for research exploration [4, 18, 19].

2.3 The TOC in Project Management

TOC principles applied to Project Management practices, the Critical Chain [20] was introduced by Goldratt in 1997, and more conceptuality detailed later on [21–23]. This TOC tool is currently known as Critical Chain Project Management (CCPM).

CCPM can be applied in products or services development projects. Whenever a project is planned, several generic objectives are commonly considered, namely: duration (deadline), cost (budget), resources (materials, equipment, …) and competencies, according to defined specifications or requirements. Among these objectives, time is particularly relevant, as it is a non-cumulative resource, i.e., whether it is used or not, it is spent and cannot be reproduced, resulting in unrecoverable loss of opportunity if not properly exploited.

CCPM applies TOC principles to project scheduling, allowing the best management project duration and resource utilization, while also promoting human resources behavior change. In fact, an effective management of the project execution time, was already highlighted in [24], proposing that in order to maximize the probability of project success, namely the completion of a project within its deadline, a realistic completion date should be established. This should include several types of relationships precedence and resource constraints, in which the only acceptable scheduled durations should be the exact time durations needed to execute the activities, since longer durations would be wasted by the effect of Parkinson's Law [25]. But to ensure that the project is completed on time, the project network must also accommodate uncertainty in the execution of the activities, thus establishing a time buffer at the end of the project and also at the critical chain integration points, known as Feeding buffers. This allows handling sudden changes on the critical activities and preserve management focus.

It is worth to notice that, in addition to the mentioned critical chain scheduling perspective, CCPM must also include specific changes in human behaviors during project activities execution, such as:

- The Relay Runner Behavior or Mentality, e.g., quick activity execution and work deliver as soon as it is completed.
- Full dedicated resources to eliminate or reduce bad multitasking.
- Frequent report of activities expected durations for their completion.
- Prioritize all requests considering the buffer report.
- Use tasks priority lists to dynamically change and assign resources considering buffer penetration reports.

These aspects will have impacts in several other procedural areas of project management, as in costs, quality, communication, risk and procurement in projects [26, 27].

3 Exploring TOC in Collaborative Networks

In this chapter, we will explore the application of TOC in collaborative networks. Although this is a position paper, the authors feel that a motivation example helps to illustrate how the TOC could be applied in the management of a collaborative networks. In the second part of this section, some ideas on how to apply TOC in CNM are provided.

3.1 Motivation Example

This section presents a motivation example illustrating the application of the Theory of Constraints in collaborative networks, focusing in CCPM as starting point.

Typically, a project is specified by a set of activities, with durations and precedencies. For instance, as shown in Table 1, activity a5 can only start after activities a2 and a3 are finished.

Table 1. Project activities precedence table

Activity	Most likely	Pessimist	Optimist	Precedence
a1	3	4	1	–
a2	5	6	2	a1
a3	3	4	2	a1
a4	4	6	3	a1
a5	8	10	5	a2, a3
a6	5	7	3	a3, a4
a7	3	5	1	a5, a6

Each activity requires certain resources, generically represented by r1, r2, … which might be material, money, equipment, know-how, etc. Assuming it is a collaborative project, these resources are provided by potential partners who will then work together in the execution of the project activities, according to the necessities illustrated in Table 2(a).

Table 2. (a) Required resources in the project, and (b) Availability resources

(a)

Activity	Required resources					
	r1	r2	r3	r4	r5	r6
a1	1			3		2
a2		2			4	
a3	2		5			
a4				4		3
a5		6				
a6	3				2	
a7		2	3	3		

(b)

Partner	Available resources					
	r1	r2	r3	r4	r5	r6
p1	5			5		
p2	2		4		1	
p3		5		5	3	
p4			4		2	1
p5	1	5				
p6						4

Table 2(b) shows a set of partners who, in an earlier collaboration phase, namely partners selection, have already been evaluated in terms of trustworthiness, reliability and past collaborations. In the next phase, the allocation of partners to activities is performed according to the availability of resources for the respective activities.

The TOC's critical chain scheduling allows identification of constraints affecting the project, namely its critical activities. Applying this approach, the project requires 19 days plus 3 for project buffer (PB), which results in 22 estimated days for the project completion, requiring also two Feedings Buffers (FB) as shown in Fig. 2. The project critical activities (which establishes the critical chain) are in red on the project Gantt representation at the right side (a1, a2, a5 and a7).

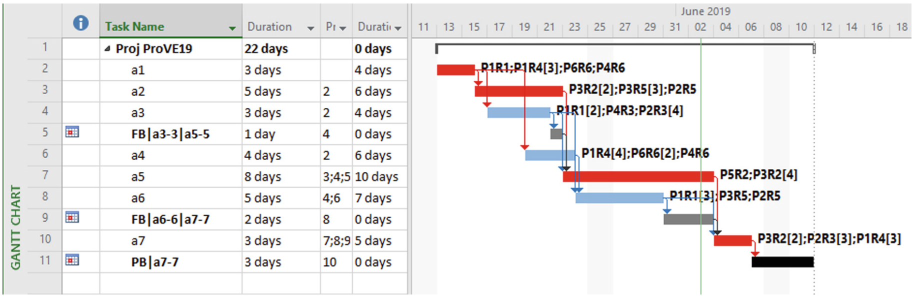

Fig. 2. Project schedule with resource allocation (Color figure online)

While CCPM allows addressing constraints from the project level. We can observe the same information from a collaboration perspective, enabling to focus on other project aspects which might help identify new potential risk factors.

From Fig. 2, we can perceive the interactions that are established between the partners in the project. The assumption here is that partners who work together in the same activity interact more intensively than in different ones. We can represent these interactions in a graph (Fig. 3), which can then be studied with Social Networks Analysis methods. This partners' interaction view can then be used to support collaborative decision making and problem resolutions during project execution.

Each vertex of the graph represents one partner. Each arc and weight represent the number of common project activities between two partners. But in order to represent the proximity concept, the inverse of the number of activities is used. For example, a value of 0.3(333) in the graph indicates that the respective partners work together on three activities (e.g. p1 and p4).

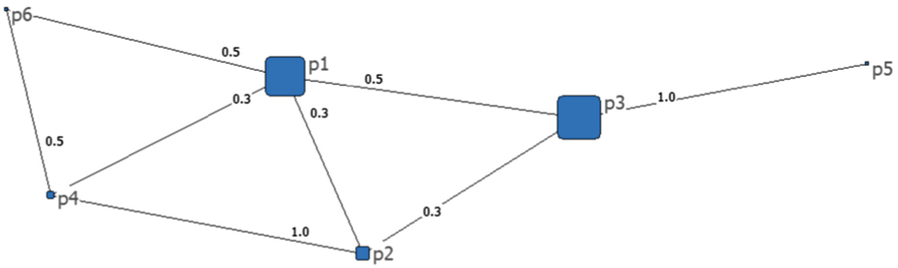

Fig. 3. Social network graph subjacent to the partners participating in the project

With the obtained social network graph, several indicators can be used to explore network properties relevant to collaboration. For example, the node sizes shown in the graph are proportional to the betweenness centrality measure [28]. This measure allows the identification of the network elements with greater authority and control over the flow of information, acting as brokers in the sharing of this information [29]. These authors also indicated empirical research showing that when an element with high betweenness leaves a network, it can cause severe disruptions to information flow. Furthermore, it is suggested in [28] that a high betweenness indicates elements with great influence in the collaboration between the members of a network. In the context of this example, this indicator can then be used in project management, in order to more closely monitor the activities of these partners.

3.2 Potential Research Lines in Collaborative Networks

Collaborative networks are complex and multidimensional structures, requiring the management and supervision of multiple processes that are developing simultaneously. The fundaments of Collaborative Networks, morphology and lifecycle are out of scope of this study, which can be found in [30, 31].

The most important contribution of TOC could be to help handling the complexity of CN management. As stated by Goldratt [1], “Focusing on everything is synonymous with not focusing on anything”. TOC could therefore be applied in CN to provide methods to support collaboration contexts, so that a network manager could focus on the most important constraint, or core problem, in a collaborative project. For such, the potential methods from TOC that can be applied in CNM are identified in Table 3, highlighted in bold.

Table 3. Summary of the TOC methods, adapted from [32]

	Prescriptive domain	Reflection and assessment domain
Strategic/Tacit level	Concepts and principles	Problem analysis and resolution
	Main conceptual prescriptions: **The Basic Questions** **The POOGI Five Focusing** Steps **The Six Levels of Resistance**	Logical Tools (**TOC TP**): **Goal Tree (GT)** **Current Reality Tree (CRT)** **Conflict Resolution Diagram (CRD) or Evaporating Cloud (EC)** **Future Reality Tree (FRT)** **Negative Branch (NBR)** **Prerequisites Tree (PRT)** **Transition Tree (TT)** Validation principles: Categories of Legitimate Reservation (CLR)
Operational level	Specific logical applications	Performance evaluation measures
	Rope-drum-reserve (DBR) **Critical-Chain (CC)** **Buffer Management (BM)** V-A-T Analysis	Throughput, T Inventory/Investment, I Operating Expense, OE

Earlier research works concerning the application of TOC in collaborative networks can be found in [32, 33]. But a more in-depth study must start by attempting to fit the TOC's methods from Table 3 with CNM aspects presented in Table 4. In this table, there are some suggestions of how TOC can be applied in CNM.

Table 4. TOC contributions for collaborative network management

Management aspect	How it can be done (with mappings from Table 3)
Collaborative project definition	Characterization of the project in terms of activity precedencies, required resources, and competencies. TOC methods can use this information to find the critical chain, detect and resolve resource constraints, to manage and adjust the expected project duration (**CCPM**)
Partnership formation	TOC can be applied to help achieve the best possible allocation of partners to project activities, having in mind resources availability and critical chain buffer management (**TOC TP&CCPM**)
Partners selection issues	There are many methods for partners selection. For instance, partners competencies, reliability, trust, collaboration preparedness (and other traits), skills, and resources are some of the ingredients in partners selection approaches. In TOC, these aspects could be explored in terms of availability versus needs in the project activities and evaluate them for eventual conflict issues (**TOC TP**)

(*continued*)

Table 4. (*continued*)

Management aspect	How it can be done (with mappings from Table 3)
Operation monitoring	TOC can be used to identify deviations from plans, and alert mechanisms can be provided for the VO-planner (**BM**). For instance, eventual disturbances affecting resources availability may pose impacts on the project's critical chain and delay its completion. They can be spotted during project execution (**CCPM**) and resolved by **TOC POOGI/TOC TP**
Performance assessment	Development of new indicators and monitoring rules for the detection of relevant impacts on project planned time objectives (**CCPM**)
Network reconfiguration	TOC can be used to manage change. Whenever there is a shift in goals, activities can be rescheduled, and resources utilization verified for eventual conflicts resolution (**TOC TP & CCPM**)
Risk assessment	As the project progresses, it is possible to observe its status proactively and thus reduce or manage risk of resource or competencies unavailability, spot potential conflicting partners and reduce delays occurrence (**CCPM**)
Trust assessment	There is a significant amount of research works dedicated to trust in collaborative networks, such as [34]. Information provided by trust indicators could be considered in the identification of constraints and risk (**TOC POOGI cycle/TOC TP)**
Collaboration preparedness assessment	The ability to collaborate is a relevant aspect in a collaborative network, as a partner's low score on this trait can be used to foretell relationship issues undermining project execution. Similar to trust, preparedness to collaborate indicators could also be used to assess the need to reconfigure the network (**TOC POOGI/TOC TP**)

4 Main Conclusions and Future Work

This position paper explored the integration of the Theory of Constraints in the context of Collaborative Networks Management. The foundations of this management theory were firstly presented. Then, the methodological integration of TOC into CNM was researched in two parts, starting with a motivation example, and then with an exploratory exercise, to illustrate the correspondence between a few TOC methods and typical phases of CN lifecycle.

The motivation example allowed identify several preliminary results. For instance, from the project definition, the critical chain method allowed identify conflicts in partners' resources utilization. The "betweenness closure" measure, from the realm of Social Networks analysis, was used in the example to identify potential collaboration-related risks. In this regard, disruptions involving partners with high betweenness can pose significant impacts on network performance, including at collaboration level. As such, the example helped highlight potential benefits from the use of TOC in Collaborative Networks Management.

Given the suggested hypotheses, proposed during this position paper, we can expect potential benefits in the use of the Theory of Constraints in collaborative networks. These aspects must be further explored and detailed in future research work. In addition, a CNM/TOC combination should be addressed assuming a multi-disciplinary perspective, involving researchers from distinct areas, namely Industrial Engineering Management, Sociology and Information Technology.

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