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An exploration investigation on measuring the impact of information technology on bullwhip effect on supply chain management

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A B S T R A C T

Information technology plays an important role on the success of different organizations. In today's competitive environment, there is a need to reduce the cost of products by increasing productivity and quality of products and services. Bullwhip effect is one of the most important issues influencing production planning reducing the efficiency of production planning by increasing unwanted materials, etc. Bullwhip effect occurs for many reasons such as lack of good demand estimation, poor communication between vendors and suppliers, etc. In this paper, we present an empirical investigation based on DEMATEL technique to find the effect of information technology on reducing the bad consequences of bullwhip effect. The study first uses systems dynamic to build a cause-and-effect relationship between different factors influencing bullwhip effect and then using fuzzy DEMATEL, the effect of information technology on bullwhip effect has been confirmed.

1. Introduction

Bullwhip is one of the most important issues, which could influence the performance of production planning, significantly (Hoffman, 2000; Kim et al., 2006). Bullwhip effects are created when supply chain members process the demand input from their immediate downstream member in generating their own forecasts (Lee et al., 1997). In supply chain management, one of the most important problems, which need significant amount of effort to deal with, is to understand how to quantify and alleviate the effect of bullwhip effect – the phenomenon in which information on demand is distorted while moving upstream (Luong, 2007). Machuca and Barajas (2004) performed an investigation to study the impact of electronic data interchange on reducing bullwhip effect and supply chain inventory costs. Miragliotta (2006) investigated different layers and mechanisms in supply chain management by introducing a new taxonomy for the bullwhip effect.

Aggelogiannaki and Sarimveis (2008) presented an adaptation method for the online identification of lead time in production–inventory control systems. In this survey, the tuning parameters are updated in real time to improve the efficiency of the system based on the lead-time estimate. Caplin (1985)

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developed a general theory of the aggregate implications of (S, s) inventory policies and explained that (S, s) policies could add to the variability of demand, with the variance of orders exceeding the variance of sales.

Supply chain management has been recognized as the management of key business processes across the network of organizations, which comprise the supply chain (Day, 1984). While many have considered the advantage of a process approach for managing the business and the supply chain, most do not good description about what processes are to be considered, what sub-processes and activities are contained in each process, and how the processes exchange information with each other and with the traditional functional silos (Lo & Chen, 2012). Croxton et al. (2001) provided strategic and operational explanation of each of the eight supply chain processes detected by members of The Global Supply Chain Forum, as well as descriptions of the interfaces among the processes and an instance of how a process approach can be applied within an organization. Chou et al. (2004) explained the trend in supply chain management by studying Web technologies that transform and streamline the supply chain management. Croom (2005) concentrated on the developments in e-business system adoption and deployment in support of supply chain management. Demeter et al. (2006) examined the connection between strategy and SCM and analyzed how the strategy of focal firms determined the supply chain (SC) configuration and management practices used between SC parties. The results supported the proposition that the connection between strategy and SCM was very strong.

Disney et al. (2004) explained that a suitable objective function was linearly associated with the bullwhip and inventory variance amplification ratios and then optimized the PIC system for various weightings of order rate and inventory level variance. They highlighted two kinds of the objective functions, one where "the golden ratio" can be applied to determine the optimal gain in the inventory and WIP feedback loop and another, which permits the complete range of possible solutions to be visualized.

Geary et al. (2006) detected 10 published causes of bullwhip, all of which are capable of elimination by re-engineering the supply chain and suggested some evidence on the present "health" of a family of supply chains, and pinpoint much good practice. Ha and Krishnan (2008) outlined a hybrid method, incorporating multiple methods into an evaluation process, in order to choose competitive suppliers in a supply chain. It enables a buyer to do single sourcing and multiple sourcing by calculating a combined supplier score (CSS), which accounts for both qualitative and quantitative factors that influence on supply chain performance. Lu and Wang (2008) analyzed the characteristic of network economy and proposed a topological structure of it. They described the interactive coefficient matrix of network economy to explain the effect of network economy.

DEMATEL was first presented at Battelle Memorial Institute of Geneva Research Center and it has been applied for various complicated problems in the world such as famine, energy, environmental protection, etc. (Fontela & Gabus, 1976).

DEMATEL is one of the well-known multi criteria decision making (MCDM) techniques and maintains the capability of converting the qualitative designs for quantitative analysis (Lee et al., 2011). The primary objective of DEMATEL is to convert the relationships among different criteria, causal dimensions from a very complex system into an understandable structural framework of that system (Dalalah et al., 2011). All criteria of a system, directly or indirectly, are mutually associated with each other in a general reciprocal system. Najmi and Makui (2010), for instance, provided hierarchical approach for measuring supply chain performance using AHP and DEMATEL methodologies. Sofiyabadi et al. (2012) presented an integrated balanced score card combined with DEMATEL technique to prioritize different alternatives for SC implementation.

In this paper, we present an empirical investigation to study the effect of information technology on reducing the bad consequences of bullwhip effect. The study uses systems dynamic to build a good cause and effect form and using fuzzy DEMATEL, the study detects important factors reducing bullwhip effect.

2. The proposed study

We first present details of the fuzzy logic needed in this paper.

2.1. Fuzzy-logic

Many organizations adopted group decisions to determine a solution, group decision means to reach an agreement through dialogue among many experts, and in this case, an acceptable decision needs to be adopted. Of course, in such decision associated with complex systems, assessment by experts or decision-makers about a qualitative criteria object will be presented, always couched in language. The theory of fuzzy collection can be implemented to measure vague concepts based on unreal (personal) judgments. Table 1 demonstrates change the vague judge to fuzzy triangle numbers.

Table 1
The correspondence of linguistic terms and values

Linguistic values	Linguistic terms
[0.75,1,1]	Very high influence(VH)
[0.5,0.75,1]	High influence(H)
[0.25,0.5,0.75]	Low influence (L)
[0,0.25,0.5]	Very low influence (VL)
[0,0,0.25]	No influence (NO)

Fuzzy triangle number can be a regular triplets of the form of (l, m, n) or 1≤m≤n . For both fuzzy triangle numbers $A_1 = \{l_1, m_1, r_1\}$ $A_1 = \{l_2, m_2, r_2\}$, the arithmetic operations are performed as follows,

$$A_1 + A_2 = (l_1 + l_2, m_1 + m_2, r_1 + r_2)$$
$$A_1 - A_2 = (l_1 - l_2, m_1 - m_2, r_1 - r_2)$$
$$A_1 \otimes A_2 = (l_1 l_2, m_1 m_2, r_1 r_2)$$
$$\lambda A_1 = (\lambda l_1, \lambda m_1, \lambda r_1), (\lambda > 0)$$

In recent years, various types of defuzzy techniques have been used (Opricovic & Tzeng, 2003). In the meantime, the especial unknown and instable environment where fuzzy numbers are applied by considering suitable defuzzy technique. This study implements changing the fuzzy data into determined values (CFCS) proposed by Opricovic and Tezeng (2003) to de-fuzzy. Based on the process of CFCS method, first, right and left values are determined with a minimum and maximum fuzzy based on the fuzzy numbers based on the group evaluating and then the final definite number are measured in the form of average weight based on membership subject.

2.2 The Fuzzy DEMATEL steps:

1.Specify evaluation factors according to expert committee's opinion and research background,

2.Determine each factor influences on whole system, according to expert's opinion. To do so, we use discussed wordy expressions in Table 2 and Fig. 1. Then, we used CFC method (Eqs. 1-9) to convert the fuzzy results into crisp values.

Table 2
The correspondence of linguistic terms and values

Linguistic values	[0.75,1,1]	[0.5,0.75,1]	[0.25,0.5,0.75]	[0,0.25,0.5]	[0,0,0.25]
Linguistic terms	Very high influence(VH)	High influence(H)	(L) Low influence	Very low influence (VL)	No influence (NO)

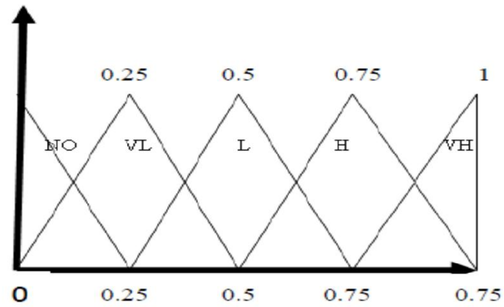

Fig. 1. Fuzzy triangle numbers

$$XL_{ij}^{k} = (L_{ij}^{k} - \underset{1 \le k \le k}{minL_{ij}^{k}})/\Delta_{min}^{max} \tag{1}$$

$$XM_{ij}^{k} = (M_{ij}^{k} - \underset{1 \le k \le k}{minL_{ij}^{k}})/\Delta_{min}^{max} \tag{2}$$

$$Xr_{ij}^{k} = (r_{ij}^{k} - \underset{1 \le k \le k}{minL_{ij}^{k}})/\Delta_{min}^{max} \tag{3}$$

$$\Delta_{min}^{max} = maxr_{ij}^{k} - minL_{ij}^{k} \tag{4}$$

$$Xls_{ij}^{k} = \frac{Xm_{ij}^{k}}{(1 + Xm_{ij}^{k} - Xl_{ij}^{k})} \tag{5}$$

$$Xrs_{ij}^{k} = \frac{Xr_{ij}^{k}}{1 + Xr_{ij}^{k} - Xm_{ij}^{k}} \tag{6}$$

$$X_{ij}^{k} = \left[Xls_{ij}^{k}\left(1 - Xls_{ij}^{k}\right) + Xrs_{ij}^{k} \,.\, Xrs_{ij}^{k}\right]/(1 + Xrs_{ij}^{k} - Xls_{ij}^{k}) \tag{7}$$

$$BNP_{ij}^{k} = minL_{ij}^{k} + X_{ij}^{k}\, \Delta_{min}^{max} \tag{8}$$

$$a_{ij} = \frac{1}{k} \sum_{k}^{1 \le k \le k} BNP_{ij}^{k} \tag{9}$$

A= $[a_{ij}]$ is direct relations matrix of experts opinions.

3. Calculate total relations matrix T- I where I is an identity matrix $n \times n$ and $T = \left[t_{ij}\right]$ representing the elements indicating the direct and indirect impacts of factor i on factor j. Now, matrix T is the indicator of general relationships between each pair factor in the system. Matrix D is the normalized matrix $D = \left[d_{ij}\right], 0 \le d_{ij} \le 1$.

$$D = \frac{1}{\underset{1 \le i \le n}{max} \sum_{j=1}^{n} a_{ij}} A \quad (10)$$

$$T = D(I - D)^{-1} \quad (11)$$

4. Calculate row summation and column summation of T matrix – i row summation is indicator of all direct and indirect effects of i factor on all other factors and so can call r_i as the impacting degree. C_j is similarly, the column summation and we can call it as influenced degree of j factor.

$$r_i = \sum_{1 \le i \le n} t_{ij} \quad (12)$$

$$C_j = \sum_{1 \le i \le n} t_{ij} \quad (13)$$

Therefore, when $i = j, r_i + C_i$ shows both the influence of which i factor can have on other factors of system and also the impacts of other factors of system on i factor. So, $r_i + C_i$ show the significant degree of i factor in whole system, and $r_i - C_i$ indeed shows the influence of i on system. If $r_i - C_i$ is positive, i factor belong to the cause group and if $r_i - C_i$ is negative, i factor belong to the effect group.

5. Demonstrate the diagram of factors influencing on $r_i - C_i$ and $r_i + C_i$ bases. This diagram is drawn by ($r_i + C_i$, $r_i - C_i$) coordinate (Huang, 2009).

3. System dynamics

System dynamics is a technique for understanding the behavior of complex systems over time and it deals with internal feedback loops and time delays, which influences the behavior the entire system. What makes using system dynamics totally different from other techniques for studying complex systems is the approach of feedback loops and stocks and flows (Forrester, 1961, 1994). Fig. 1 demonstrates a sample of different loops where the left side demonstrates Reinforcing loop and the right side shows a Balancing loop.

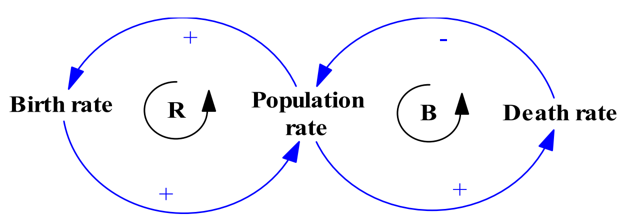

Fig. 1. Cause and effect loop

4. The proposed model

The proposed model of this paper uses systems dynamic to show the effects of various factors on supply chain management. Fig. 3 demonstrates the summary of our proposed model,

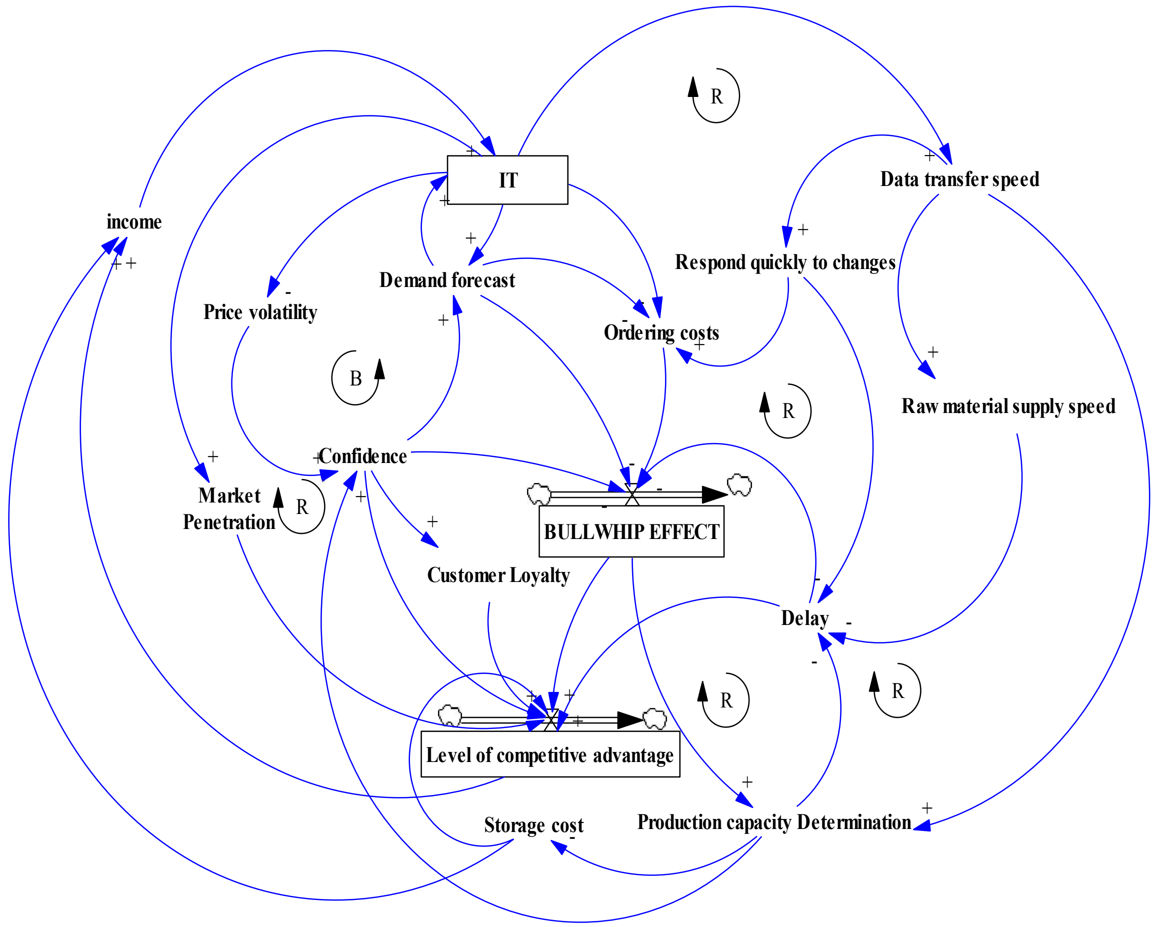

Fig. 2. The cause and effect diagram for bullwhip effect

As we can observe from Fig. 2, there are different factors influencing bullwhip effect on production planning and we need to measure the relative impact of these components. The survey indicates that as we get better information technology enhancement, we have better demand prediction, which reduces inventory expenses. The proposed study of this paper uses fuzzy DEMATEL to measure the effects of these factors. Table 1 summarizes the important factors extracted from Fig. 2.

Table 1
The summary of influencing factors on Bullwhip effect

Variable	Effective factor	Variable	Effective factors
A1	BULLWHIP EFFECT	A 9	Ordering costs
A 2	Level of competitive advantage	A 10	Demand forecast
A 3	Customer Loyalty	A 11	Price volatility
A 4	Storage cost	A 12	income
A 5	Production capacity Determination	A 13	It
A 6	Delay	A 14	Data transfer speed
A 7	Market Penetration	A 15	Respond quickly to changes
A 8	Raw material supply speed	A 16	Confidence

We first find the direct and indirect relationships among various components of the survey. Table 2 demonstrates the results of direct and indirect factors.

Table 2
The summary of direct and indirect factors

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.026	0.211	0.008	0.062	0.29	0.075	-0.012	-0.017	-0.010	0.005	-0.011	0.083	0.018	-0.007	-0.017	0.088
2	-0.005	-0.036	-0.012	-0.012	-0.004	-0.014	0.007	-0.005	0.017	0.016	0.01	0.321	0.104	0.027	-0.004	-0.005
3	-0.023	0.224	-0.030	-0.016	-0.020	-0.021	-0.008	-0.012	-0.006	-0.009	-0.010	0.067	0.015	-0.004	-0.012	-0.017
4	-0.012	0.228	-0.017	-0.031	-0.011	-0.020	0.004	-0.009	0.014	0.012	0.006	0.326	0.103	0.025	-0.008	-0.010
5	0.196	0.268	0.07	0.249	0.022	0.305	-0.014	-0.022	-0.011	0.049	-0.005	0.15	0.037	-0.004	-0.022	0.338
6	0.289	0.294	-0.011	0.005	0.071	-0.010	-0.011	-0.016	-0.008	-0.006	-0.012	0.095	0.023	-0.004	-0.016	0.012
7	-0.023	0.224	-0.015	-0.016	-0.020	-0.021	-0.022	-0.012	-0.006	-0.009	-0.010	0.067	0.015	-0.004	-0.012	-0.017
8	0.028	0.022	-0.014	-0.012	-0.007	0.152	-0.012	-0.027	-0.013	-0.015	-0.014	-0.002	-0.009	-0.012	-0.014	-0.014
9	0.153	0.009	-0.010	-0.002	0.031	-0.004	-0.012	-0.013	-0.027	-0.013	-0.014	-0.004	-0.009	-0.012	-0.014	0
10	0.311	0.062	0.006	0.007	0.075	0.017	-0.015	-0.017	-0.015	-0.017	0.153	0.016	-0.005	-0.014	-0.018	0.072
11	0.121	0.126	0.076	-0.008	0.019	0.048	-0.013	-0.016	-0.013	0.046	-0.019	0.035	0.002	-0.011	-0.016	0.336
12	0.036	0.009	-0.007	-0.005	0.032	0.002	0.043	0.009	0.073	0.078	0.057	-0.020	0.326	0.103	0.014	0.024
13	0.145	0.084	0.004	0.012	0.127	0.038	0.143	0.044	0.234	0.252	0.187	0.02	-0.025	0.315	0.061	0.097
14	0.048	0.062	0.007	0.067	0.318	0.117	-0.020	0.186	-0.020	-0.003	-0.020	0.03	-0.004	-0.032	0.236	0.093
15	0.032	0.044	0.007	0.054	0.252	0.065	-0.014	-0.016	-0.014	0	-0.013	0.023	-0.002	-0.012	-0.031	0.075
16	0.388	0.419	0.244	0.003	0.092	0.172	-0.017	-0.024	-0.014	0.159	0.012	0.135	0.031	-0.008	-0.025	0.009

In addition, Table 3 demonstrates details of our computations for the proposed study of this paper Fig. 3 presents details of our results.

Table 3
The summary R, J, R+J and R-J

	R	J	R+J	R-J
A1	0.791	1.712	2.503	-0.920
A2	0.405	2.250	2.655	-1.846
A3	0.120	0.305	0.425	-0.185
A4	0.600	0.358	0.958	0.243
A5	1.605	1.268	2.873	0.336
A6	0.695	0.901	1.596	-0.207
A7	0.120	0.026	0.145	0.094
A8	0.039	0.032	0.071	0.007
A9	0.059	0.180	0.239	-0.121
A10	0.617	0.546	1.163	0.071
A11	0.713	0.297	1.010	0.416
A12	0.773	1.340	2.113	-0.567
A13	1.739	0.622	2.360	1.117
A14	1.067	0.348	1.415	0.720
A15	0.451	0.104	0.554	0.347
A16	1.577	1.081	2.658	0.496

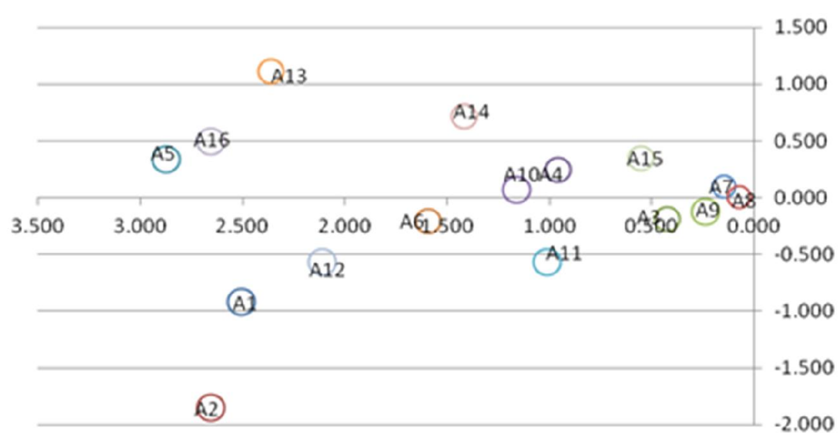

Fig. 3. The summary of the position of various factors influencing Bullwhip effect

Fig. 4 summarizes the effects of different factors on bullwhip effect based on the implementation of fuzzy DEMATEL.

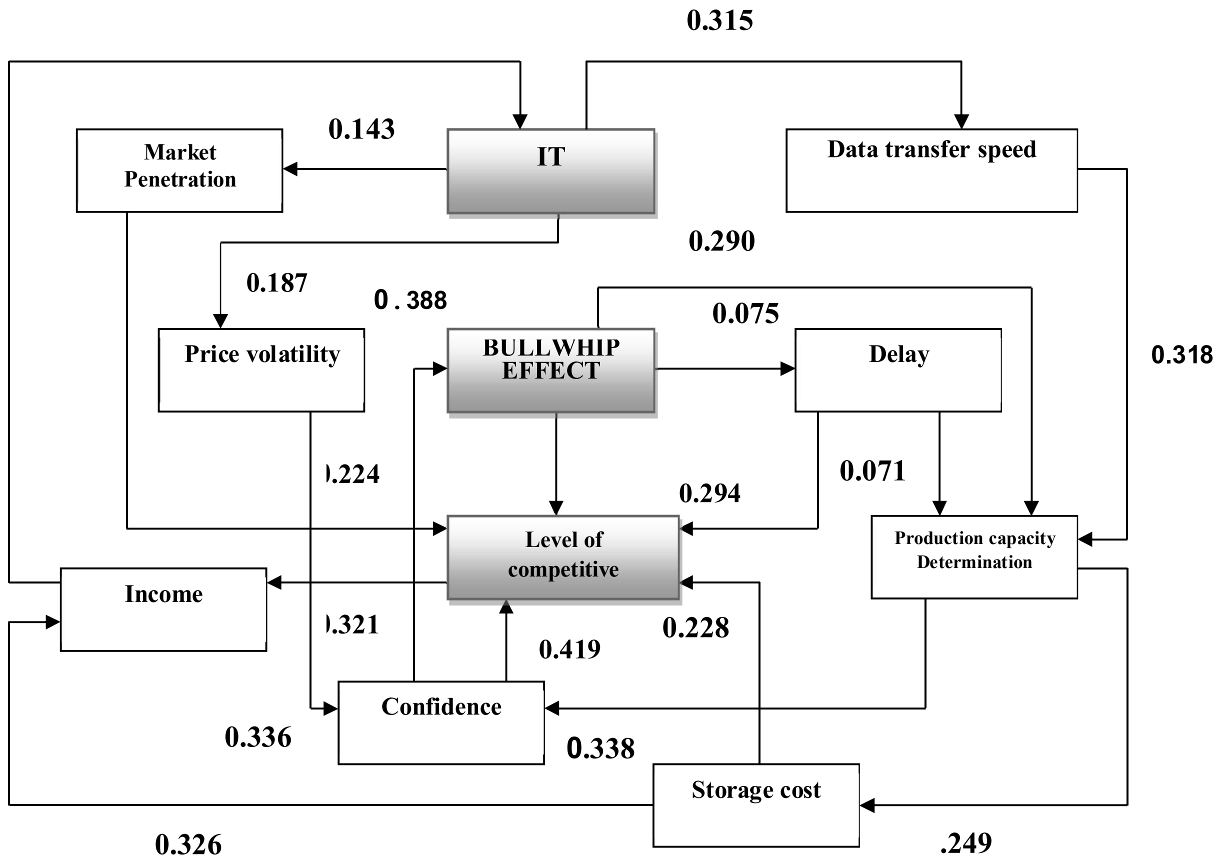

Fig. 3. The summary of the position of various factors influencing Bullwhip effect

As we can observe from the results of Fig. 3, information technology expedites data transformation on one side and it could increase market penetration on the other side. Bullwhip effect influences production capacity determination and reduces customer's confidence, significantly.

4. Conclusion

During the past three decades, there have been tremendous changes on information technology in the world and many business owners apply different features of information technology to reduce the cost of their products and services. There is a growing concern that information technology could help business owners find better access to customer's demand and plan ahead of time. This paper has presented an investigation to confirm the positive effect of information technology on reducing bullwhip effect. The results of this survey have also confirmed that any reduction on bullwhip effect could have positive impact on economy building better infrastructure to reduce inventory expenditures, increase productivity and efficiency of organizations.

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