PROPAGATION AND DISTORTION OF VARIABILITY INTO THE PRODUCTION CONTROL SYSTEM: BULLWHIP OF CONVERSATIONS OF THE LAST PLANNER

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ABSTRACT

During a construction project, the production control system allows the creation of conditions to manage operations. The Last Planner System is a production control system whose use has been related to superior project performance. We suggest that there is an opportunity to improve the Last Planner System application in the patterns of conversation variability along its subprocesses from a Language Action Perspective. These patterns are called Bullwhip Effect of Conversations, because they resemble the concept of propagation of variability in the supply chain.

We update previous research about Instability of Conversations, adding new data, evaluations and interpretations. This paper is based on five mining and road construction projects. Our research analyses variability propagation and distortion of conversations along the Last Planner System subprocesses, and their relationship with the Percentage Plan Complete Index. The findings suggest that the Bullwhip Effect of Conversations exists. It impacts the production control reliability. Also we conclude that it represents the coordination variation throughout the production control subprocesses. This concept seems useful to improve management processes; further research is still required.

KEYWORDS

Last Planner System, Language Action Perspective, Variability, Bullwhip Effect

INTRODUCTION

Projects' lack of effectiveness is a frequent condition in the Architectural Engineering and Construction Industry (Flyvberjg et al 2004). For Lean Construction practitioners, variability and its propagation across operations is a key element of this problem (Tommelein et al 1999, Alarcon & Ashley 1999). To address this problem, the *Last Planner System* (LPS) was introduced and it was defined as a *Production Control System* (PCS), a sequence of interrelated management processes which create reliable conditions to manage downstream production processes (Ballard & Howell 1998). Its use has been related to reduction of variability propagation between production processes to achieve a better work flow, achieving both productivity and performance improvement (Tommelein et al 1999, Leal & Alarcon 2010).

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However despite this progress, to date, the quantification of propagation and distortion of variability along the management processes of the PCS itself has received little attention. These elements are important because they make the PCS variable, become an unstable process, and so unreliable that it will impact downstream operations´ productivity and goals; also, from a cost perspective, it seems plausible that there is a positive relationship between a deficient PCS and overhead overrun. Conceptually, this variability issue could be better described by a Line of Balance of Operations, representing the variability propagation along production processes (Alarcón & Ashley 1999), preceded by a management processes sequence, such as the LPS process (Figure 1a). To address this issue, the Bullwhip of Conversations concept was developed (Alarcon & Zegarra 2012). It aims to describe and quantify the propagation and distortion of variability along PCS subprocesses. This concept describes the management processes that precede the realization of physical production processes, using stocks of conversations to represent LPS processes from a Language Action Perspective (Figure 1b). The following sections of this paper will update the research presented in Alarcon & Zegarra 2012 regarding the existence and impact of this concept.

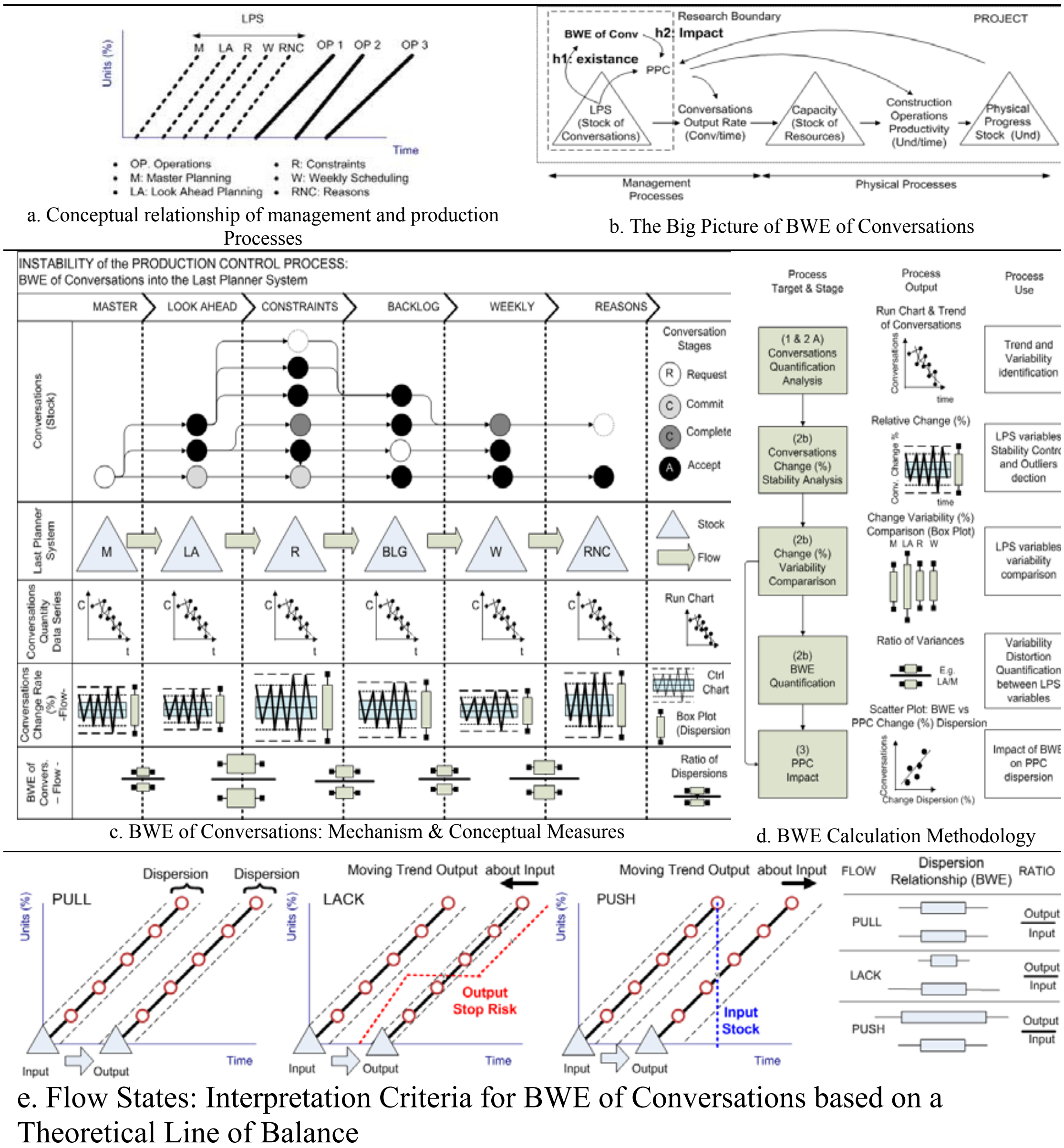
LITERATURE REVIEW

The Bullwhip of Conversations of the Last Planner System (BWE) describes the variability propagation of conversations along PCS sub processes. It was inspired and based on the concepts of (1) Supply Chain Bullwhip Effect and (2) "conversations" of Language Action Perspective (LAP), respectively.

The Bullwhip Effect (Forrester 1961; Lee et al 1989) is the progressive amplification of the variability of information and physical stocks along a supply chain. It arises from the structure of the system, deteriorates the system's performance and is inevitable. A particular case of this phenomenon is the Planning Bullwhip (Moscoso et al 2010): it is observed in Material Requirements Planning (MRP) systems, and describes the variability propagation within push planning systems. It includes concepts such as MRP Nervousness, which are frequent changes of inputs to the MRP (Heizer & Render 2004), and Lead Time Syndrome, characterized by frequent changes of the lead time of inputs to the MRP (Mather and Plossl 1978 in Moscoso et al 2010).

Language Action Perspective (LAP) and Conversations (Flores & Ludlow 1980): This communication theory describes a basic process of interactions between people based on action related to utterances or "speech acts." In LAP, a process that includes a sequence of these actions is called conversation; a sequence of subprocesses or "speech acts" and control milestones, which are both explicit and visible for those involved. To use this concept, in practical terms, a formalization of speech act is required, setting requirements, commitments and monitoring milestone achievements; in this context, the articulation and activation of conversations has been understood as a management process. Macomber & Howell 2005 pointed out that the LPS mechanisms allows a roductive articulation of conversations, hence effective management, and that explains the LPS positive results.

BWE of Conversations (Alarcon & Zegarra 2012) (Figure 1c): The Instability of conversations is a progressive propagation and distortion (increasing and/or decreasing) of variability of conversations, along the production control process, impacting its reliability. The causal mechanism was described as a management problem of consecutive stocks of conversations. This concept understands the conversations variability as the dispersion of the “rate of change (%)" of conversations´ data series.



a. Conceptual relationship of management and production Processes

b. The Big Picture of BWE of Conversations

c. BWE of Conversations: Mechanism & Conceptual Measures

d. BWE Calculation Methodology

e. Flow States: Interpretation Criteria for BWE of Conversations based on a Theoretical Line of Balance

Figure 1. (a) Conceptual Relationship, (b) the Big Picture, (c) BWE Model, (d) BWE Methodology, and (e) BWE, Push, Pull & Lack States: Interpretation Criteria

HYPOTHESES

The BWE existence and impact was evaluated with the following hypotheses: (H1) BWE exists between PCS variables and (H2) BWE is related to the PCS reliability (Table 1).

Table 1. BWE of Conversations in the LPS Variables Dictionary for the Hypotheses

Variable Name	Symbol	Description	
		Conceptual	Operational
Last Planner	LPS	Production Control System	LPS={M,LA,R,BLG,W,RNC}
Master	M	Quantity or Stock of Conversations within a LPS variable: M (Master Schedule), LA (Look Ahead schedule), R (Unsolved Constraints), BLG (Solved Constraints), W (weekly Schedule) and RNC (Reasons of non-completion).	Number of records within a database of M, LA, R, BLG, W and RNC respectively
Look Ahead	LA		
Constraints	R		
Backlog	BLG		
Weekly	W		
Reasons	RNC		
Bullwhip of Conversation	BWE	*Variability Distortion*: i.e. Amplification and Sensitivity of conversations E.g. How much is the gain of the output about the input	Ratio of Variances of normalized data of two LPS Variables (S^2_{Output}/ S^2_{Input}), where Input: LPS i Output: LPS i+1
		Variability Propagation: i.e. Pull, Push or Lack of conversations. E.g. How much is the output % of change about 1% of change of the input	
Reliability Trend	PPC t	PPC of the system, free of external distortions	Mobile average of PPC

METHODOLOGY

The research strategy, based on a case study approach, uses conversations to quantify and analyze the variability of successive management processes, such as PCS subprocesses. It includes the concepts of time series analysis, control charts for variability monitoring and Supply Chain, instability quantification (Brockwell & Davis 2002, Cachon et al 2007, Fransoo & Wouters 2000, NIST/SEMATECH 2012); we also developed an interpretation criteria for the BWE output. The strategy's main features are:

(1) Research Design: It used multiple cases & units of analysis to study five projects, during the construction stage, in Peru and Chile between 2004 and 2010 (Table 2).

(2) BWE Units of Analysis: The following BWE indexes, which have been considered to be LPS subprocesses, were used: (LA/M) Tactical Planning and Scheduling, (W/LA) Weekly Scheduling of Assignments, (R/LA) Constraints Identification, (BLG/R) Constraints Liberation, (W/BLG) Assignment use per liberated constraint, (W/R) Assignments use per identified constraint and (RNC/W) Problem Causes Identification.

(3) Data: We use the following data to quantify the variables: LPS project records generated with excel spread sheets (e.g. weekly schedules) and with Primavera Project Planner (only for the master schedule). Each record, within a variable data base, was considered as a conversation in progress.

(4) Process (Figure 1d): The BWE analysis included the following stages: (1) Quantification, (2) Analysis ((2a) Qualitative and (2b) Quantitative) and (3) Reliability Impact measurement. These stages had the following goals and outputs:

Stages (1) and (2a) quantify conversations and evaluate the stationarity of data (i.e. if the data trend and variability changes over time); its outcomes were run charts and trends. They are important because the relationship analysis of variables whose data series exhibits changing trends and heteroscedasticity could produce spurious results.

Stage (2b) considers three steps. The first one (Equation 1) is used to deal with the variation along time as previously mentioned; to do so, it transforms the data series by taking logarithms and by successive differentiation; this step linearizes the data and generates as an output which is a statistical residual useful to detect outliers in the data; because of the two transformations, this residual can be understood as rate of change (%) between data items (Nau 2005); these new data series of change (%) where statistically analyzed with control charts to assess their stability –if variables were under statistical control- and to systematize the search for outliers. The second step of (2b) synthetizes the change (%) data series using boxplots (they use the max., min., 90^{th} and 10^{th} percentile values of change (%) data series); this allows the comparison of the variability of stocks of conversations within the PCS. The third step of (2b) quantifies BWE indexes at project level; it takes the change (%) data series, calculates its variance and then evaluates the ratio of variances for several variable pairs (Equation 2). The global evaluation of several BWE indexes used a multiplicative BWEg index (Equation 3). Finally, Stage (3) assesses BWE impact on the PCS Reliability. It, graphically, shows their relationship at project level. For concordance, this stage used the Variance of the Change (%) of the *Percentage Plan Complete* (PPC) as a reliability measure.

Table 2 Case Studies

Case ID	Project Type	Scope of work	Data Records (Weeks)
1	Mining	Earthmoving Project	37
2	Mining	Drainage Project: Civil, Piping, Mechanical and Electrical	27
3	Mining	Lines for Power Supply: Civil and Electro-mechanical	42
4	Mining	Service-Buildings: Civil, Steel Erection, and Electrical	42
5	Road	Road maintenance: quarry, surface treatments, signalization	19

(5) *Measurements and Criteria used to detect BWE Amplification:*

- Change (%) = Log (X_{t+1}) – Log (X_t), where: (Equation 1)
- X_t: LPS variable during a week t
- $BWE_{i+1} = S_{i+1}^2 / S_i^2$, (Cachon et al 2007), where: (Equation 2)
- S_i^2: Variance of Change (%) for any LPS variable
- If BWE> 1 then it does exist amplification (Cachon et al 2007).
- $BWEg = BWE_1 * \ldots BWE_{i+1}$ (Fransoo and Wouters 2000) (Equation 3)

(6) *Interpretation Criteria* (Figure 1e): This research considered that each BWE index measures three conditions: “Distortion” (amplification or reduction), “Sensitivity” (how easily the BWE changes) and “Flow” of the variable output about the variable input. The Flow could be in a Push (BWE> 1), Pull (BWE = 1) or Lack (BWE <1) state. The *Pull state* was considered a perfect equilibrium situation (the output changed 1% for each 1% change of the input); it did not generate waste and was considered efficient and effective. The *Push state* represented a state where the variability of output changed more than the variability of the input; this process

tended to be efficient but ineffective; the maximum value of Push was considered to be a bottleneck, since it reflects a demand >= than capacity; in this case an input stock bigger than the output stock is expected. Finally the *Lack state* represented a state where the variability of output changed less than the input; in this case the risk is that the output will be faster than the input. Finally, these criteria take into account that the sequence of BWE indices describes the process of articulation of conversations along the LPS and that the aggregate BWEg synthesizes it.

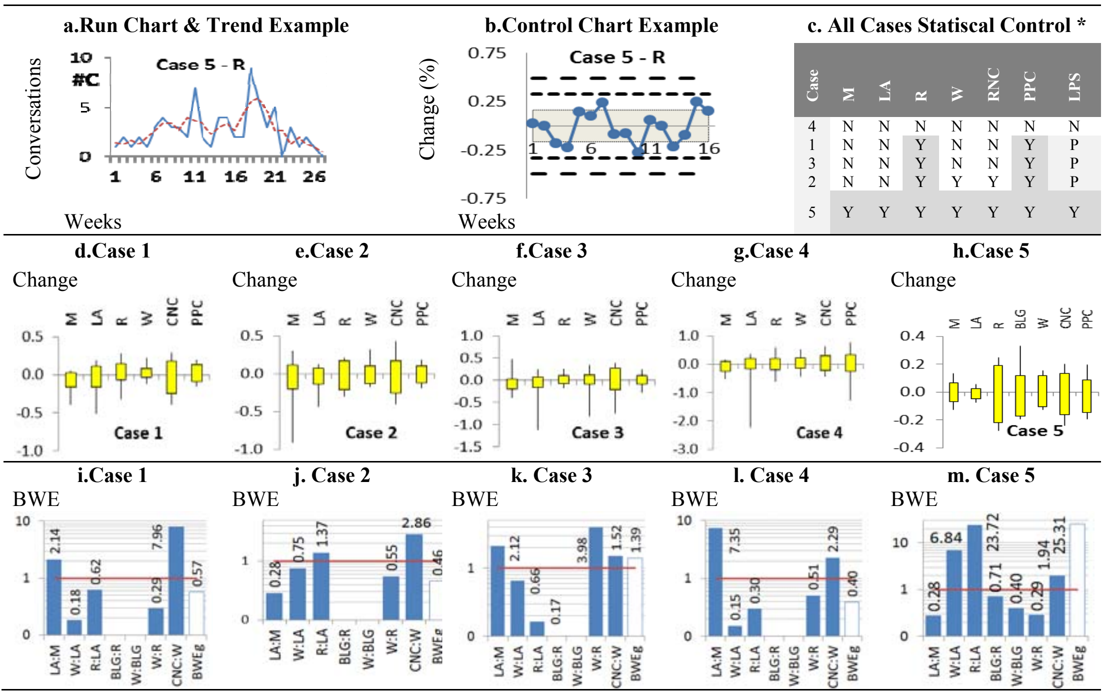


Figure 2. (a) run chart & trend, (b) control chart, (c) statistical control (*n: out of control, y: in control, p: partial control), (d to h) Box plots, and (i to m) BWE indexes

RESULTS

The main results observed for Hypothesis H1 and H2 are:

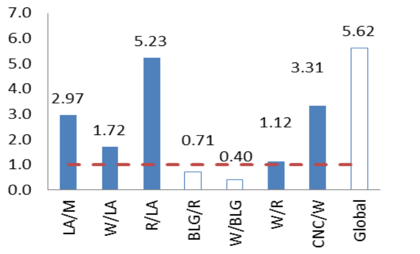
H1.Quantity and Trend of Conversations: The data suggests changes in trend (upward, downward or mixed) and in variation (and bigger at trend peaks) in all cases (Figure 2a). *H1.Change (%) of Conversations*: Case 5 is under control, without outliers; cases 1, 2 & 3 are under partial control and case 4 is out of control. Total or partial control of the LPS is observed when the PPC and the R are under control. (Figure 2b & 2c).

H1.Box Plot of change (%) of conversations: All cases showed variation of dispersion along the LPS variables (Figure 2 d to h).

H1.BWE: There are values of BWE> 1 for indexes LA/M (cases 1, 3 and 4), W/LA (case 5), R/LA (cases 2 and 5), W/R (case 2) and RNC/W (in all cases); Also there are BWEg > 1 (cases 3 and 5) and <1 (cases 1, 2 and 4). (Fig 2 i to m) (Table 3a) (Figure 3b).

A. BWE Indexes

Case	LA/M	W/LA	R/LA	BLG/R	W/BLG	W/R	RNC/W	BWEg
1	**2.14**	0.18	0.62	-	-	0.29	**7.96**	0.57
2	0.28	0.75	**1.37**	-	-	0.55	**2.86**	0.46
3	**2.12**	0.66	0.17	-	-	**3.98**	**1.52**	**1.39**
4	**7.35**	0.15	0.30	-	-	0.51	**2.29**	0.4
5	0.28	**6.84**	**23.7**	0.71	0.4	0.29	**1.94**	**25.3**
Mean	**2.98**	**1.72**	**5.23**	0.71	0.4	**1.12**	**3.31**	**5.62**



B. Mean BWE & Pull Threshold (---)

C. Mean BWE Interpretation

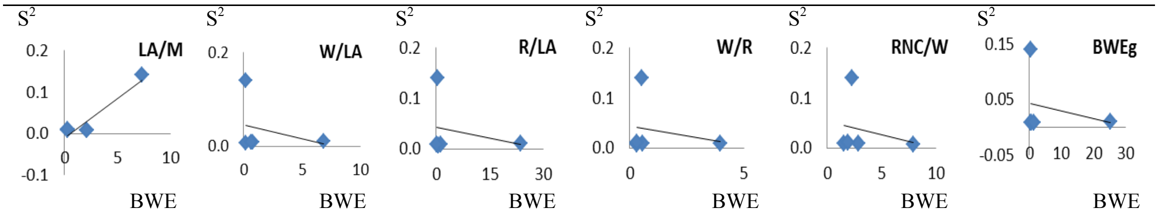
	LA/M	W/LA	R/LA	BLG/R	W/BLG	W/R	RNC/W	BWEg
Distortion	++	+	+++	-	--	+	++	+++
Sensitivity	++	+	+++	-	--	+	++	+++
Change Dificulty	--	-	---	+	++	-	--	---
Flow	++	+	+++	-	--	+	++	+++
Bottle Neck			BN					
Flow Type	push	Push	Push	Lack	Lack	Push	Push	Push
**Efficiency*	+	+	+	-	-	+	+	+
**Effectiveness*	-	-	-	+	+	-	-	-
Flow Agility	-	-	-	+	+	-	-	-
**Output Latency*	+	+	+	-	-	+	+	+
**Output Stock*	+	+	+	-	-	+	+	+
**Input Stock*	-	-	-	+	+	-	-	-

D. Reliability Measures

Case	PPC (%)	S_{ppc} (%)	Cp	Change(%) of PPC Prom	Change(%) of PPC S^2
1	71.9	16.9	0.49	0.008	0.008
2	68.7	20.9	0.4	0.009	0.008
3	57.7	23.5	0.35	0.001	0.009
4	56.1	34.1	0.24	0.004	0.141
5	58.0	17.8	0.47	-0.007	0.011

Sppc: PPC stand. Dev.
Cp: Process Capability

(+) Better
(-) Worse
BN: Bottle Neck



E. BWE vs Variance (S2) of Change of PPC (each dot represents a project)

Figure 2. (a) BWE Indexes, (b) Mean BWE & Pull Threshold, (c) Mean BWE Interpretation, (d) Reliability Measures, and (e) BWE vs Variance of Change of PPC

H2.Reliability: All the cases exhibit a PPC > 50%.The PPC values for cases 3, 4 and 5 suggest a similar performance; On the other hand, the PPC dispersion values for cases 3, 4 and 5 suggest a different performance. The Cp Index suggests that the LPS process is not always able to overcome a value of PPC = 50% (i.e. a Cp <1); Case 4 exhibits the maximum PPC dispersion and the case 5 the most consistent (Table 3d).

H2.BWE – PPC relationship: The BWE affects the variance of the change(%) of PPC as follows, (1) an increasing LA/M increases it; (2) an increasing W/LA, R/LA, W/R and RNC/W respectively, reduces it; (3) an increasing BWEg reduces it (Figure 2e).

ANALYSIS

The hypotheses H1 (existence) and H2 (Impact) are considered plausible, based on:

The articulation of conversation in the LPS process tends to amplification, sensitivity and Push flow. The mean synthesis rate (BWEg) suggests that the LPS process exhibits amplification of variability. It is sensitive (it is easy to increase its value) and it has a push flow that implies that the flow type of the articulation of conversations along the LPS is efficient, ineffective and not agile (Table 3c).

The BWE index oscillates along the LPS and suggests the existence of three sectors (Figure 3b) (Table 3c). These are: (1) An “Identification and disaggregation” sector with indexes of BWE> 1 and spread through LA/M, W/LA, and R/LA; it tends to amplification, sensitivity (changes easily), push flow and contains the LPS bottleneck. For example, the constraints identifying process (represented by the R/LA index) tends to amplification, since from a few “LA” conversations emerge many “R” conversations; it is sensitive (the constraints number grows easily), and it presents push flow. The push flow suggests that this process is efficient and ineffective (it is easy to identify constraints, but they are not solved right away). It is also a non-agile process with big variability and latency, therefore the restrictions could grow considerably and management would require more time).

(2) A “Use and combination” sector, with BWE <= 1; it tends to reduction, to insensitivity (difficult to change) and to lack flow type. It includes BLG/R, W/BLG and W/R measures; the BWE <=1, suggests that in sector 2, the flow would be inefficient and effective (i.e. tends to use less stock and time). (3) A “Corrections” sector with BWE> 1; it tends to amplification, sensitivity (easy change) and push flow and includes the RNC /W index. Additionally, the BWE > 1 suggests that sectors 1 and 3 would be efficient and ineffective (they tend to a bigger use of stock and time).

The results suggest that BWE affects the PPC (Table 3d, Figure 3e). - In general terms, increasing BWEg reduces the variability of the change (%) of the PPC. The BWE indexes (for each LPS variables pair) suggest that a bigger LA/M amplifies the variation of PPC change (%) and that bigger W/LA, R/LA, W/R and RNC/W values reduce it.

DISCUSSION

This study explored an opportunity to improve the production control process. Its contribution is unique since to date the existence of BWE and its effect on variability patterns of conversations during the production control process had not been evaluated. It suggests that the following hypotheses are plausible: (H1) the BWE exists between variables and (H2) the BWE affects planning reliability. In this section, we document how BWE describes the coordination of the project team, we highlight differences with current literature, and finally potential applications are indicated

The BWE of Conversations in LPS may describe the behaviour of the “coordination” during PCS; this interpretation has two elements, (1) structure and (2) dynamics: The structure considers the BWE a coordination variation along the production control process. The premises of this claim are: (1) Each LPS subprocess is a management process; (2) each management process is an articulation of conversations (Flores & Ludlow 1980), sorting conversations in a productive way; (3) this sorting depends of the interactions between elements (Eppinger 1997); managing these interactions is coordination (Malone & Crowstone 1994). Finally, the dynamics refers to the variation of BWE indexes over time.

The BWE of Conversations is different from Supply Chain Bullwhip and Planning Bullwhip. Unlike Supply Chain Bullwhip, the BWE in PCS focuses on distortion of speech acts during the management process instead of the distortion of information (e.g. purchase orders) and physical operations; also it seems that its theoretical profile is different, since it exhibits an oscillation rather than a progressive increase. Regarding the Planning Bullwhip, the BWE in PCS is different because (1) it is based on LAP and that changes the focus from "information for plans" to "acts during the production control"; also (2) it evaluates more management processes and not only the planning process.

The BWE is not a direct measure of conversations quantity within each LSP variable. Although accounting for conversations within each LPS variable is a key input, it should be reiterated that the BWE do not directly describe quantities of conversations. Rather, it is a ratio of rates of change (%) of conversations between two variables. The reason is that: (1) A time series of data, resulting from conversation counting, is not adequate to directly analyze the distortion because it is unstable and exhibits heteroscedasticity. (2) To use this data series, it is necessary to apply a mathematical transformation, like logarithms and differences. (4) The transformed data series describe the change (%) of the conversations quantities. (5) The change (%) dispersion is use for BWE Calculation.

In practical terms, this concept seems compatible with several uses**:** (1) To improve the production control process by helping to monitor and balance the LPS sub processes, by identifying trends, special causes of variation, unstable LPS sub process and bottlenecks.(2) To provide a high level synthesis for control at the firm level, such as for dashboards use). (3) To provide visual control of the LPS performance. (4) For Benchmarking at a project and company level. (5) To set performance specifications**.**

This research updates an analysis presented in a previous study. While adding new information for cases 1 to 4, which allows a better understanding of the patterns observed; it provides additional concepts to analyze aggregated BWE indexes; finally due to the new data available, it was possible to enrich the analysis of BWE's impact on reliability

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions about the BWE are that: (1) it allows the representation of distortion patterns of variability of conversations along the PCS; (2) it exists and it impacts the PCS reliability; (3) it allows the quantification of the flow of conversations between two LPS variables and along the LPS process; (4) it represents the coordination of the project team during the PCS process; and (5) it could be used to describe, monitor and improve the process of production control. Further development of the BWE could be useful for tailored PCS design and for behavior studies of PCS.

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