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A PRODUCTION CONTROL TOOL FOR COORDINATION OF TEAMS, MEETINGS AND MANAGERIAL PROCESSES

Omar Zegarra[1] and Luis Fernando Alarcón[2]

ABSTRACT

During construction projects, the productive deployment of operations depends on the reliable supply of the production control function, where the proper coordination of teams, meetings and managerial processes is crucial for performance. Currently the use of the Last Planner System for providing this function has been successful; despite the importance it claims in the social domain, it does not explicitly regulate the coordination of teams and meetings with the managerial processes. In order to address this gap, we developed a prototype tool, based on a Multi- Domain Matrix, for handling and tracking the performance of these elements.

This paper introduces the *Matrix of Interacting Groups*, which evaluates the interaction of teams, meetings and managerial processes during the production control function supply. It was initially tested in a Chilean housing project and it allows the identification of team members, meetings, processes, and provides insight into the system key properties. It enables a comprehensive description of the production control function and generates a framework for tracking and for potentially fine tuning it. Although the tool is still under development, it seems promissory for providing a high level and practical regulation of production control.

KEYWORDS

Production Planning, Control, Complexity, Design Structure Matrix, Coordination

INTRODUCTION

During the execution of construction projects, the production planning and control function (PCF) is the bottleneck of performance. It precedes and regulates the deployment of operations. Ideally, the PCF supply could be depicted as a sequence of managerial processes that emerge from the interaction of functional, social and technical elements in order to meet project demands through the generation of reliable outcomes (Zegarra and Alarcón, In press). In this view, the social agents are the key action triggers; they perceive the environment's incoming stimuli and then react in order to respond to them (Winograd, 1987; Heylighen and Vidal, 2007).

Currently a successful tool for PCF supply is the Last Planner System (LPS). Its

1 PhD Candidate and Graduate Researcher at Centro de Excelencia en Gestión de Producción (GEPUC) at Pontificia Universidad Católica de Chile. E-mail:ozegarra@uc.cl, (56 2) 354-4244

2 PhD, Professor, Dep. of Construction Management Pontificia Universidad Católica de Chile, E-mail: lalarcon@ing.puc.cl, (56 2) 354-4201, (56 2) 354 4244.

use up to now has generated many positive outcomes (Fernandez-Solis et al., 2013). The Last Planner System (Ballard and Howell, 1998) emphasizes a proactive and progressive solution of project goals using an arrangement of managerial processes and meetings driven by an empowered team. The proper LPS use is evaluated mainly by the percentage of plan completed (PPC) and its effects on operations.

Despite the importance the LPS puts on the relationship between teams, meetings and managerial processes, these elements lack an explicit mechanism to depict and regulate their proper joint work. The LPS emphasizes and details the arrangement of various managerial processes and meetings, and although the need for empowering the team is clearly mentioned, it does not provide a view about how these elements fit together with the project's social network (Priven and Sacks, 2013).

There is a lack of explicit regulation of the elements upstream of the managerial processes of the PCF supply; this gap has the potential to impact the PCF performance. The value provided by a system is driven by its architecture (Eppinger and Browning, 2012). The variability propagation over this causal structure affects its performance and the PCF supply is not the exception (Zegarra and Alarcón, 2013).

In order to address this issue, this work introduces a prototype tool entitled Matrix of Interacting Groups (MIG). It aims to analyze and manage the interaction of team members, meetings and managerial processes over the PCF supply structure. The tool considers the PCF as a complex system and uses a special type of Design Structure Matrix as the basis for analysis and the LPS to describe managerial processes used.

This work addresses the background, then the MIG features, next the method, results & analysis of the pilot case used to test the tool and finally a discussion.

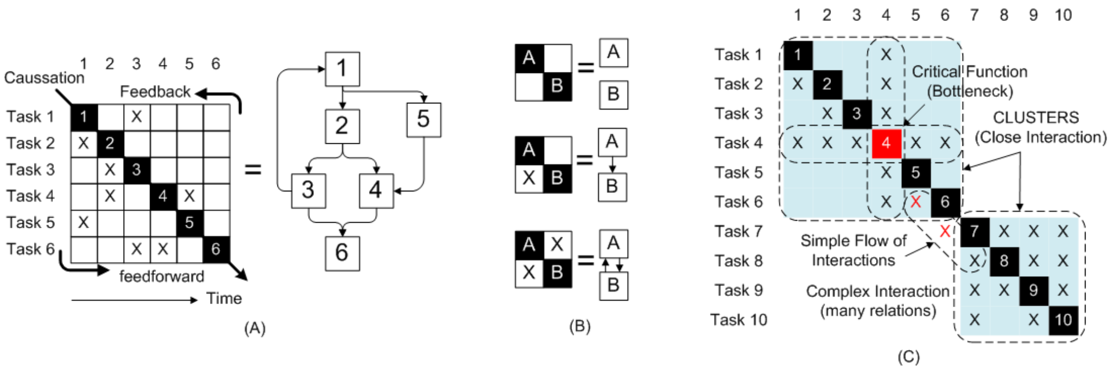

Figure 1: Design Structure Matrix (DSM). (A) & (B) adapted from Eppinger & Browning 2012, (C) Structural Features Adapted from Lano (1977*)*

BACKGROUND

DESIGN STRUCTURE MATRIX (DSM) (LANO, 1977)

The DSM "*is a simple tool to perform both the analysis and the management of complex systems. It enables the user to model, visualize, and analyze the dependencies among the entities of any system and derive suggestions for the improvement or synthesis …*" (Lindemann, 2015). This tool is a square NxN matrix (Figure 1A) that describes the system's elements and their relationships; its key benefit is its graphical layout which enables an easy and useful representation of the system architecture (Eppinger and Browning, 2012; Lindemann, 2015).

The DSM depicts causal dependences between elements within one domain. The included elements are depicted as headers of rows and columns as well as over the matrix diagonal line. The “X” marks represent links between elements, where a column of marks depicts the outputs generated by an element; a row of marks depicts the inputs received. The diagonal lineal also depicts the causal organization of elements over time so the marks below & above the diagonal may depict feedforward (FF) & feedback (FB) interactions respectively (Lindemann, 2015). In Figure 1A, the DSM depicts the arrangement of six tasks and an equivalent graph for the same six tasks (where the elements are depicted by nodes and each edge between two nodes depicts a relationship). The feedback relationships, such as 3 to 1 and 5 to 4, are depicted by the marks above the diagonal line in the locations (1, 3) and (5, 4). The other relationships are depicted below the diagonal; e.g. 1 to 2 is depicted in (1, 2).

The DSM display reveals the system structural configuration and provides clues for its management. It includes three basic relations as shown in Figure 1B: parallel (no links, and elements do not interact), sequential (one link, with the effect of one element on another) and finally coupled (two links, showing an intertwined relationship). The combination of these arise as a structure that allows us to identify key structural features (figure 1C), e.g. bottlenecks, clusters, etc., the handling of these features can improve the system’s behavior (Lano, 1977; Lindemann, 2015).

The links depict non-deterministic causal relations in the system. Grossly depicted by processes or probabilities (Schaffer, 2011), these links drive the emergence of features and value (Eppinger and Browning, 2012), and their management, depicts the coordination effort over the system (Malone and Crowston, 1994).

One special type of DSM is the Multiple Domain Matrix (MDM). It enables a system multi-domain representation. An MDM layout depicts various related DSMs (each DSM depicts a different domain), all in a single matrix. The relationship between two DSM matrixes, e.g. [A] & [B], is depicted by rectangular matrices which reveal the correspondence of [A] & [B] elements. The rectangular matrices, according to their location above or below the diagonal, can be labelled as feedforward or feedback respectively (Lindemann, 2015).

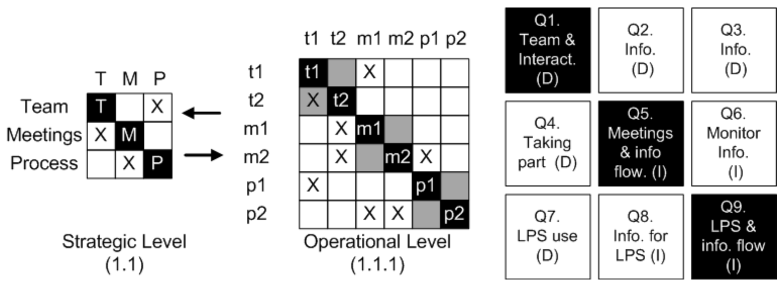

Figure 2.Matrix of Interacting Groups (MIG): (A) Architecture & (B) Interactions

MATRIX OF INTERACTING GROUPS (MIG)

DESIGN: CONCEPT & DEFINITIONS

The Matrix of Interacting Groups (MIG) is a tool for the analysis and management of the PCF. The goal of MIG is to enable a high level analysis and management of the social and process domains of the PCF. This tool is complementary to methodologies which provide an operational platform for executing the PCF supply (Zegarra, 2012).

The tool includes two interacting matrices which depict operational and strategic views of the PCF. Each matrix encompasses three categories of elements: *Teams*, *Meetings*, and *Managerial Process*. The operational matrix is a low level description of the interaction between project team members, meetings and the managerial process used. The strategic matrix is a high level description of the interaction between sub-teams, meetings types and managerial process types. The strategic matrix is built based on the operational matrix and then the strategic matrix status provides feedback to the operational matrix driving changes on it. These matrices and their interacting elements depict a hierarchical multi-domain organization of the PCF supply which is evaluated over time based on the matrices' features (Figure 2A).

The Team category depicts the human agents involved in the PCF and it includes two levels: Sub-teams (1.1) and Individuals (1.1.1). Level 1.1 depicts functional groups, e.g. safety, and level 1.1.1 indicates occupations, e.g. project manager.

The Meetings category depicts the meetings held over the duration of the project and it includes two levels: Meetings Type (1.1) & Meetings (1.1.1). These levels depict categories according to the managerial process they helped to run; for example, planning meetings (type) or weekly meeting (meeting).

The Managerial Process category depicts the PCF supply processes and it includes two levels: Processes Types (1.1) & Processes (1.1.1). These levels depict, respectively, the processes grouped by categories for example plan type and the specific managerial processes used over the project, such as the LPS lookahead.

The interactions depict the dependences between elements. The MIG interactions are represented using language since they depict a communication/action process, specifically conversations (Winograd, 1987). In some cases these links depict communication acts, i.e. face to face utterances or flows of information (meaningful data) and in others only actions i.e. situated data (environmental information) perceived by the human agents (Heylighen and Vidal, 2007). In a previous and related study, a method to measure the flow of formalized conversations over the PCF supply was tested (Zegarra and Alarcon, 2013). This research completes that study by assessing the non-recorded conversations which support the flow of formal conversations and that relate them to the meetings and the social network of the PCF.

CONSTRUCTION OF MATRICES

Matrix Structuring

Figure 2B and Table 1 depict the matrices' structure and elements. Quadrants Q1, Q5 & Q9 depict the elements and interactions from teams, meetings and managerial process. Then Q4, Q7 & Q6 (feedforward) and Q2, Q3 & Q6 (feedback) depict dependences between these. Also, Figure 2B depicts the attribute used to represent each interaction and indicates if the data is collected in a direct (D) or indirect way (I).

Data

The direct data is collected using a field survey and the indirect data is calculated using direct data. The direct data depict measured links; for example, the Q4 interactions are obtained by directly by asking the team. If the direct evaluation is complicated to obtain, then, the data about the link is calculated based on pertinent and available links; for example, in Q5 it is hard to directly assess the information flows between meetings, hence the Q5 links are calculated using Q4 & Q2 data (for feedforward and feedback links respectively). Q4 includes information about all the persons who attended the different meetings; the weighting of this information provides a way to depict the meetings´ links (Wasserman and Faust, 1994).

Table 1: MIG Elements

Category	Level 1.1 (Strategic)	Level 1.1.1 (Operational)
Team	*Sub Team:* Management (MGMT), Tech. Office (OT), Administration (ADM), Safety (PdR), Production (PROD), Sub Contract (SC).	*Members:* Site Manager, OT Chief, OT Eng., Accountant, Safety Eng., Warehouseman, Superintendent, Foreman, Sub Contractor
Meeting	*Meeting type*: Plan, Get, Set, Do, Ctrl	*Meetings:* LPS Weekly Coordination Meeting, Daily Instructions, etc.
Process	*Sub processes type*: Plan, Get, Set, Do, Ctrl	*Sub processes*: LPS Weekly Scheduling, etc.

Data Collection

The Instrument for data collection is a field survey. It included 16 closed questions about the outputs & inputs for each element of the matrix. The team questions ask about outputs generated and inputs received by members. The meetings questions ask about attendance, duration, times per week and perceived utility of meetings. Finally, the managerial process questions ask about the use of LPS elements.

Matrix Building

The Matrix building involves arranging the data into the matrix display. This process was executed using an MS Excel Dynamic Table. The building process includes:

Step 01: The collected data is arranged and transformed into data for the matrices. The output from this step is the calculation of the relative importance of the dependences obtained by direct evaluation.

Step 02: The data is arranged into the square N x N Operational Matrix display. The information from surveys constitutes direct data for quadrants Q1, Q2, Q3, Q4 & Q7. Then the indirect data were calculated using the following considerations: Q5=f (Q2, Q4), Q8 =f (Q4, Q7), Q6=f (Q2, Q3) and Q9=f (Q7 Q8, Q3 & Q6). The logic for assessing these indirect links has been the use of direct relationships which could help to build a plausible indication about the indirect links' configuration. For example, for Q5, a person's traffic between meetings (Q4) is used as an indicator of the proactive information flows between meetings, and the feedback received by the team after meetings is used to describe the feedback of information flows between meetings.

Step 03: The Strategic Matrix is calculated using the data from the Operational Matrix. The level 1.1 (sub teams, meetings & processes) are used as adding categories.

Indexes

The evaluation of the MIG structure depicts the importance of its elements and their interactions. Currently it is based only on the use of the interactions and excludes the inherent features of the elements. It considers three parts: Interactions' Importance, Multi -Attribute Evaluation of Elements and the Coordination level.

Interactions' Importance: They provide an evaluation of the MIG matrix display in order to categorize the interactions and facilitate their interpretation. This evaluation uses four categories (depicted by colors): > 75% (Darkest dots), > 50% (dark grey dots), >25% (light grey dots), <25% (white dots) and 0% (w/o dots). This scale depicts the logic of the Likert scale -1 (nil) to 5 (max)- used in the closed questions of the field survey. In the case of direct data (Q1, Q2, Q3, Q4 & Q7), it depicts direct outputs from the survey. The logic of the calculated links (indirect data) is similar because they are constrained by the values of the Likert scale.

Multi-Attribute Evaluation of Elements: It assesses the elements' importance based on the interaction density of Q1, Q5 & Q9, feedback (FF) and feedforward (FB) quadrants. The density (ratio of observed over potential interactions) represents the frequency of interaction. The FB and the FF depict the sum of all the inputs and outputs of each element i.e. for Q1, FF=f(Q4, Q7) & FB =f(Q2,Q3), then for Q5, FF =f(Q4,Q8), FB =f(Q2,Q6) and finally for Q9 FF =f(Q7, Q8) and FB = f(Q6, Q3). Finally the elements' importance is calculated as: Importance = Frequency*FF*FB.

Coordination: It is evaluated using the interactions' density. This index is calculated for Q1 (team), Q5 (meetings), Q9 (process) and for the overall matrix.

Tracking

The tracking of MIG matrices depicts the evolution of their descriptive indexes and of their structural configuration displays over time. This assessment depicts the existence of isolated elements (with a lack of interactions, so vulnerable to underperformance), of clusters (highly interconnected elements, so vulnerable to failure), and of critical elements (connected to every one).

Table 2: Project Features

Characteristics	Description
Project Type/Scope	Housing, 121 Houses, From 65 to 94 square meters
Team (12 Persons)	01 Site Manager, 02 Project Engineers, 01 Warehouseman, 01 Superintendent, 01 Safety Engineer, 01 Administrative, 03 Foremen, 02 Subcontractors
Key Items (Cost %)	Masonry (26%) Sanitary Installations (18%), Painting (11%), Concrete (11%), Interior wood work (10%)
Bottleneck	A procurement activity centralized in the headquarters

RESEARCH METHODOLOGY

The goal of this study was to test the MIG prototype. The work was carried out by using the case study logic; it involved first developing the tool concepts, then testing them and finally considering improvements. The test process itself encompassed five stages: Data Collection (by field survey), Matrix Building, Index Calculation, Tracking & Reports Queries, and finally Outcomes Analysis. The test relied on a project in construction stage (housing) located in Santiago de Chile (Table 2) that used the LPS. The information was collected weekly during five weeks and generated 1,617 records, reflecting the outcome of questions asked of 12 team members about their team interaction, their meeting attendance and their use of LPS. Finally the information was loaded into a MS Excel database.

RESULTS

The key MIG results are the Operational and the Strategic Matrices. Only the last one is exhibited here (Figure 3). Also a summary of the main outcomes from these matrices (Table 3) and an example of index tracking (Figure 4) are depicted here.

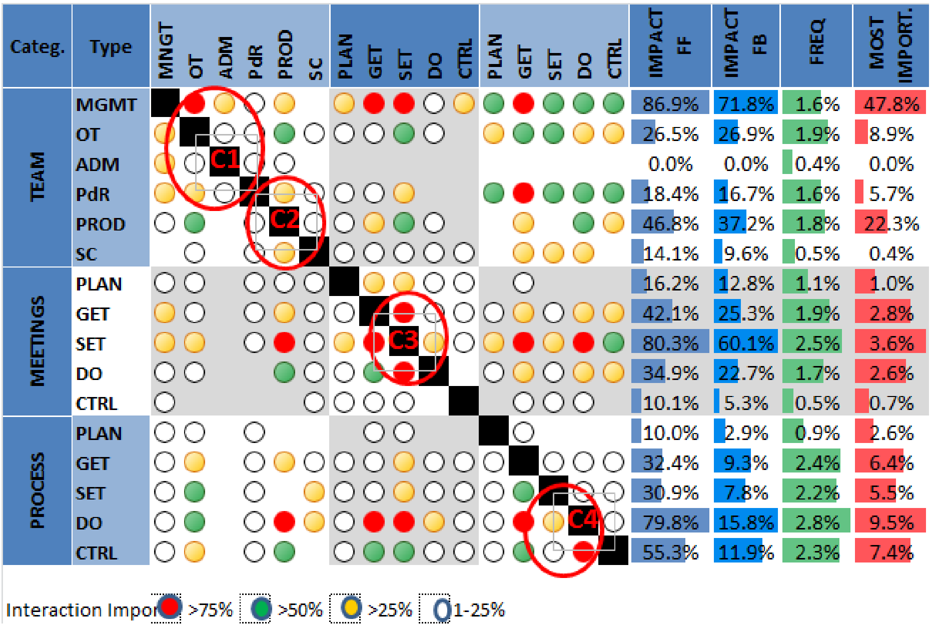

Figure 3: MIG Strategic Query (Average values) (level 1.1)

Table 3: Main Outcomes from Strategic and Operational Matrices

Key Items	Team (T)	Meetings (M)	Process (P)
Interactions*	MGMT⇦OT	Get⬄Set, Set⇨Do	Get⇨Do, Do⇨Ctrl
Important functions	MGMT, PROD	SET, GET	DO, CTRL
Clusters Location	Office, Prod.	Around Set	Toward process end
Most Important operational elements	- Site Manager - Superintendent	- Weekly Meetings - Daily Orders	- Weekly Schedule - Improvement Process

*(⇨) Feedforward link of A on B, (⇦) Feedback link of B on A and (⬄) A&B interaction.

ANALYSIS

The MIG is a tool for the analysis and management of the production planning and control function. The goal of this work has been to test a prototype tool, which exhibits capabilities for identifying key elements and for evaluating the structure of the PCF supply, considering the team, meetings and managerial processes involved.

Team: The most important sub-teams are management (MGMT) & production (PROD). Their relevance is caused by the presence of the project's critical individual agents, i.e. project manager and superintendent. These individual agents generate the most frequent and important interactions, plausibly as part of their duties.

Additionally these two sub-teams lead the meeting attendance, LPS use (PROD only) and also they are the most important receptors of information from meetings and LPS. Their rich amount of dependences produces the clusters of interactions C1 & C2.

Meetings: The most important meeting type is SET, although GET & DO also rank high. The SET relevance is caused mainly by three meetings which concentrate the most important interactions: (1) weekly coordination meeting, (2) daily staff coordination meeting & (3) daily stand- up instructions meeting. They define a critical hub where the most important inputs and outputs from Team and LPS converge, generating the C3 Cluster which may be the potential focus of coordination

Process: The most important managerial processes are DO & CTRL, albeit GET & SET also rank high. Their relevance is driven by the weekly scheduling and by the sub-process that studies the reasons of non-compliance. They receive and generate the most important inputs and outputs from team and meetings. In Q9, the cluster C4 suggests that feedforward dependences are stronger than the feedback ones and are located toward the end of the LPS processes; this may suggest a reactive coordination.

Tracking: Over time The MIG is depicted by time series indexes and by their corresponding structural displays. Fig. 4 depicts the frequency index evolution for team and meeting (average value) where an inverse relationship seems plausible; lower levels of team interaction may be compensated by more meeting interaction.

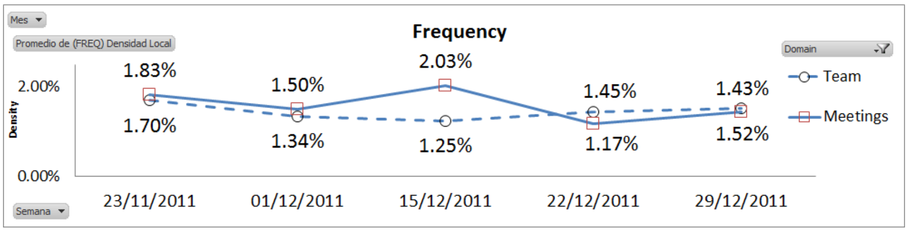

Figure 4: Frequency Index Tracking: Team and Meetings

DISCUSSION

The tool provides a framework for describing, analyzing, tracking and potentially for regulating coordination over the PCF supply. The tool depicting management emphasis may detect potential weak points and hence detect improvement options. The following comments refer only to the strategic matrix due to space limitations.

Team: The social interaction could be improved. A fragmented interaction pattern deteriorates response under stressing conditions (Krackhardt and Stern, 1988). In Q1 fostering the merge of the C1 & C2 clusters seems convenient to increase interaction, which between Management (MGNT) & Subcontractors (SC) is nil and between Administrative (ADM) Technical Office (OT), Production (PROD) & SC is poor/nil.

Team, Feedforward (FF) & Feedback (FB) Links: The links of Team with meetings and process could be improved. First, MGMT values the FB obtained from meetings and processes (i.e. dark dots over Q2 & Q3) but it exhibits a low proactive action on them (Clear FF dots on Q4 & Q7). Then ADM seems isolated; it does not interact with meetings & process i.e. nil FF & FB (in fact, the person in this role was frequently absent from the job site because he was working with another project too). Next, Safety (PdR), receives FB but its proactive involvement with meetings (e.g. FF in DO is nil) and processes is low. PROD is mainly proactively involved with SET & DO meetings and DO & CTRL processes, while the links between PROD and PLAN in both cases are poor (in fact the project did not use phase scheduling). Finally, the SC links are even weaker than those of PROD, showing various nil and low links.

Meetings: The network of meetings could be improved. The meetings catalyse the effect of team on processes (Priven and Sacks, 2013) In Q5, the improvement of interactions by pulling the focus of cluster C3 toward PLAN and GET could generate positive outcomes due to an increased level of anticipatory action. DO & CTRL do not interact, indicating potential poor learning activities.

Meetings, Feedforward (FF) & Feedback (FB): The links of Meeting with LPS could be improved. The meetings seem to regulate the LPS processes mainly by acting proactively on DO (dark dots on Q8) and by receiving FB from GET, & DO (dark dots on Q6); however the interaction between meeting and PLAN is low.

Process: In Q9, the LPS processes' interactions require improvement. First, the FB links are mainly poor and in the case of PLAN they are nil ; this is a condition which may suggest possible poor learning (Sterman, 2000). Then the cluster C4 could be pulled toward GET & SET, fostering action in the upstream LPS processes.

Practical Contribution: In summary, the contributions were:

- An improved PCF supply description. This implies the use of elements (team, meetings & interactions) up-stream the managerial processes that potentially impact the variability propagation over the PCF (Zegarra and Alarcón, 2013).
- A framework for tracking and potentially for tuning the PCF supply. It tries to provide a kind of "value stream map" of the PCF supply and its managerial processes, providing a strategic level view of this system (Figure 3).

Relationships to other PCF tools: The MIG aims to complement other tools for PCF supply. The tool aims to provide an additional view to help PCF supply improvement. The MIG benefits also could be provided, in some way, using the Social Network Analysis (SNA) (Priven and Sacks, 2013) albeit, from a weaker perspective because SNA has a more limited view of causal structure than the DSMs.

Limitations: *This paper represents on-going research*. There are issues which still need attention such as the simplification of MIG inputs, the dependences calculation, & the inclusion of element features in the multi attribute evaluation among others.

Theory Contribution: The objective of MIG is to depict the coordination efforts over the complex structure of the PCF supply. The description uses two special DSMs which include interdependent elements from social & process domains, both at strategic and operational levels (Lindemann, 2015). The causation of this arrangement may be complex because it involves the interaction of elements from different domains and hierarchies. The operational level (by bottom-up causality) generates the emergence of the strategic level; that, in turn, by top down causality, drives the operational level regulation (Ellis, 2008). Finally coordination has been defined as *"managing dependences between activities"* (Malone and Crowston, 1994); in this sense, MIG aims to depict and manage these dependences over the PCF supply.

CONCLUSIONS

The MIG is a tool for analysis and management of PCF itself. It involves two special type of DSM, each depicting interacting teams, meetings and managerial processes. It may depict the coordination effort features over the complex, hierarchical and multi-dimensional structure of the PCF supply mechanism. The MIG's most important implications are its capabilities for describing, analyzing and potentially for regulating the PCF supply structure. The final stage of this work is going to test a hypothesis of performance improvement of the PCF supply, based on the diagnostic and handling of the clusters of interactions.

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