IDENTIFYING THE BULLWHIP EFFECT OF LAST-PLANNER CONVERSATIONS DURING THE CONSTRUCTION STAGE

Luis F. Alarcón[1] and Omar Zegarra[2]

ABSTRACT

Often the successful performance of a project is problematic. The Lean Construction community has approached this issue by emphasizing variability reduction of the production process using the Last Planner System (LPS). In this context, we suggest that the variability characterization of managerial actions along the LPS process itself is an improvement opportunity. We used the concept of conversations from Linguistic Action Perspective (LAP) and the premise that the Bullwhip Effect (BWE) exists between the LPS variables to explore the variability impact of managerial actions during the LPS process. This paper reports the characterization of BWE of LAP conversations between LPS variables and its impact on planning reliability in five projects in the construction stage.

Evidence collected suggests that BWE exists between the LPS variables and its existence may be related to the degradation of planning reliability. Although additional work will be required to corroborate these initial findings, this outcome seems useful to quantify management-efforts variability during the LPS process. It is expected that further exploration of these results could help to act proactively to prevent variability generation during the LPS process, where they can be used as a systemic-feedforward variables of disturbance related to the project social-domain.

KEY WORDS

Last Planner, Variability, Bullwhip Effect, Lean Project Dynamics, Linguistic Action

INTRODUCTION

The Construction Industry is a critical economic activity. It generates around 10% of the Global GDP (Crosthwaite 2000) and it is a key factor of countries competitiveness. Despite its importance, the accomplishment of project objectives, historically, has been a questionable issue (Flyvbjerg et al. 2003).

The Lean Construction community has face this issue using a strategy based on a better understanding and management of the complex structure of the project delivery process, in opposition to an only economical and contractual view (Koskela and Ballard 2006) (Winch 2006).One tactic of this view is the strengthening of the production-control process. The goal is to increase the planning-reliability, to impact the productivity of workflows and hence the project performance (Alarcon and

[1] Head and Professor, Department of Construction Engineering and Management, Pontificia Universidad Católica de Chile.E-Mail: lalarcon@ing.puc.cl

[2] Candidate and Graduate Resercher at Centro de Excelencia en Gestión de Producción (GEPUC), Pontificia Universidad Católica de Chile.E-Mail: ozegarra@uc.cl

Ashley 1999)(Thomas et al. 2002).The Last Planner System (LPS) (Ballard 1994) is the tool used for this end (Ballard & Howell, 1994).

This work is focus on the construction stage and it explores one alternative to reduce the variability of the production-control process itself. It is based on the propagation analysis of the managerial variability during the LPS process. To do it, we analyzed the relationship between patterns of variability of LPS variables – inspired in the Bullwhip Effect (BWE) (Forrester 1961) - from a social angle that is based on the Language Action Perspective (LAP) (Flores and Ludlow 1980).

LITERATURE REVIEW

Based on the concepts of Variability (V), the Bullwhip Effect (BWE), The Last Planner System (LPS) and the Linguistic Action Perspective (LAP), we found that the BWE is a harmful propagation of variability and the LPS-process articulates a network of LAPs commitments to face variability.

The variability is a very important fact. It exists in all the production systems, impacts performance, arise from many sources and can propagate (Hopp and Spearman 2000); The LPS is a production control mechanism focused on variability reduction by improving planning-reliability (Ballard and Howell1994)

The BWE (Forrester 1961, Lee et al. 1997) is a cumulative distortion of variability in the upstream steps of a supply chain that deteriorates the system performance (Simchi-Levy et al. 2003) (Figure 1). It has received a lot of attention because it is pointed out as an important source of inefficiency (Geary et al. 2006). It can, also, be described as time-series patterns (e.g. Amplification) (Sterman 2006).

The BWE is cause by the complex interaction of several variables and its handling depends of the system organization and the behaviour of the people. It is triggered by operational (e.g., batch size, lead times, etc.) and behavioural causes (e.g., heuristics, etc.) (Lee 1997) (Geary et al. 2006) (Sterman 1986). It cannot be fully eliminated (Lee 1997). The subjacent mechanism that relates these causes can be described as a stock problem (managers seek to maintain it at a particular level) affected by human ordering-heuristics (Sterman 2006).

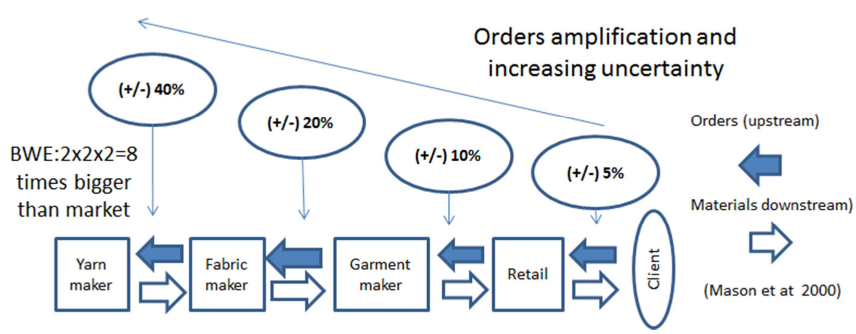


Figure 1 The Bullwhip Effect Arising in a Supply Chain (Mason et. al. 2000)

The LAP is a theory that describes a basic work-process of persons-interaction. It was developed for computer-systems use, based on Austin, Searle and Habermas theories of language and actions of people (Schoop 2001). Its use has claimed persons-interaction improvement (Sull and Spinoza, 2007). It describes a process of persons-interaction using of the "pragmatic dimension of language", this interaction process is named "conversation" and it is a sequence of explicit and mutually visible "Language Acts" (e.g. commitments) and time tokens (Winograd 1988). It considers the organization a network of conversations and the management work as a generation and articulation of them. Its practical use needs to track conversations. One use is an alternative explanation of the LPS (Macomber and Howell, 2005).

THE BWE OF CONVERSATIONS INTO LPS

In this section, the concepts of V, BWE, LPS and LAP are related in a hypothesis to explain the instability of conversations during the LPS-process (it excludes the variability description of operational-activities, e.g (Alarcon and Ashley 1999)):

Ho: The Instability (BWE) is the cumulative distortion in the quantity of conversations along the LPS process and it impacts on the planning reliability. It is caused by the propagation and accumulation of the variability of conversations.

This hypothesis suggests that the management process (generation and articulation of conversations) carried out with the LPS, generates patterns for the variability of conversations that impacts planning reliability. The subjacent premises are that the BWE exists, it can negatively affect the LPS capacity, it arises because of operational and human factors in the LPS structure and it can be mitigated.

The BWE is important because it could reduce the LPS-capacity to manage conversations. The capacity could be wasted or also insufficient because of the variations in the volume of conversations that LPS need to solve weekly with the same staff capacity (until some point where new capacity is added).

There are several facts that suggest the BWE existence into the LPS. E.g. irregular patterns exhibited by the time series of LPS variables (e.g. the number of constraints varies over time), the presence of accumulations (e.g. databases), etc.

The LPS instability manifestation may include the following dynamic patterns: (1)Original Time Series (2) Amplification or Bullwhip (increase of variability between variables), (3) Oscillations (cycles exhibited by time series), (4) Phase Lags (timing shifts of cycles, (4)Trends (original time series free of distortions), (5) Seasonal Variations (Systematically long term variation about the trend caused by external factors, e.g. Christmas), (6) Irregular Variations (after filtering seasonality and trend, it represents external short-term variations, e.g. unexpected social issues).

The mechanisms behind Instability into the LPS could be explain as a stock-management problem impacted by a human component (this is strongly base on Sterman J. 1986,2000 and 2006).For this work we understand the variables of the LPS as a sequence of connected stocks (Figure 1) that correspond to data use and record during the LPS process. The stocks structure aims to represent the causal relationship between LPS variables, where each stock represent the total quantity of conversations recorded for each variable into a database(M is a stock of conversations, that is successively disaggregated into LA and R conversations, then once the R has become BLG they are aggregated into W conversations. The CNC represents the stock of fail conversations discovered after W). It is assume for this work that even though these conversations belong to different planning hierarchies they can be compare from the point of view of volume of conversations handled on each variable of LPS. In this context it seems logical to try to keep the stocks fill with the right quantity of conversations to enable the generation of throughput. This LPS stock-structure of conversations may be further develop to consider a behavioural component, e.g. heuristics -This assumption is not show in Figure 1.

The instability into the LPS arises because of the variability originated by operational and behavioural causes (We assume this based on (Sterman 1996)). It is not possible to exactly coordinate all the conversations into the stock structure of LPS due to operational constraints (e.g. lags in the system, different lead times, etc.) and behavioural reasons (e.g. rationality, limitations and fails of the LPS users).

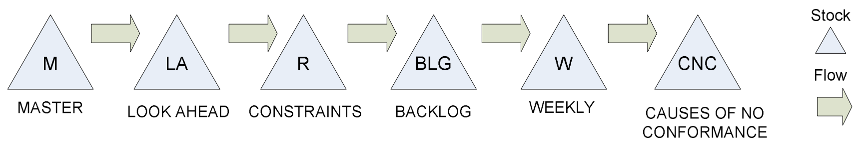


Figure 1.LPS causal model

METHODOLOGY

This section contains a research design to probe the existence and impact of BWE:

Hypothesis: **(1)** H1: The BWE exists between the LPS variables, **(2)** H2: The BWE is correlated to the program reliability.

Design Type: We used a multiple-case with multiple units of analysis (Yin 1994) because: (1) the interest was related to "how" and "why" the BWE impact on PPC, (2) the availability of data from projects that used LPS.

Cases and Units of Analysis: Five projects (in the construction stage) were used (Table No.1). In each case, the presence of BWE between LPS variables (Table 2) was evaluated for various units of analysis (pairs of LPS-variables) (Table 3):

Table 1 Cases of Study

ID	Project Type	Scope of work	Data (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	Public Infrst.	Road maintenance: quarry, surface treatments, signalization	19

Measures and BWE Existence Criteria:

- BWE = Variance of Output/Variance of Input = So^2/ Si^2 (Lee 1997)... (1)
- BWE existence if: $(So^2/ Si^2)>1$ and $(So^2- Si^2)$ is positive (Cachon et al. 2007)
- PPC Reliability Measures (for original and trend): PPC, Standard deviation (S), Variation Coefficient (VC) and process capacity (Cp) (Where: PPC lower limit (LL) = 50%, upper limit (UL) = 100%, and Cp = (UL-LL)/6S).

Process: The analysis included the next steps: (1) Database construction–from weekly records- for each LPS-variable available into each case. (2) Quantification of records for each week (# of conversations). (3) Construction of Original Time Series sets of variables for each case. (4) Filtering: mobile average for 3 consecutive records, logarithmic transformation of it and differentiation between consecutive averages. (Cachon et al. 2007) (5) Calculation of variances for each variable, BWE index for each unit of analysis and application of the existence criteria. (Cachon et al. 2007) (6) Calculation of PPC indexes: Media, Standard deviation, variance coefficient and capacity index for both PPC original time series and PPC trend. (7) Calculation of the delta for PPC and PPC trend indexes. (8) Comparison of BWE indexes and PPC.

Table 2: LPS Variables

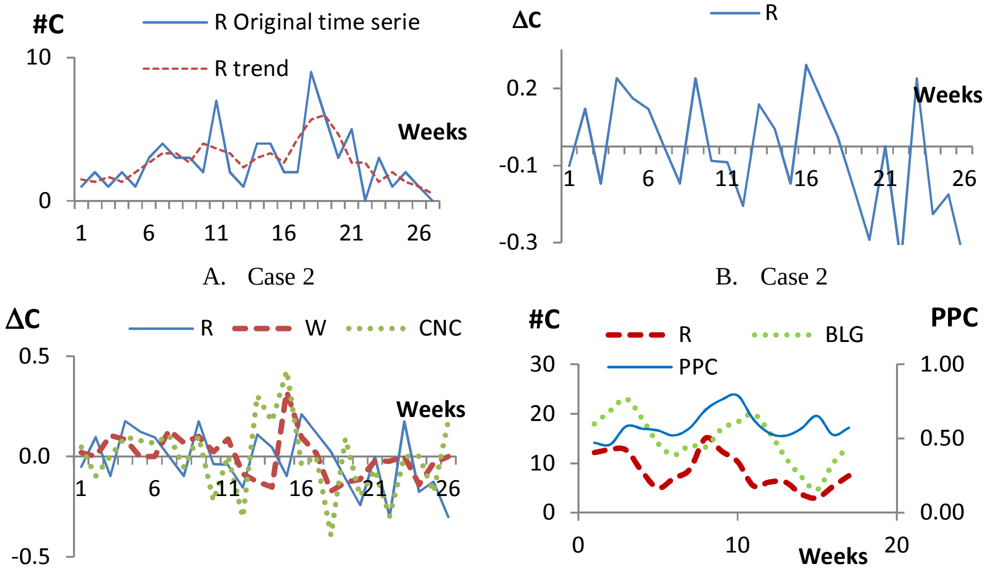
Variable Name	Symbol	Description	
		Conceptual	Operational
Master Schedule	M	# of conversations at M	# of records in a Database of M, LA, R, BLG, W and CNC respectively
Lookahead Schedule	LA	# of conversations at LA	
Constraints	R	# of convers. At Unsolved Constraints	
Backlog	BLG	# of conversations at Solved Constraints	
Weekly Schedule	W	# of conversations at W	
Causes of No Conformance	CNC	# of conversations at Weekly schedule	
Bullwhip or Amplification	BWE	Variability distortion between two LPS-variables	Ratio of Variances: (Output/ Input)
Reliability Trend	PPC t	PPC free of external distortions	smoothed PPC
Delta PPC	ΔS, ΔVC	Reliability distortion about the trend	Ratio of dispersions (PPC/PPCt)
	ΔCp	Capability distortion to deliver reliability over 50% about the trend	Ratio of capabilities (PPC/PPCt)

Table 3 BWE Units of Analysis Meaning

BWE unit of analysis	Description	
	Conceptual	Operational
LA/M	Disaggregation of LA about M	• Ratio: variability Output/variability Input • e.g. LA/M is the quantification of the amplification of variability or BWE between LA (output) in relation to M (input)
W/LA	Disaggregation of W about LA	
R/LA	Disaggregation of R about LA	
BLG/R	Consolidation of BLG about R	
W/BLG	Consolidation of W about BLG	
W/R	Consolidations of W about R	
CNC/W	Arise of CNC about W	
BWE-PPC	Impact of BWE on Reliability	Correlation graph BWE-PPC measures

RESULTS

The results are present in Tables 3 and 4. The Figures 2 and 3 exhibits a typical example of the behaviour of the LPS variables analysed to quantify BWE. The main findings present here are: (1) Values of BWE >1 exists for CNC/W in all cases, arise in W/R in some cases and they are present in W/LA and R/LA. (2)The average PPC-values, range from “working to control” to “in control”. (3)The most effective PPC values (the bigger Cp) belong to cases 1, 5 and 2. (4)The most consistent PPC values (the smaller VC) belong to cases 1, 2 and 5. (5) The BWE for CNC/W increase as the VC is smaller and the Cp is bigger. (6)The BWE appears for the W/R ratio when VC grows and Cp falls: e.g. case 3. (7)The BWE behaviour in W/R is not captured by PPC: e.g. cases 3 versus 5. (8) The BWE is hidden if the variability is big: e.g. case 4 and (9) more work is needed to gain insight about the early stages R/LA and W/LA.



A. Case 2 B. Case 2

C Case 2 D Case 5

Figure 3 (A) Original Time Series, (B)(C) Filtered Variation and (D) Phase Lag of Trends

Table 4: BWE indexes

Case	BWE = variability output/ variability input = (So/Si)						
	LA/M	W/LA	R/LA	BLG/R	W/BLG	W/R	CNC/W
1	1	-	-	-	-	0.29	*7.96*
2	1	-	-	-	-	0.55	*2.86*
3	1	-	-	-	-	*3.98*	*1.52*
4	1	-	-	-	-	0.51	*2.29*
5	0.28	*6.84*	*23.72*	0.71	0.4	0.29	*1.94*

Table 5: Reliability Indexes (PPC)

Case	PPC Original T. Series (A)				PPC Trend (B)				Delta PPC (A/B)		
	PPC	S_{PPC}	VC	Cp	PPC t	$S_{PPC\ t}$	VC t	Cp t	ΔS_{ppc}	ΔVC	ΔCp
1	71.9%	16.9%	0.24	0.49	71.5%	10.5%	0.15	0.8	1.62	1.61	0.62
2	68.7%	20.9%	0.3	0.4	68.4%	11.6%	0.17	0.72	1.8	1.8	0.55
3	57.7%	23.5%	0.41	0.35	57.8%	15.2%	0.26	0.55	1.55	1.55	0.65
4	56.1%	34.1%	0.61	0.24	56.8%	30.5%	0.54	0.27	1.12	1.13	0.9
5	58.0%	17.8%	0.31	0.47	58.6%	9.2%	0.16	0.9	1.93	1.95	0.52

ANALYSIS OF RESULTS

The review of each variable provides information about its stability (Figure 3). Figure 3A describes the absolute change in R conversations and suggests that it is unbalanced (two peaks) even without the external variability-impact (trend). Figure 3B describes the rate of change of weekly R conversations without the trend. Figure 3C exhibit the variation for consecutive variables. The band of variation seems similar for W and R but not for W and CNC. Figure 3D exhibit the shift in time of the trend behaviour between variables (its quantification is not included in this paper).

THE BWE EXISTS BETWEEN LPS VARIABLES

The BWE >1 is present in CNC/W for all cases, in W/R for case 3 and in W/LA and R/LA for case 5. These values suggest that for each 1% of input-variation, the output fluctuate more than it. For CNC/W the index may reflects that one change in W would trigger more than one change in CNC; for W/R it suggests that one change in R will cause several changes in W. The effect for W/LA and R/LA is more intuitive, one change in LA will trigger big changes in W and R. (e.g. 1% variation in LA is related to 24% variation in R). A complementary interpretation, suggested here, considers this ratio as a rate of flow between the two stocks (inputs and outputs); it may represent a Push, Pull or Lack state of inputs to outputs. From this perspective a BWE=1 is an ideal pull situation (1% input variation produce 1% output variation).

The BWE may be used to represent the differences in mechanisms use: e.g. LA/M reflects LA application. The BWE=1 for cases 1 to 4 was assigned instead of calculated. It describes the content of LA plans reported as a mechanical transcription of the Master plan; In these cases M considers many items in advance to describe the project (this suggest that a lot of update effort could be require) and invite to question how practical are both the LA and the M in use. The BWE < 1 for case 5 was calculated. It describes an M with few items and a LA that expand them to lower levels weekly. In this case LA plan is used to control not only the deliverables stated in M, but also other processes that are required in the field. From a practical perspective, the second case helps to control in paper more details –in a weekly basis- that cannot be include in a Master Plan because it would not be practical.

The BWE index varies along the causal structure of LPS. In the case 5, it presents values <1 for LA/M, >1 for W/LA and R/LA, <1 for BLG/R, W/BLG, and W/R, and finally >1 for CNC/W. This behaviour would describe the variability of a process of disaggregation an aggregation of conversations (at several hierarchical levels) that is required to create conditions for throughput generation.

THE BWE AFFECTS PLANNING RELIABILITY

The average PPC is a location index that needs dispersion indexes to better explain behaviour. The best performances are exhibit by cases 1 and 2 ("in control" with a PPC> 65% (Alarcon et al. 2005)) and the cases 3, 4 and 5 are similar too ("struggling to control" with a PPC >50% (Ballard and Howell 2004).A better characterization of the variation emerges after using the PPC dispersion measures (for average and trend).e.g. the VC and the Cp of the case 4 are the double of the case 5 and for the trend the difference is even bigger. The Delta PPC attempts to quantify the impact of external variability on the reliability trend and give insight about it.

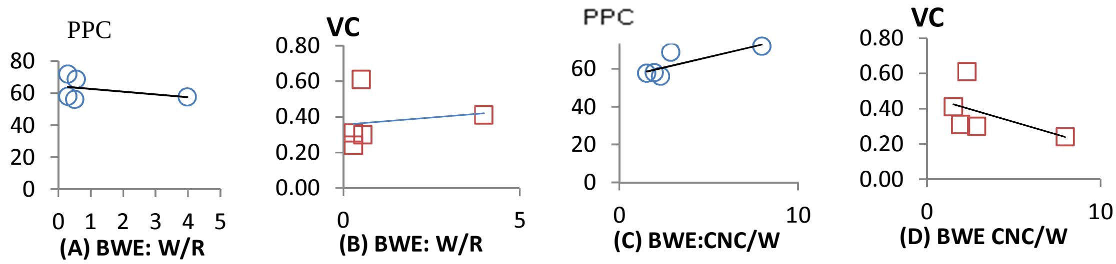


Figure 4 Relationship PPC–BWE and VC-BWE

The BWE is not fully detected by PPC. The Scatter plot for PPC and BWE of W/R exhibit a slightly negative relationship (Figure 4). But based on the cases 3, 4 and 5 it is easier to see that similar PPC values have very different values of BWE. This situation is overcome by the comparison of VC and CP against BWE.

It is suggest that there exists an effect of BWE on PPC. The values of CNC/W suggest that as the performance grows (high PPC and less variability) this BWE ratio increases (it seems to become more sensitive at high performance). The value of W/R increases with a smaller Cp and a bigger VC respectively (a degradation effect).

The BWE of CNC/W seems to reflect the LPS sensitivity about error-generation. A big value suggests a positive impact on problems (it has an inverse correlation with VC) (Figure 4 D). We could understand this situation as the LPS ability to detect problems. None the less the case 4 do not completely fit in this trend (big BWE and low VC). This behaviour invites to think that a system with small error generation (low BWE and high VC) is also possible and desirable.

In this work case 4 is considered a kind of outlier (despite its acceptable value of PPC) because of its big variability**.** Its VC and Cp values are the biggest and the smallest respectively. The delta PPC measures suggest a small difference between the subjacent system (trend) and the system after the impact of variation. This could be interpreted as an irregular system and as the explanation for the values of BWE that do not fit in the observed trends; e.g. the small value of BWE for W/R.

The BWE of Case 5 at R/LA and W/LA highlight the importance of these elements. The big values of BWE suggest a big activity between these variables. In the case of R this situation is even more important because of the impact of R on PPC. Also this fact drives to question if pull of constraints (R) is excessive or insufficient.

DISCUSSION: THE BWE EXITS AND IT IMPACTS RELIABILITY, SO WHAT?

BWE Meaning: Variation Sensitivity (Table 6). *We understood the BWE as the response capability of one variable about the change in other* (assuming positive relationship); it could present a sensitive (BWE>1) or insensitive (BWE<1) response. For these reasons it could be used to control the responsiveness of one sub systems about a another and based on that tuning its use, e.g. track how sensitive is the R generation about LA variation and evaluate if the subjacent subsystem that drives R generation is productive enough for the project goals. This information seems valuable to monitor the big picture of management processes of production control.

Table 6:BWE Units of Analysis Meaning and Utility

BWE	Meaning: Sensitivity of	Utility: Monitor Response-Capability for
LA/M	Disaggregation of LA about M changes	Pulling of operations (volume)
W/LA	Disaggregation of W about LA changes	Assignment of weekly work volume
R/LA	Disaggregation of R about LA changes	Identification of constraints
BLG/R	Aggregation of BLG about R changes	Generation of Backlog of solved constraints
W/BLG	Aggregation of W about BLG changes	Generation of assignations about backlog
W/R	Aggregation of W about R changes	Generation of assignations about constraints
CNC/W	Generation of CNC about W changes	Identification/detection of problems

BWE Utility: Monitor Pull, Push, Lack of Conversations. To evaluate the BWE performance for a LPS sub system in time, we need to use a reference level. We suggested that a BWE = 1 could represent an ideal and instantaneous PULL of conversations (the subsystems response is balanced: 1% of input change generates 1% of output change). A BWE >1 would represents a PUSH situation (the variation is sensitive and could be excessive) about the equilibrium, and a BWE <1 a LACK situation (the variation is insensitive and could be not enough). In the practice the equilibrium values of BWE for subsystems could be over or below the ideal and the PULL level for control purposes should consider a band with some lack and push.

BWE Limitations: Trend Use. We evaluate the BWE using the variables subjacent-trend. According to the literature the BWE calculated with it could be bigger. None the less, we use it because we want to analyze the subjacent system (the one under the project-team control) without external distortions (e.g. the effect of a strike due to social issues in the community where the project is located)

How this ideas help to perform better? : The BWE or instability measuring helps to understand and quantify how the production-control mechanism and its sub systems are working (on in relation to one another). They allow taking action for tuning the LPS use in the project and remove instability (a more uniform operation).

CONCLUSIONS

Based on the analysis presented, it is possible to argue that the management-process carried out with the LPS, generate patterns for the variability of conversations that in turn impact on the schedule reliability. The literature suggests that these patterns are generated into the system structure triggered by operational and behavioural causes. The data analysis suggests that the BWE exists, it impacts reliability and it is not fully detected by the PPC. In this context the BWE represents and quantify the cumulative variability of the management efforts carried out with the LPS. The present conclusions require further research to better understand the patterns of variability, mainly, into the least study variables of LPS; also it is expected that this measures will be useful for a better characterization, and feedforward handling of variability.

REFERENCES

Alarcón L.F., and Ashley D.B. (1999). “Playing Games: Evaluating the Impact of Lean Production Strategies on Project Cost and Schedule.” *PROC IGLC-7*, July 1999, Berkeley, CA, USA.

Alarcón L.F., Diethlm S., Rojo O. and Calderon R. (2005). “Assesing the Impacts of Implementing Lean Construction.” *PROC IGLC*, 13 Sydney, Australia.

Ballard G. and Howell G. (1994). “Implementing Lean Construction: Stabilizing Work Flow.” *PROC IGLC – 2*, July, Santiago de Chile, Chile.

Ballard, G. (1994). "The Last Planner." *Spring Conference of the Northern California Construction Institute*, Monterey, CA

Cachon G.P., Randall T. and Schmidt G.M. (2007). “In Search of the Bullwhip Effect.” *Manufacturing & Service Operations Management*, 9(4), Fall, 457-479.

Crosthwaite, D. (2000). “The Global Construction Market: A Cross-Sectional Analysis.” *Construction Management and Economics*, 18 (5), 619-627.

Flores, F., J.J. Ludlow (1980). “Doing and Speaking in the Office.” In: G. Fick, H. Spraque Jr. (Eds.). *Decision Support Systems: Issues and Challenges*, Pergamon Press, New York, pp. 95-118

Flyvberg B., Mette K. Skamris Holm and Søren L. Buhl (2003).” How common and how large are cost overruns in transport infrastructure projects?” Transport Reviews 23(1), 71-88

Forrester J. (1961) *Industrial Dynamics*, The MIT press, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Geary S. Disney S.M. and Towill D.R. (2006). “ On bullwhip in supply chains- historical review, present practice and expected future impact”. *Int. J. Production Economics*, 101, 2-18.

Hopp W. and Spearman, M. (2000). Factory Physics, 2nd Ed, McGraw Hill, USA.

Koskela L. and Ballard G. (2006)”Should Project Management be based on theories of economics or production?” *Building and Research & Information*, 34 (2),154-163

Lee H.L., Padmanabhan V. And Whang Seungjin (1997)” The Bullwhip Effect in Supply Chains” Sloan Management Review, Spring1997, 93 – 102.

Macomber G. Howell G.A. and Reed D. (2005) “ Managing Promises with the Last Planner System: Closing in on Uninterrupted Flow”. *PROC IGLC – 13*, Sydney, Australia.

Mason-Jones R and Townhill D.R. (2000). “ Copying with the Uncertainty: Reducing the “Bullwhip” Behaviour in Global Supply Chains.” *Supply Chain Forum an International Journal*, 1, 40-45.

Schoope M. (2001). “An Introduction to the Language- Action Perspective”, *SIGGROUP Bulletin August*, 22 (2), 3-8.

Sterman J.D. (1986). “Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment.” Management Science 35(3), 321-339.

Sterman, J.D. (2006). “Operational and Behavioral Causes of Supply Chain Instability.” In Carranza, O. & Villegas, F. (eds.) *The Bullwhip Effect in Supply Chains.* Palgrave McMillan.

Sull D.N. and Spinosa C. (2007).” Promise-Based Management. The Essence of Execution.” *Harvard Business Review*, 85(4) 76-86..

Thomas R.H. Horman M.J. Lemes de Souza U.E and Zavrski I (2002). *ASCE, J. Constr. Engrg. And Mgmt.*, 128 (2), 144 – 154. March/April Issue.

Winch G. (2006). “Towards a theory of construction as production by projects.” Buildings Research & Information 34 (2), 164-174.

Winograd T. (1988). “A Language/Action Perspective on the Design of Cooperative Work.” *Human-Computer Interaction*, 3 (1), 3-30.