MANAGEMENT OF DYNAMIC PRODUCTION NETWORKS FROM A CRITICAL CHAIN PERSPECTIVE

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MANAGEMENT OF DYNAMIC PRODUCTION NETWORKS FROM A CRITICAL CHAIN PERSPECTIVE

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Abstract
Collaborative networks are typically assumed to bring clear benefits and competitive advantage to the participating members. However, as the networks are typically formed by heterogeneous and autonomous enterprises, the development of methodologies that facilitates the management process is an important element for the wide adoption of this paradigm. Departing from a brief presentation of Critical Chain Project Management Concepts, this paper introduces an approach of these concepts to collaborative networks and discusses its potential application in the context of a dynamic production networks. Finally, experimental results based on data from a network in construction industry are presented.

Keywords
Project Management, Critical Chain, Collaborative Networks, Cooperation, Industrial Engineering

1. Introduction
Cooperation among enterprises is certainly not a new phenomenon, but it has gained a new dimension in the last decade. The business environment has faced dramatic challenges in recent years, which are boosted by the continuous advances in the information and communication technologies, and leading to the emergence of a large variety of collaborative networks. Advanced and highly integrated supply chains, virtual enterprises / virtual organizations (VO), virtual (professional) communities, and value constellations, represent only the tip of a major trend in which organizations seek complementarities that allow them to participate in competitive business opportunities and provision of advanced emerging services in both commercial and public domains.

According to Penã and Arroyabe [1] there are three environmental factors that have had the most decisive influence to encourage cooperation among organizations. The first is economic globalization. The world economy at the start of the twenty-first century is experiencing one of its moments of greatest dynamism and change. This dynamism is reflected in the growing interdependence of markets for goods, services and factors of production. The second factor is the increase in business uncertainty. The speed under which changes are occurring in the economic world is introducing uncertainty. This is specially the case in business areas where constant transformations, resulting from reductions in technological and product life-cycles, improvement in productive processes, and so on, which are often difficult to predict, demanding greater follow-up capacity from enterprises in order to adapt to the new surrounding conditions.
Finally, the third feature is the high level of competitive rivalry. The increased customer requirements and market saturation are forcing the enterprises to constantly dig deeper in their search for competitive advantages to improve their position in the market. As a result of this, there is a tendency for enterprises to concentrate on core know-how, or on those aspects of the added value chain they really master.
Consequently, there is an assumption that production networks bring clear intuitive advantages to its members and represent even a survival factor in turbulent socio-economic scenarios. On the basis of these expectations are, among others, the following factors: sharing of risks and resources, joining of complementary skills and capacities, acquisition of an apparent higher dimension, access to new / wider markets and new knowledge. However, it is also frequently mentioned that cooperation also involves additional overheads due to the higher coordination costs (e.g. transaction costs), loser control structures, risks due to internal conflicts etc. and the lack of tools tailored to support management activities is an obstacle for a wider acceptance of this paradigm.

In order to contribute for development of a tool that support the management activities in a collaborative context the suggested approach is not to "re-invent the wheel" but rather to take into account and adapt possible contributions from other disciplines. It is, however, necessary to take into account that both these approaches and corresponding tools have been developed for different contexts. Therefore their application to dynamic network paradigm requires assessment, adaptations, and further developments. Furthermore, there are a large number of different perspectives in a dynamic production network, which cannot be covered by a single theory or single modeling approach.

This paper introduces some discussion about the critical chain concept and discusses its potential application in the context of a dynamic production networks.

2. Promising Approaches to Support Management Activities

As mentioned above, dynamic production networks can be modeled from multiple perspectives or for different purposes.
Table 1 shows some promising theories and approaches that can contribute for development of tools that support management activities in dynamic networks [2].

Table 1: Promising disciplines to support management activities

Theories/ Models	Short Description	Applicability to support dynamic network management	Limitations/Challenges
Game Theory	A mathematical framework designated for analyzing the interaction between several agents whose decisions affect each other. An interactive situation is described as a *game* that has an abstract description of the players (agents), the courses of actions available to them, and their preferences over the possible outcomes. It is assumed that players employ rational decision-making, that is, each player's objective is to maximize the expected value of his own payoff, which is measured in some utility scale.	• Non cooperative game theory: good for selecting partners, sustaining cooperation and trust • Cooperative game theory: distribution of responsibility and resources.	• Needs to identify all "players" • Needs to know all possible "moves" and associated results • Assumes that player's behavior does not change once the game starts • It is difficult to capture subjective relationships.
Graph theory	A branch of mathematics concerned about how networks can be encoded and their properties measured. The main goal is to represent a network in symbolic terms, abstracting reality as a set of linked nodes.	• Represent networks of relationships - topology, routing, activity, flow • Perform computations on flows • Optimization	• Basic theory is very rigid - needs extensions to represents non tangible, qualitative relationships (fuzzy dimensions), and multi-criteria
Social Actors Networks theory	Extension of graph theory to include relationships between social actors. Social Actors Networks are a way to highlight the structural relationships among social actors, enabling the conceptualization of their actions in a systematic way.	• Analysis of social and organizational structure of networks (connectiveness, trust, awareness, etc.) • Creation / reconfiguration phases of collaborative networked organizations.	• Offers a structural view on the network but does not provide any means to model an agency point of view i. e., what, how and why activities are performed in a network. • Needs to be used with a business process engineering method.
Multi-Agent Systems	A multi-agent system is a loosely coupled network of problem-solver entities that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity. Hence, it is concerned with coordinating intelligent behavior among a collection of autonomous intelligent agents, how they can jointly coordinate their knowledge, goals, skills and plans to take action or to solve problems.	• Model societies of autonomous, heterogeneous, evolving entities • Coalition formation and negotiation • Simulate self-organizing behavior	• Needs further developments in social aspects of agency, dealing with uncertainty and interoperation with other models (e.g. process modeling languages)
SCOR – Supply Chain	SCOR is a process reference model that has been developed by the Supply-Chain Council as the cross-industry standard diagnostic tool for supply-chain	• For management SCOR offers a set of Key Performance Indicators	• SCOR focuses mainly at the representation of intra-organisational processes

	management. It is a process reference model for supply-chain management which describes the business activities associated with all phases of satisfying a customer's demand. SCOR uses graphical decomposition of processes from the Level 1 Functions PLAN-SOURCE-MAKE-DELIVER-RETURN to level 3 process elements. Modelling of inter-enterprise processes is done through connecting one process element (i.e. source) from one SC member to the process element (i.e. deliver) of another SC member.	(KPI's) that can be used to measure and compare (benchmarking) the performance of companies in their domains.	within production environments.
Metaphor Theory	Metaphors are an integral part of our society and language (informal or semi-formal language that can use graphic description like bubbles, arrows, charts, matrices) which makes it a form of communicating that is deeply ingrained and understood intuitively by Western cultures. That is one of the most important tools for trying to comprehend partially what cannot be comprehended totally.	• Quick description for human communication (a possible help in expressing complex ill-defined concepts) • Use in early stages (conceptual design)	• Risk of taking metaphors too strictly • Needs further evaluation and research in consistent understanding in the creation and interpretation of metaphors
Operations Research	A mathematical approach to decision-making, which seeks to determine how to best design and operate a system (optimization process), usually under conditions requiring the allocation of scarce resources.	• Can be used mainly at operational level to support: • Network creation, • Network Optimization, • Operations and production management, • Logistic management	• High level of abstraction and notation, • Difficult communication, • Heavy and computationally demanding tools.

3. The CCPM Concept

The Critical Chain Project Management (CCPM) concepts were introduced by Goldratt in 1997 [3] as an alternative approach to classical approaches of Project Management as PERT (Program Evaluation and Review Technique) or CPM (Critical Path Method). CCPM is one applied component of TOC (*Theory of Constraints*) which can be seen as a prescriptive theory promoting systems performance improvement by the identification and performance improvement of the main constraint of any system in a systematic, successive and continuous way [4].

CCPM integrates one technical component of planning, schedule and time management of project networks and a operational component which include specific human action and behaviors like the r*oadrunner mentality* which promote the use of dedicated resource, fast activity execution and report expected activity conclusion and its conclusion as soon as concluded. According to this approach the network planning and schedule process is developed in four fundamental phases:

- **Network Building** - The network is built in two phases: firstly the network is created using an inverse logic i.e. from the last to the first activity. During this phase the project management team should identify the deliverable associated at which activity, the prerequisites and assumptions assumed. During the second phase the classical direct logic is used to verify and reformulate if necessary the activities relations identified in the first phase. The output of this approach will be an activity on node (AON) network with mainly F*inish-to-Start* activities and assumed resource constraints.

- **Estimating the Duration of the Activities** - The activity duration is probabilistic [3] and at least two estimations have to be made: a target duration (generally median or average duration) and a pessimistic duration.
- **Critical Chain Identification** - The critical chain (CC) is the path that defines the project duration, based on a set of activities interconnected by technical and resource dependencies, scheduled according to *As Late as Possible* (ALAP) process.
- **Time Buffers Insertion and Scheduling–** The time buffers are time blocks incorporated on schedule that are introduced in special points of the network to reduce the impact of duration variability of the activities on network.

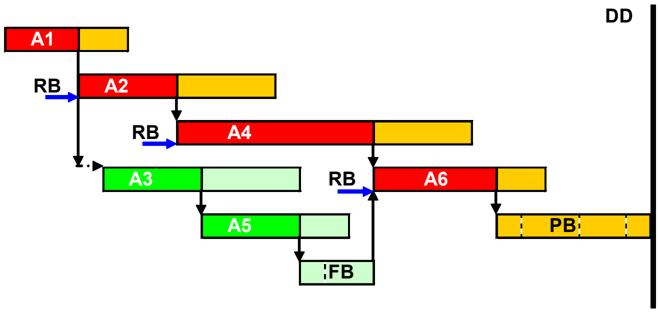

Figure 1: CCPM Scheduling

Figure 1 illustrates a very simplified AON network with six activities (from A1 to A6) where the bar size defines the activity duration. The critical chain is given by path A1, A2, A4, A6 and to protect the Due Date (DD) of the project from the Critical Chain (CC) variability a time buffer was introduced after the last activity of the project designated by Project Buffer (PB). The PB will work as a time pillow or damper against schedule variability of critical chain activities and will be used as a visual register of the time impact of the randomness occurred in the network activities. This register is used as the control tool of the project which is intended to be efficient, focused and global.
And, to protect the Critical Chain (CC) from the duration variability of non critical activities (A3 and A5) another time buffer was inserted in the arc that connects non critical activities to critical activities. This type of buffer is designated by Feeding Buffers (FB).

4. Potential Application in Dynamic Production Network Context

As the concept of dynamic network is considered by a growing number of authors [5] as a temporary network of enterprises, that is formed to explore a business opportunity. And, the concept of project it is also a temporary effort to produce a product or service that could be represented by a set of activities.
Assuming the structure of a dynamic network can be managed through a project network where the activities are changed by enterprises and the links between activities represent dependences among them. Thus, both concepts can be related as illustrated in Figure 2.

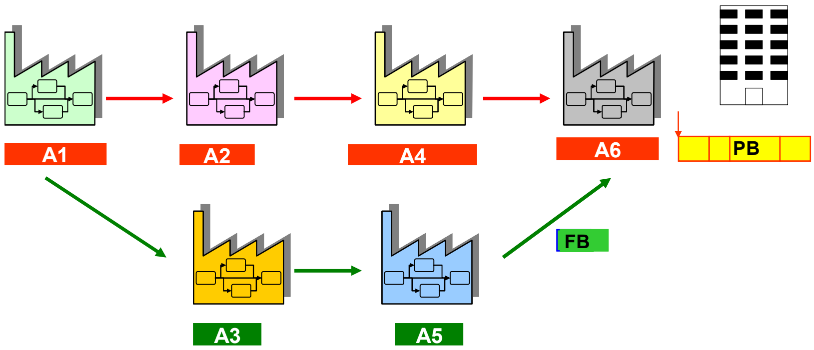

Figure 2 – Relation between project and dynamic network

5 . Experimental Results

The approach described was applied in a major civil construction project, which comprised the construction of two buildings at the municipality of Lisbon. The first tower was managed using classical tools for project management and the second tower using the CCPM collaborative approach. According to the contract agreement the main goal was to build the towers within the time settled. The contractor was in charge of the planning, scheduling and construction, worked with several subcontractors, resulting in a collaborative network with different entities and activities to develop.

In the second tower, designated by CCPM tower, the process of planning and scheduling the resources was applied at macro level. Based on this approach each member of the collaborative network had a set of tasks and sequences which were not programmed in the baseline of the collaborative network but at company level.

After identified the critical chain of the collaborative network the time buffers were introduced. The size of all time buffers was calculated according to SMC method [6]. This method consists in sizing feeding buffers, in an ALAP scheduling, applying Monte Carlo Simulation for each activity. With SMC the size of the buffers were reduced and buffer consumption improved without exceed the due date of the project [7].

During the project execution the schedule actualization was done considering not just the percentage completion of the undergoing activities but also using estimated and approved activity remaining durations. Target duration of activities immediately following the undergoing activities was also changed if needed to reduce project buffer consumption. For that each member, if needed, reschedule his intra-company schedule according with the changes approved in the collaborative schedule in site reunions.

In general, if we compare all durations of activities of the collaborative baseline network and real durations, one can see that the majority of the baseline durations were not accomplished, as it can be seen in Figure 3.

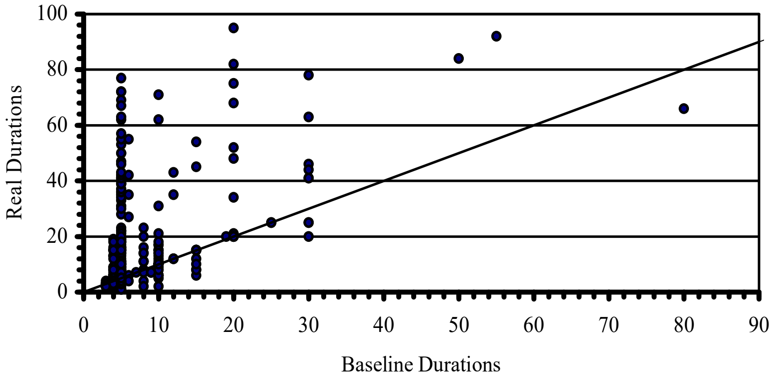

Figure 3: Real durations *versus* Baseline durations

However, if we compare the scheduled durations with the real ones, it can be seen that there is a greater adjustment (Figure 4) between real and schedule durations. These results shows that a more aligned schedules durations with the real activities durations, as a result of having applied the estimated remaining durations to face the uncertain reported factors.

In Figure 5 is presented a graphic with the differences between the estimated durations for the “finish stage” of the first tower – which was managed according to company traditional procedures, with the CCPM Tower scheduled according to CCPM principles.

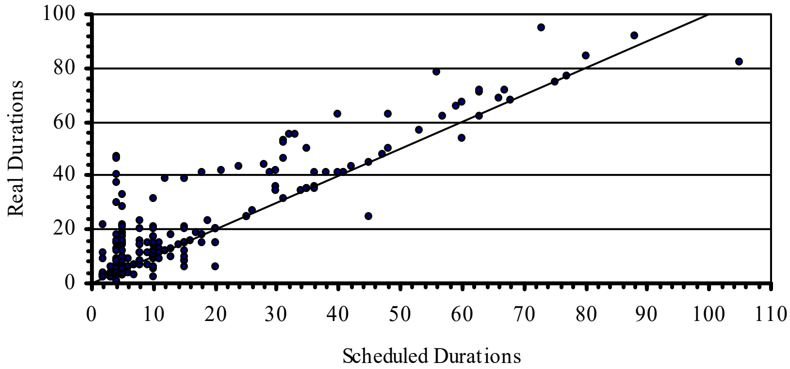

Figure 4: Real durations *versus* Schedule durations

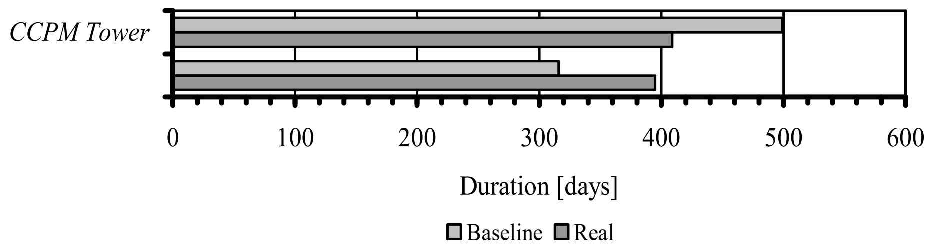

Figura 5: Finishing phase durations of First Tower and CCPM Tower

6. Conclusion

Developing models and tools that support management activities in collaborative environments will not only help to better understand the area, but also for a wide adoption of the collaborative networks paradigm in its various manifestation forms.

Some preliminary steps in this direction, inspired in critical chain concept were presented. Initial results illustrate the applicability of the suggested approach. Further steps are necessary towards the elaboration of a robust tool as well its validation.

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