The Bullwhip Effect in Closed Loop Supply Chain: a Systematic Literature Review

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Abstract

The bullwhip effect one of the most studied phenomenon in forward supply chains is also growing interest from the academia to be studied in closed loop supply chains. This paper aims to compare the bullwhip effect causes and factors in forward supply chains with those for closed loop supply chains. The methodology used was a systematic literature review of the papers that were published in academic journals and conferences about bullwhip effect in closed loop supply chains. We find that the factor: increasing product return rate to mitigate or decrease the bullwhip effect was quantitatively the most representative, since this factor is fundamentally inherent of the closed loop supply chains dynamics, we have proposed that implementing the closed loop supply chains instead of the forward supply chains can reduce or even eliminating the bullwhip effect .

***Keywords**: closed loop supply chain, bullwhip effect*

1. Introduction

Forward supply chains (FWSC) involves material flow from manufacturer to the end user, reverse logistics involves reverse product flows from the final user, followed by reprocessing (through recycling, remanufacturing, refurbishing, repairing and/or reusing) the end of life products into a new useable form. If we consider forward and reverse supply chains simultaneously, the result network will construct a closed-loop supply chains (CLSC) (Govindan et al., 2015).

CLSC refers to this complete loop—from raw materials to final customers, back for the reprocessing operations, and then once again back to the customer (Quariguasi Frota Neto et al., 2010). A typical CLSC involves collection, inspection/separation, reprocessing, disposal and redistribution activities, CLSC's often differ with respect to some features and parameters such as product acquisition, returns volume, return timing and quality, test, sort, grade, reconditioning, distribution and selling. Some degree of uncertainty is likely to be associated with these critical stages (Guide & Van Wassenhove, 2002). It is widely discussed in Supply Chain Management, how the uncertainty associated with end customers' demand affects the whole supply chain, the so called bullwhip effect (BWE) (Forrester, 1961). BWE occurs when the demand variability propagates upstream in an amplified form.

There is a well established research stream on studying BWE causes and impacting factors, as well as how to mitigate it. A brief search in Scholar Google, shows approximately 20.000 results for the query "BWE in supply chains".
In spite of this consistent literature on BWE in FWSC, to our knowledge, little research has been done in investigating the BWE in CLSC.
Motivated by this fact and also by the theoretical and practical relevance of better comprehending this theme, this paper aims at contributing to the existing knowledge on BWE in CLSC.
Using a systematic literature review, as research method this article attempts to answer the following research questions: how is the bullwhip effect characterized in CLSC? Are the causes and factors that lead to BWE in FWSC are the same as those found in CLSC?
The paper is organized as follows. Section 2 presents a brief literature review about the main concepts studied here. Section 3 describes the methodological approach. Section 4 describes the results and presents its discussion. Finally, in section 5 we present our final considerations and further research directions.

2. Literature review

In this section, we discuss the basic concepts used in this research. We present the concept of closed loop supply chain and bullwhip effect.

2.1 Closed Loop Supply Chain

The scarcity of resources, problems with pollution caused by industrialized countries (and the environmental, social and economic uncertainty of recent years have led many researchers to address the issue of sustainable development from many points of view. (Schneider et al., 2010). One of the main issues in Sustainable Operations is how to reduce the consumption of finite raw materials, such as oil, water and minerals. In this sense, practices aimed to reduce environmental impact in thorough supply chains are gaining importance.
A number of processes can be added in order to improve the sustainability in supply chains, such as product design, product management during use, product life extension and recovery processes at end-of-life products. Recovery processes include reuse, testing, repairing, disassembling, refurbishing, remanufacturing, recycling and energy recovery, the reverse chain. (Linton et al., 2007). If we consider forward and reverse supply chains simultaneously, the result network will construct a CLSC (Govindan et al., 2015).
CLSC refers to this complete loop—from raw material to final customers, back for the reprocessing operations, and then once again back to the customer (Quariguasi Frota Neto et al., 2010). A typical CLSC involves collection, inspection/separation, reprocessing, disposal and redistribution activities, CLSC's often differ with respect to some features and parameters such as product acquisition, returns volume, return timing and quality, test, sort, grade, reconditioning, distribution and selling.
Quariguasi Frota Neto et al. (2010) proposed useful extensions for existing CLSC optimization models to ensure that CLSC's are at the same time sustainable supply chains, Fig. 1.

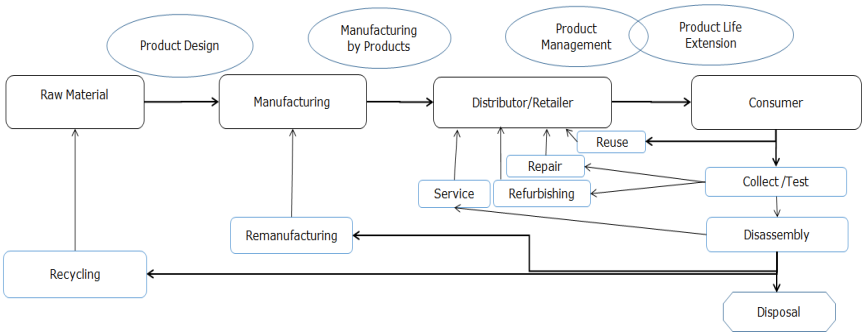

Fig. 1. Closed loop supply chain, adapted from: Quariguasi Frota Neto et al., (2010).

2.2 Bullwhip effect

The bullwhip effect is one of the most studied phenomenon in the FWSC. It means where orders to the supplier tend to have larger variance than sales to the buyer (demand distortion), and the distortion propagates upstream in an amplified form (variance amplification), (Lee et al., 1997).
The bullwhip effect phenomenon has been recognized in many diverse markets. Procter & Gamble found that the diaper orders issued by the distributors have a degree of variability that cannot be explained by consumer demand fluctuations alone. At Hewlett-Packard, the orders placed to the printer division by resellers have much bigger swings and variations than customer demands, and the orders to the company's integrated circuit division have even worse swings. Also, it is often said that the DRAM market faces a much higher volatility than the computer market (Zhou et al., 2016).
Forrester (1961) illustrates the effect in a series of case studies, and points out that it is a consequence of industrial dynamics or time varying behaviors of industrial organizations. In other words, the basic form and policies used by an organization can give rise to characteristic and undesirable behaviors in the supply chain. In an inventory management experimental context, (Sterman, 1989) reports evidence of the bullwhip effect in the "Beer Distribution Game."
Lee et al., (1997) described four main sources/causes contributing factors of the BWE in the FWSC: demand signal processing, the rationing game, order batching, and price variations. They also proposed counter measures methods to reduce the impact of the BWE (Table 1).

Table 1: The causes, contributing factors and counter measures, adapted from: Lee et al., (1997).

FWSC Causes	Contributing Factors	Counter measures
Demand Signaling	No visibility of end demand	Access sell-thru or POS data
	Multiple forecasts	single control of replenishment
	Long lead-time	Lead-time reduction
Order Batching	High Order Cost	EDI &CAO
	FTL Economics	Discount on assorted truckload, consolidation by 3rd party logistics
	Random or correlated ordering	Regular delivery appointment
Fluctuating prices	High-low pricing	EDLP - Every Day Low Price
	delivery and purchase asynchronized	Special purchase contract
Shortage Game	Proportional rationing scheme	Allocate based on past sales
	Ignorance of supply conditions	Shared capacity & supply information
	Unrestricted orders & free return policy	Flexibility limited over time; capacity reservation

3. Methodology

3.1 Research methodology

In order to answer our research questions - how is the BWE characterized in CLSC? Are the causes and factors that lead to BWE in FWSC are the same as those found in CLSC? We chose to perform a systematic literature review.
The systematic literature review is an appropriate method to achieve our objectives, since it addresses a specific question, utilizes explicit and transparent methods to perform a thorough literature search and critical appraisal of individual studies, drawing conclusions about what we currently know and do not know about a given question or topic. Systematic simply means that reviewers follow an appropriate (but not standardized or rigid) design and that they communicate what they have done. In essence, conducting systematic reviews means applying the same level of rigor to the process of reviewing literature that we would apply to any well-conducted and clearly-reported primary research (Briner & Denyer, 2012).
The rationale behind the literature reviews approach is that it allows extracting "interesting" connections, to reference between items based on a comparison of past experience – manifested through literature reviews – as means toward developing theory (Weick, 1989).
In conducting our research we followed the flowing steps, proposed by Tranfield et al., (2003), Fig. 2:

Stage I-Planning the review
Phase 0 - Identification for the need for a review
Phase 1 - Preparation of a proposal for a review
Phase 2 - Development of a review protocol
Stage II—Conducting a review
Phase 3 - Identification of research
Phase 4 - Selection of studies
Phase 5 - Study quality assessment
Phase 6 - Data extraction and monitoring progress
Phase 7 - Data synthesis
Stage III-Reporting and dissemination
Phase 8 - The report and recommendations
Phase 9 - Getting evidence into practice

Fig. 2. List of stages in conducting systematic review, adapted from: Tranfield et al., (2003).

3.2 Stage I - planning the review, was done through defining our research questions and by performing our preliminary literature review, which allowed to define our keywords and research protocols.

Our review focused on peer-reviewed English-language; document type: articles; source type: Journals and Conference/Proceedings, covering until December 2016.
We selected the keywords, with the string: "closed loop supply chain" AND "bullwhip effect".
The keywords were applied to all topics of the articles in the major databases: Scopus, Web of Science, Springer and Science Direct. The keyword search was repeatedly applied from October 24 to December 14, 2016, to research process to ensure actuality and accuracy of the search results.

3.3 Stage II - Material collection, selection of studies, study quality assessment, data extraction and synthesis

In this first phase: a total of, 291 full-text articles were identified. After that as second phase, each abstract and title article was manually reviewed by a researcher, to determine their relevance for the review. The criterion for the inclusion of articles into the sample was if the article studied bullwhip effect or the closed loop supply chain. A total of 66 articles remained. In the third phase, a full-text review of each remained article was conducted to assess if the article qualified for the final sample. As criterion for the inclusion of articles into the final sample, studying the BWE on the CLSC had to be one of the central study unit applied in the article. A total of 32 articles satisfied the mentioned criterion and thus presented the core sample of literature review. This process is summarized in Table 2.

Table 2: Material collection and selection of studies process summary.

Database name	web address	1st Phase search	2nd Phase Each abstract article was manually reviewed	3rd Phase A full-text review of the article was conducted
Scopus	https://www.scopus.com	163	42	17
Web of science	https://webofknowledge.com	31	18	12
Science Direct	https://www.sciencedirect.com	49	4	2
Springer	https://link.springer.com	48	2	1
	Total	291	66	32

We have used content analysis that is a class of methods within empirical social science that can be applied both in a quantitative and a qualitative way (Seuring & Gold, 2012).
To do the data extraction and synthesis, main analytic categories have been gotten by the technique of summarizing content to a pre-defined abstraction used for inductive category building (Seuring & Gold, 2012) to answer our research question: how is the BWE characterized in CLSC? Are the causes and factors that lead to BWE in FWSC are the same as those found in CLSC?
To do so the method of data analysis started with the category data gathering (Seuring & Gold, 2012) using the secondary objectives:
Identify the BWE causes in the FWSC;
Identify the counter measures or factors to mitigate the BWE in the FWSC;
Identify the BWE causes in the CLSC;
Identify the factors to mitigate the BWE in the CLSC;

3.4 Material evaluation

We have followed the four main steps forming the process model of (qualitative) content analysis (Seuring & Gold, 2012):
1- The material to be analyzed is delimited and the unit of analysis is defined (3.3 material collection, selection of studies and study quality assessment);
2- Formal characteristics of the material are assessed, providing the background for subsequent content analysis (4. - descriptive analysis and results);

3- Structural dimensions and related analytic categories are selected, which are to be applied to the collected material (3.3 - data synthesis and 4. Category selection 4.); and
4- The material is analyzed according to the (analytic) dimensions (3.4 - material evaluation).

The core research sample of 32 papers was coded and analyzed according to category fit, and the distribution of articles across categories, journals, year and the results are presented and discussed in the following section, aiming to highlight links between the analytic categories of factor to decrease the BWE and factor to mitigate the BWE in the CLSC as outlined in the literature.
In addition, the identification of research gaps may also be of value to drive focused supply management research. As stated above, the categories used for the coding process are theory-based and clearly defined which increases the objectivity and transparency of the research process and enhances coding reliability. Internal validity is established as the results were discussed among the authors of the study.

4. Results and discussion

The distribution of publications per year of the selected 32 articles can be seen in Fig. 3.

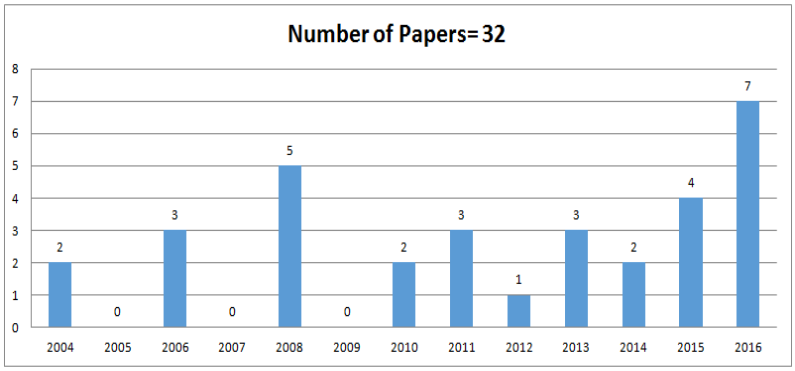

Fig. 3. Distribution of publications per year.

The distribution of publications per year and source of the selected 32 articles can be seen in Fig. 4, we can observe that from the 11 articles published in Conferences, 9 was published until 2011, and from the 21 articles published in Journals, 16 was published as of 2011 and the number of papers published by year since then have grown at least four times, so we can see the relevance of this subject.

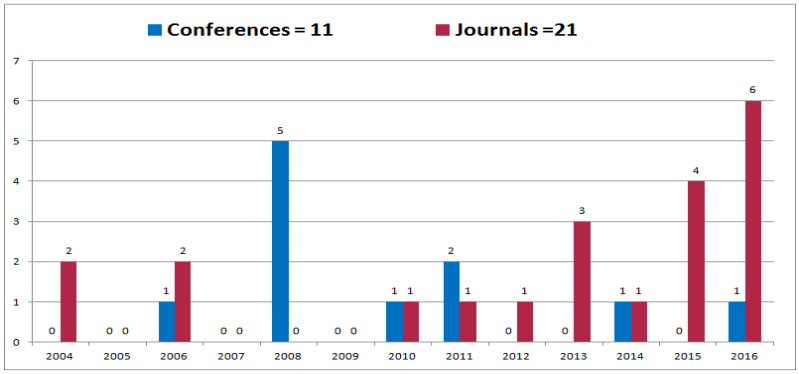

Fig. 4. Distribution of publications per year and source: conferences and journals.

The most published Conferences and Journals have focus in engineering, modeling, simulation and operational research that might be the core reason all of the 32 articles have used modeling and simulation as research methodology, as we can see in Appendix A and Table 3.

Table 3: Distribution of quantity of articles across method to study the BWE in CLSC.

Method to study the BWE in CLSC	Quantity of articles
SD system dynamics simulation	13 articles
Discrete Time and H infinity	6 articles
DES discrete event simulation	3 articles
APIOBPCS and Laplace Transform	1 article
Modeling to z-domain model	1 article
R-APIOBPCS, SD and DOE	1 article
Cider Game &Statistical Analysis	1 article
Fractal simulation	1 article
Mathematical statistic	1 article
Statistical analysis AR- Order	1 article
A state matrix model of a CLSC	1 article
APIOBPCS	1 article
APIOBPCS and SD	1 article

In order to identify the causes of BWE in FWSC and CLSC, as well to identify causes and factors to mitigate BWE in both FWSC and CLSC, we have divided the 32 selected articles, in the following three analytic categories:

Factor to Increase the BWE: the factor or cause found in the article results responsible to increase the BWE in the CLSC;
Factor to mitigate the BWE: the factor or cause found in the article results responsible to decrease the BWE in the CLSC;
Factor to Decrease the BWE: the factor or cause found in the article results responsible to decrease the BWE in the CLSC.
The results based on the systematic literature review are in the content analysis presented in Table 4, we have synthesized the factors, by grouping them, from 32 selected articles, 29 found the bullwhip can be decreased or mitigated in the CLSC due to different factors, using different methods of analysis and supply chain configuration. Only one of them (Adenso Diaz et al., 2012) has investigated the main factors affecting bullwhip in reverse supply chains using a simulator called cider game, and concluded that only the percentage of the material returned has an influence on BWE. Concerning the pattern of the evolution of BWE, an increase in the percentage of material returned reduces the odds of finding a growing BWE pattern upstream.
Regarding the causes of the BWE in the CLSC, all articles have considered the same as in the FWSC, as we can see in Table 1, section 2.2; the articles have used modeling and mathematical simulation as methodology so the BWE causes are the same.

Table 4: Distribution of articles across authors, year, journals/conferences, factor to increase, decrease or mitigate the BWE, grouping the factor and categories

Artigo	No	Authors	Year	Journal or Conference *	Article findings as factor to Increase, Decrease or Mitigate the BWE	Grouping the Factor	categories D= decrease M= Mitigate I=Increase
5	1	Zhou, et al.,	2016	IJPE	Higher return yield	Increasing product return rate	D
6	2	Cannella et al.,	2016	IJPE	Increasing product return rate	Increasing product return rate	D
10	3	He et al.,	2016	DDNS	Increasing recycling ratio	Increasing product return rate	D
11	4	Wei & Yuan,	2016	DCDIS	Improving replacement policy ratio	Increasing product return rate	D
18	5	Yuan & Zhang,	2015	DDNS	Percentage increases of recovery of recyclers	Increasing product return rate	D
23	6	Corum et al.,	2014	JOCLP	Increasing remanufacturing rates	Increasing product return rate	M
25	7	Ma et al.,	2014	Conference 2	Increasing recovery products rate	Increasing product return rate	D
28	8	Turrisi, et al.,	2013	IJPD	Collection of end-of-life products	Increasing product return rate	M
49	9	Yisheng & Dunbing,	2010	Conference 3	Higher product returns-ratio	Increasing product return rate	D
73	10	Qingli, et al.,	2008	Conference 4	Improving reuse ratio	Increasing product return rate	D
62	11	Zhou & Disney,	2006	ORSPECTRUM	Larger return rate	Increasing product return rate	D
72	12	Zhang, et al.,	2011	Conference 10	H Infinity control methods	H Infinity control methods	D
74	13	Guo,	2010	Conference 11	H Infinity control methods	H Infinity control methods	D
59	16	Guo, et al.,	2008	Conference 8	H Infinity control methods	H Infinity control methods	D
58	15	Guo, et al.,	2008	Conference 7	H Infinity control methods	H Infinity control methods	D
57	14	Guo, et al.,	2008	Conference 6	H Infinity control methods	H Infinity control methods	D
63	17	Guo & Huang,	2006	Conference 9	H Infinity control methods	H Infinity control methods	D
27	18	Jing, et al.,	2013	IJAM	PID controller	PID controller	D
67	19	Lin et al.,	2004	JPC	Proportional integral or cascade inventory control	PID controller	D
9	20	Zhang & Yuan,	2016	DDNS	Old-for-new policy and three electronic products recovery ways	Three way recovery in reverse channel	D
26	21	Das & Dutta,	2013	CIE	Three way recovery in reverse channel	Three way recovery in reverse channel	D
7	22	Barbey,	2016	Conference 5	A customers order and a stock order strategy.	A customers order and a stock order strategy.	D
14	23	Dev et al.,	2016	IJPE	Adopting periodic review policies.	Adopting periodic review policies.	M
21	24	Ignaciuk,	2015	IEEEX	Compensation mechanism with a smooth ordering pattern	Compensation mechanism with a smooth ordering pattern	M
36	25	Adenso-Diaz et al.,	2012	IJPE	percentage of the material returned	Increasing product return rate	D
42	26	Matamoros, et al.,	2011	IJPS	Shorter of lead time	Shorter of lead time	D
47	27	Pati, et al.,	2010	OPSEARCH	Degree of segregation	Degree of segregation	D
61	28	Zanoni et al.,	2006	IJPR	Remanufacturing shifted PULL policy	Remanufacturing shifted PULL policy	D
65	29	Tang & Naim,	2004	IJPR	Coupling remanufacturing within manufacturing process	Coupling remanufacturing within manufacturing process	D
20	30	Das & Dutta,	2015	IJAMT	Increasing demand variation	Increasing demand variation	I
16	31	Hosoda et al.,	2015	EJOR	with identically and independently distributed (i.i.d.)	With identically and independently distributed (i.i.d.)	I
56	32	Huang & Liu,	2008	Conference 1	short term lead time of remanufacture cycle time	Short term lead time of remanufacture cycle time	I

*Appendix A to journals and conferences name related code

From 32 selected articles, only three discussed how to increase BWE in the CLSC, with different grouping factor, using the same methods and similar supply chain configuration.
On the other hand, 29 discussed how BWE can be decreased or mitigated in the CLSC due to different grouping factors, using different supply chain configurations. The factor increasing product return rate with twelve (12) articles is the main result found, followed by the H infinity control with six(6) articles (Fig. 5).

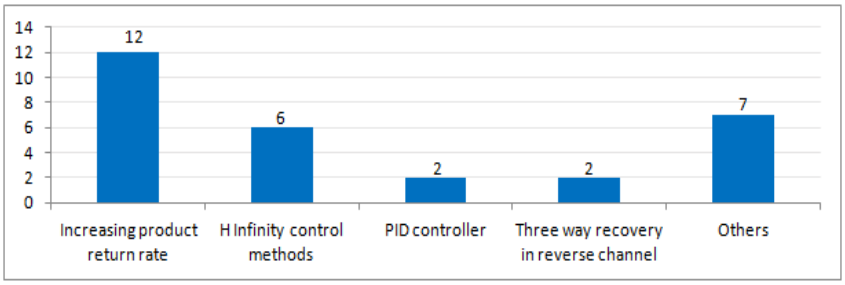

Fig. 5. Distribution of the 29 articles grouping the factor to mitigate or decrease the BWE.

Increasing product return rate was the most cited factor to mitigate or decrease the BWE, with 12 articles. Increasing the return to end of life products can reduce BWE, since the higher the return rate (or the availability of material), variability in return quantities would have less impact in the supply chain, in the same way that occurs in the FWSC.
As the main causes of the BWE are the same in both FWSC and CLSC, we can discus that Increasing product return improves the information sharing and data access reducing the demand variance and order cost, can improve the single control, can reduce the lead time, can mitigate the logistics cost by using the same truck/vehicle delivering the new product bringing back the end of life product, can improve the delivery appointment linking to the return appointment, can mitigate the fluctuating prices by a special contract linking the new product price to the cost of the returned end of life product, can improve the allocation/reservation of the production capacity, limiting the flexibility over time.
H infinity control with six(6) articles, was the second most cited factor: under the premise of the smooth production to meet the customer's demand, based on the linear matrix inequality approach, the H infinity control method is presented as a standard to furthest reduce the bullwhip effect. The essence of the method is that in the worse case the optimum strategy of the normal manufacturing

and order are made by cooperation control of node enterprises in CLSC networks to restrain bullwhip effect. As a result, it presents a new method to study the stability of CLSC networks and restrain their bullwhip effects with H infinity control cooperation, based on control theory (Guo, 2010).

5. Final considerations

This article attempted to answer the following research questions: how is the bullwhip effect characterized in CLSC? Are the causes and factors that lead to BWE in FWSC are the same as those found in CLSC?

Our results indicate that studying BWE in the CLSC is growing interest from academia. First papers were published in 2004, and since then, the number is growing. There is a large number, specially in early 2000's, from conferences, which indicates that the subject is still in its early stages. Besides that, most of the journals and conferences are from Technical Fields, with minority of works published in the area of Management, which presents an opportunity for studying this subject in this area.

Besides that, all of papers used as research method, simulation, modeling and /or quantitative approaches, which presents an opportunity to develop in depth qualitative analysis, focusing on the strategic and managerial causes for BWE and how to mitigate it, considering specific aspects of different contexts and supply chains.

In order to answer our research question and achieve our objectives, we found based on the systematic literature review presented in our study, that the 32 published selected articles have studied the BWE in the CLSC, based on the same main causes of the BWE reported in the FWSC by Lee et al., (1997).

From the 32 selected articles, 29 found the bullwhip can be decreased or mitigated in the CLSC due to different factors, using different supply chain configurations, but all those published articles were based on mathematical simulation methodology and used the same causes of the BWE in the FWSC to investigate in the CLSC.

Once all papers in our sample are based on research methodology: simulation, modeling and /or quantitative approaches, which presents an opportunity to develop future empirical researches, at the same time is our research limitation.

Academic originality/value our research found the grouping factor: increasing product return rate to mitigate or decrease the BWE with twelve (12) articles quantitatively the most representative, as the main result found. Since this factor is fundamentally inherent of the CLSC dynamics, we have proposed the CLSC dynamics can reduce the BWE.

Finally for the main practical contribution we can propose that implementing the CLSC instead of the FWSC can reduce or even eliminating the BWE.

6. Appendix A: journals and conferences name and code

Journal or Conference name	Journal or Conference Code
Computers and Industrial Engineering	CIE
4th (2008) International Conference on Wireless Communications, Networking and Mobile Computing vol 1-31 Pp: 6346-6351	Conference 1
5th(2014) International Conference on Mechanical, Industrial, and Manufacturing Technologies	Conference 2
(2010) International Conference in Engineering and Business Management	Conference 3
5th (2008) International Conference on service Systems and service management, vols 1 and 2	Conference 4
ECMS 30th (2016) European Conference on Modelling and Simulation	Conference 5
7th (2008) World Congress on Intelligent control and Automation, vols 1-23 Pp: 2206-2211 2008	Conference 6
FBIE: 92008) International Seminar on Future Biomedical Information Engineering Pp: 255-258 2008	Conference 7
ICPOM (2008) International Conference of Production and Operation Management Vols 1-3 Pp: 1299-1303 2008	Conference 8
9th (2006)International Conference on Control, Automation, Robotics and Vision, Vols 1- 5 pp. 292-296 2006	Conference 9
MSIE (2011) International Conference on Management Science and Industrial Engineering, pp. 659-663	Conference 10
Dynamics of Continuous, Discrete and Impulsive Systems Series B: Applications and Algorithms	DCDIS
Discrete Dynamics in Nature and Society	DDNS
European Journal of Operational Research	EJOR
IEEE Transactions on Systems, Man, and Cybernetics: Systems (Volume: 45, Issue: 2, Feb. 2015)	IEEEX
International Journal of Applied Mathematics	IJAM
International Journal of Advanced Manufacturing Technology	IJAMT
International Journal of Physical Distribution	IJPD
International Journal of Production Economics	IJPE
International Journal of Production Research	IJPR
International Journal of Physical Sciences	IJPS
Journal of Cleaner Production	JOCLP
Journal of Process Control	JPC
OPSEARCH	OPSEARCH

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