Developing Causal Relationships for CPFR Index: a System Dynamics Simulation Approach

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***Abstract*—Collaborative planning, forecasting and replenishment (CPFR) is one of the collaborative strategies in supply chain management that aims to coordinate the diverse processes of supply chain management. Despite being identified as playing an important role in supply chain performance improvement, the dynamic interactions among its subsystems have not been explored in previous research. This research aims to identify the interactions among effective enablers and the potential impact of each enabler on successful CPFR implementation through the development of a structural model and system dynamics simulation modelling. To reach this goal, significant enablers and results reported in previous research have been explored. The causal relationships among different variables have been analysed using through the application of system dynamics and stock and flow diagrams. A dynamic CPFR model is proposed based on a number of assumptions. The resulting causal loop helps the reader to better understand and learn the dynamic interactions of CPFR subsystems.**

***Index Terms*—CPFR implementation, implementation enablers, interpretive structural modelling, system dynamics**

I. Introduction

CPFR has been identified by [1] as "a collection of new business practices that leverage the Internet and EDI in order to radically reduce inventories and expenses while improving customer service". The Europe Efficient Consumer Response (ECR) defines CPFR as a cross-industry initiative which has been designed to improve the supplier/ manufacturer/ retailer relationship through co-managed planning processes and shared information. As provided in the guidance of CPFR by VICS, its nine-step approach has resulted in inventory reduction, lost sales decrease, service level improvements, reductions in the bullwhip effect, and a stronger relationship between trading partners, etc. [2]-[4]. Although past research on CPFR implementation have shown promising results based on both long term and short term objectives, firms face several intra-organizational and inter-organizational challenges to its successful implementation [5].

Although a more comprehensive understanding of CPFR implementation enablers and inhibitors could be useful for addressing implementation challenges, there is a narrow body of literature in this area. A need to study the relationships among the enablers and inhibitors of implementing CPFR is the motivation of this study. The current research, aims to further narrow this literature gap by exploring the interrelationships between the main enablers which positively affect CPFR implementation.

In the current research, the significant enablers and results of CPFR implementation are selected for further investigation by utilising the system dynamics. Based on the results of previous research, five of the most important enablers and five of the important results are selected to develop a dynamic model in this study [6], [7]. The proposed model is based on a logical assumption that, CPFR implementation will be improved by improving its enablers. To better recognize the effects of dominant CPFR enablers on its implementation rate, a new index is termed the "CPFR performance index". Thus, the research proposes a dynamic model for the evaluation of the CPFR performance index based on 'Enables' and 'Results', as formulated using a system dynamics approach.

II. Literature Review

A. Background of Problem

CPFR implementation has been studied by a number of researchers [8]-[13]. A portion of these researches have studied the main areas of CPFR implementation consisting of: 1- Enablers 2- Inhibitors and 3- Results of implementing CPFR. "Reference [9]" stated that although companies who adopted CPFR have reported positive and encouraging results, its implementation rate has been slower than expected. An apparent reason behind this is the lack of understanding of CPFR implementation enablers and inhibitors. In other words, to adopt successful collaboration schemes such as CPFR, firms need to identify critical enablers and inhibitors while also acknowledging that these factors may vary due to the

Manuscript received June 11, 2014; revised August 26, 2014.

doi: 10.12720/joams.4.1.1-8

differences of industries and characteristics of the supply chain. Past researchers have identified a number of critical enablers and inhibitors to implementation of CPFR [14, 10, 13, 15, 16, 5, 17] however studies to understand the relationship among identified enablers and inhibitors in different industries is still in its infancy.

Research to identify CPFR implementation barriers has been conducted by [8]. They reviewed the literature on the subject and presented several inhibitors and enablers in implementation such as, no shared targets; lack of demand variability; lack of budget for software; lack of partner trust; difficulties to benefit calculation; executive support obstacles; lack of real time coordination of information exchange; lack of promotion; no adequate information technology and expertise. More recently, [17] identified the most significant and dominant barriers and their interactions in CPFR implementation. The results of their study indicate that managerial barriers are the significant root cause of the process and cultural barriers for implementing CPFR.

In the topic of identifying CPFR implementation enablers and results, research has been conducted to comprehensively review relevant literature [5]. According to the results of this study, some enablers have been addressed by several papers which show their important role. Two examples from this area are 'high level of trust' and 'senior management support' [18, 8, 19, 14, 20, 21, 22, 23, 24, 15, 25, 26]. This paper also identified the most important results reported as an outcome of CPFR implementation in previous research which included: Improvement of forecasting accuracy- [9]; Enhance customer service quality- [16] and [27]; and improved inventory management- [4].

B. Application of Interpretive Structural Modelling and System Dynamics

ISM is one of the interactive management methods which was first introduced by [28] in 1974 and developed further by [29] in 1977 to identify the complex relationship among specific variables. According to [29] the process of ISM can transform unclear models of systems into clear and visible models.

In recent years, ISM has widely been used to study the identification of enablers and barriers in different fields. This illustrates its abilities to identify and analyse the internal relationships among different factors of a system. "Reference [30]" applied ISM methodology for understanding relationships among the obstacles that significantly affect the IT-enablement of a large supply chain such as Auto industries. "Reference [31]" using interpretive structural modelling conducted research to present a hierarchy-based model and the mutual relationships among the enablers of risk mitigation. "Reference [32]" investigated the interactions among the significant barriers which prevent the practice of energy saving in China using ISM methodology. "Reference [33]" applied the ISM methodology to model information technology enablers and to investigate the issues of information technology implementation in Indian manufacturing small- and medium-scale enterprise (SMEs). "Reference [17]" applied ISM to analyse the interaction among the major barriers, which prevent successful implementation of collaborative planning, forecasting and replenishment (CPFR) in high-tech industries.

According to the reviewed papers, ISM is an appropriate methodology applied to explore and analyse the relationship between different variables and has also been used to identify the interacting position of variables. As pointed out earlier, one of the most widely applications of ISM is analysing the causal relationships of adopting enablers of different initiatives.

System dynamics initially referred to as "Industrial Dynamics" is an approach to understand how complex systems change over time, and was developed by Jay Forrester at MIT in the early 1960s. "Reference [34]" defines "Industrial Dynamics" as "*... the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy".* On the applications of industrial dynamics, [35] remarked "… *Industrial dynamics does not apply to problems that lack systematic interrelationship. It does not apply to areas where the past does not influence the future. It does not apply to situations where changes through time are not of interest*". It deals with internal feedback loops and time delays that affect the behaviour of the entire system. System dynamics is based on the logical assumption that, each dynamic system has a certain internal structure and is affected by external factors. The system dynamics approach has therefore been used in this research for driving better insights into the dynamic interactions of CPFR sub-systems.

III. Contextual Relationship among CPFR Variables

In this paper, the various enablers of CPFR implementation and their relationships are adapted from a previous study [6]. Tables I and II show the identified enablers for CPFR implementation and their explored interactions by applying ISM method, respectively.

The ISM methodology aims to develop the complex causal relationships amongst the elements and emphasizes perceptions and views of experts by applying different management techniques such as idea writing, brainstorming and the nominal technique.

For analysing the enablers in developing the Structural Self Interaction Matrix (SSIM), the following four symbols have been used to denote the direction of the relationship between enablers i and j:

V: Enabler i will ameliorate Enabler j; A: Enabler j will ameliorate Enabler i; X: Enabler i and j will ameliorate each other; and O: Enablers i and j are unrelated.

TABLE I. STRUCTURAL SELF-INTERACTION MATRIX (SSIM)

Enablers	Notation	10	9	8	7	6	5	4	3	2
Information readiness	INR	A	A	O	X	A	A	A	A	A
Developing IT infrastructure	DIT	A	A	V	X	A	A	A	X	
Information security	INS	A	A	V	V	A	A	A		
Mutually agreed objectives	MAO	A	A	V	V	A	A			
Competition pressure	COP	V	V	V	V	V				
Clear communication plan	CCP	X	X	V	V					
High level of trust	HLT	A	A	X						
Information accuracy	INA	A	A							
Senior management support	SMS	X								
Willingness to collaborate	WTC									

IV. SYSTEM DYNAMICS MODEL FOR CPFR IMPLEMENTATION INDEX

A. Causal Loop Diagrams

To conceptualise a real world system, the system dynamics approach focuses on the structure and behaviour of the system over time. To do so, SD uses a tool called "causal loop diagram" which includes multiple feedback loops. All the significant relationships captured by the final reachability matrix (Table II) were used in developing the causal system dynamics model ("Fig. 1,"). The five dominant enablers consist of "competition pressure", "senior management support", "clear communication plan", "willingness to collaborate", and "mutual agreed objective". Five of the main results of CPFR implementation are selected for further examination in this paper. These five results include "improvement of forecasting accuracy", "service level improvement", "product availability assurance", "reduce the production and inventory costs" and "reduced overall costs". The CPFR model then consists of ten elements grouped under five "enablers" and five "results". The causal loop diagram shown in the "Fig. 1," consists of all the main elements and their sub-elements which explain the relationships among the Enablers, Results and CPFR index. This figure shows in detail a positive or negative influence of one factor to another. This figure clearly reveals the positive interaction among the CPFR performance index, its enablers and the results. These elements are: Enablers Score; Results Score; CPFR Index; Desired Results Score; Desired CPFR index; Gap of CPFR index; Gap of CPFR results. This model is developed based on the following assumptions:

- At any point in time (t), the CPFR index representing the sum of its implementation enablers and results and will be improved by improving these two subsystems. (See "Fig. 3,")
- When as a result of an improvement in the Enablers and/or Results, the CPFR Index Score increases, the Gap of CPFR Index decreases resulting in a negative interaction. (See "Fig. 2,")
- The Gap of CPFR index is equal to the difference between the Desired CPFR Index Score and CPFR Index at any time (t).
- The Gap of Goals at time (t) is equal to the difference between the Desired Results Score (DRS) and Results Score at any point of time (t).
- The Desired Results Score (DRS) is the ultimate score that each and every organisation desires to achieve by implementing CPFR.
- The Desired CPFR index contains five values to show the different maturity levels. These five values are 200, 400, 600, 800, and 1000. For example, if the CPFR index score at a point of time (t) is equal to 150, the firm is at its first CPFR implementation level. The Desired CPFR Index for the first level and at this point of time is 200 points which is the maximum point for this level.

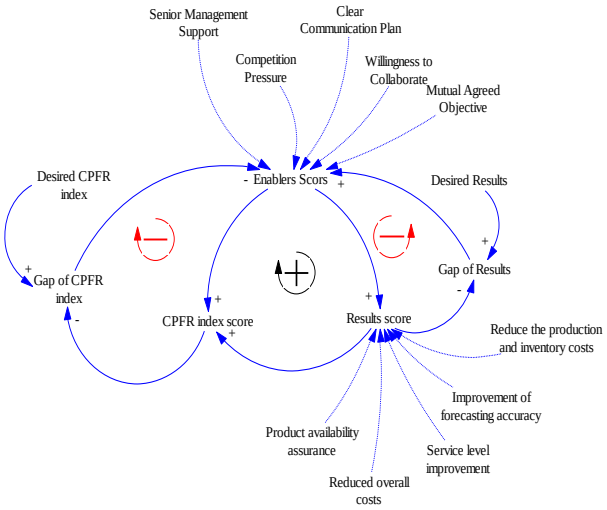


Figure 1. A causal loop diagram of the CPFR index

TABLE II. FINAL REACHABILITY MATRIX

Enablers	1	2	3	4	5	6	7	8	9	10	Driving power	Ranks
INR	1	0	0	0	0	0	1	0	0	0	2	6
DIT	1	1	1	0	0	0	1	1	0	0	5	4
INS	1	1	1	0	0	0	1	1	0	0	5	4
MAO	1	1	1	1	0	0	1	1	0	0	6	3
COP	1	1	1	1	1	1	1	1	1	1	10	1
CCP	1	1	1	1	0	1	1	1	1	1	9	2
HLT	1	0	0	0	0	0	1	1	0	0	3	5
INA	0	0	0	0	0	0	1	1	0	0	2	6
SMS	1	1	1	1	0	1	1	1	1	1	9	2
WTC	1	1	1	1	0	1	1	1	1	1	9	2
Dependence	9	8	7	5	1	4	10	9	4	4	60	
Ranks	2	3	4	5	7	6	1	2	6	6		

B. CPFR Index

The CPFR index is equal to the sum of the scores of the CPFR different performance enablers and CPFR performance goals (results) as shown in "Fig. 2," and "Equation (1)," Here, the CPFR index is assumed as a system with an input (enabler) which improves the performance of the system and an output which is the expected result of this system. Five enablers are identified consisting of "competition pressure", "senior management support", "clear communication plan", "willingness to collaborate", and "mutual agreed objective" "Equation (2),". The significant results are identified as "improvement of forecasting accuracy", "service level improvement", "product availability assurance", "reduce the productive inventory costs" and "reduced overall costs" "Equation (3),". For illustration purpose, some of the system dynamics equations are represented below. In Equation (4), 'K' is a constant value when the initial scores of the enabler are assumed zero. This 'K' reveals that the initial value of the results is not zero and before implementing CPFR, companies have a minimum value of the results. For instance a firm's initial value of "product availability" level is not zero when starting CPFR with partners which is logical and convenient.

$$CPFR_{index} = \sum_{i=1}^{n} ENB_i \oplus \sum_{j=1}^{m} RES_j \quad (1)$$

where:

$$\sum_{i=1}^{n} ENB_i = COP_t \oplus SMS_t \oplus CCP_t \oplus WTC_t \oplus MAO_t \quad (2)$$

$$\sum_{j=1}^{n} RES_j = IFA_t \oplus SLI_t \oplus PAA_t \oplus PIC_t \oplus ROC_t \quad (3)$$

$$\sum_{j=1}^{n} RES_j = K \oplus (Coef \otimes \sum_{j=1}^{n} ENB) \quad (4)$$

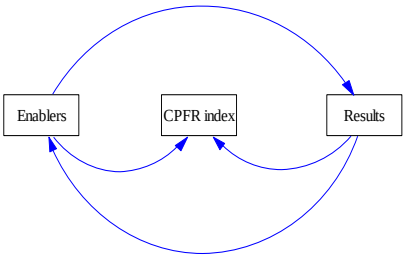


Figure 2. CPFR INDEX

C. Stock and Flow Map

A Stock and Flow diagram is used to quantify different variables and their effects on each other. Stock and Flow diagram for the CPFR model ("Fig. 3,") is generated from the final casual loop of the CPFR index with the help of Vensim (PLE) software. The interrelationships among level variable, rate variables, decision factors and decision points are defined. The system dynamic equations have been generated in the model to represent the dynamics of the systems, encapsulating the rate of changes with complex interactions. This figure can be used for quantitative analysis of the interactions of the CPFR enablers, results (goals) and CPFR index over the time, with the help of simulation tools.

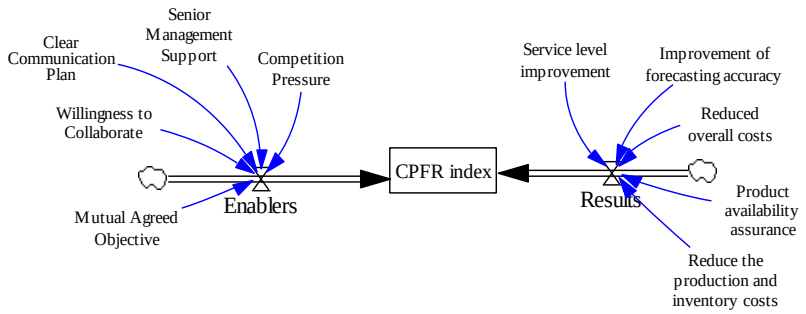


Figure 3. Stock and flow diagram

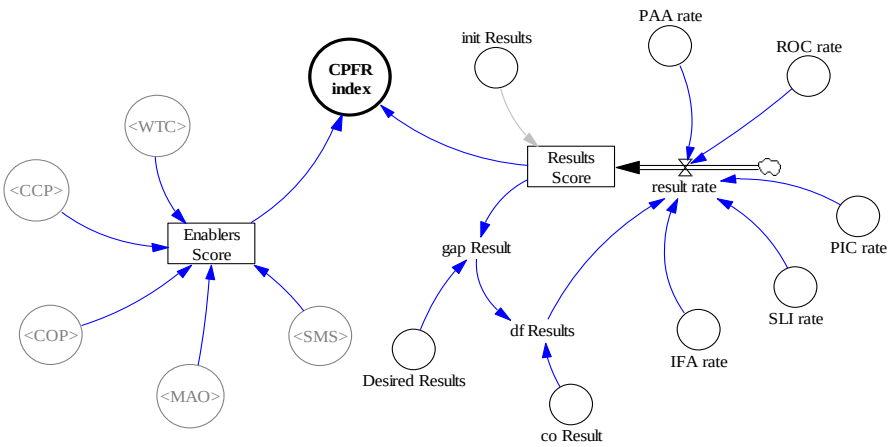


Figure 4. CPFR index-summery model

D. The CPFR Dynamic Model

From the final reachability matrix and CPFR causal loop diagram, it is assumed that "competition pressure" drives all the other enablers and this enhances the CPFR index. In other words, a high "competition pressure" drives "senior management support", "clear communication plan", "willingness to collaborate" and "mutual agreed objective", resulting an increase in the CPFR implementation index as it is shown in the final model (Fig. 4). The CPFR dynamic model is generated to provide a better understanding of the interrelationships among enablers and the CPFR implementation goals. For the variables identified in this research, the model developed depicts that to successfully implement CPFR, competitive pressure is an imperative that would help to develop other factors.

V. Simulation Results

In this study the Vensim (PLE) software has been utilized to simulate the CPFR dynamic model. Vensim can provide a simple and flexible way for building simulation models. The CPFR system dynamics is simulated using hypothetical data to investigate the changes in the enablers, results and CPFR index. In the base run simulation, the initial values of the five enablers were assumed to be zero. The simulation time interval was set at 1 week and simulation period time as 100 weeks. "Fig. 5," shows the relationship between the enablers, results and the CPFR index. Table III illustrates the results of analysing against three different time horizons consisting of a short-term, midterm and long-term.

TABLE III. The Results of Analyzing against Three Time Horizon

Variables	Short-term (1-30 Weeks)	Mid-term (30-60 Weeks)	Long-term (60-100 Weeks)
Enablers	355	508	553
Results	391	399.813	400
CPFR Index	746	908	953

The trend charts for enablers, result and the CPFR index variables are shown in the "Fig. 6,"and "Fig. 7," and "Fig. 8," and "Fig. 9," compares the trend of each enabler.

From the results, as the five enablers' values increased, the result scores and the CPFR index increased. The simulation continued until the enablers and results scores reached their maximum values of 600 and 400 respectably and the CPFR index then reached the desired CPFR index (1000 points). As shown in "Fig. 5" to "Fig. 9", the enablers increased significantly in the first 30 weeks and thus the CPFR index increased at a fast rate. In other words, the rates of increase for enablers, results and the CPFR index are highest in the short-term period. From week 30, the model stabilizes and a relatively slow growth occurs in the CPFR index between weeks 30 and 60. It also can be seen that, highest result scores will be achieved at the earliest phases of CPFR implementation up to week 30 (391 of the 400 possible results).

Simulation results of the enablers, results and CPFR index are shown as a monthly base in Table IV. As it is shown, it takes nine months for the company to progress from the first to the fifth CPFR maturity level. Table IV also shows that the company will achieve a CPFR score of 1000 after month 25. From the simulation results, it seems that reaching the final maturity level (desired CPFR index) is a very challenging task.

TABLE IV. Simulation Results of the Enablers, Results and CPFR Index

Month	Enablers Value	Results Score	CPFR index	CPFR Maturity level
1	7.37	160.1	167.5	1th
2	35.5	256.1	291.7	2th
3	84.2	313.7	398	2th
4	147.9	348.2	496.2	3th
5	216	368.9	584.9	3th
6	279	381.3	660.6	4th
7	332	388.8	720.8	4th
8	374.7	393.3	768	4th
9	408.5	395.9	804.5	5th
10	435.3	397.5	832.9	5th
12	456.6	398.5	855.1	5th
13	473.7	399.1	872.8	5th
14	498.9	399.6	898.6	5th
15	508.3	399.8	908.2	5th
16	516.3	399.88	916.2	5th
17	523	399.93	922.9	5th
18	528.7	399.96	928.7	5th
19	533.7	399.97	933.6	5th
20	538	399.98	938	5th
21	541.7	399.991	941.7	5th
22	545.1	399.995	945.1	5th
23	548.1	399.997	948.1	5th
24	550.7	399.998	950.7	5th
25	552.5	399.999	952.5	5th

By reviewing the increasing rate of the five enablers' scores at the early stage of the simulation, it is apparent that 'competition pressure' was the strongest and 'senior management support' was the weakest enabler in boosting the CPFR index. For more clarification, at the end of week 30, when the rates of increase for enablers, results and the CPFR index are highest, the 'competition pressure' score was 118.6 out of 150 scores and 'senior management support' rate was 65.4 out of 130 representing 79 % and 50.3% of the maximum possible rate, respectively. Therefore, to boost the enablers' scores, and achieve the highest CPFR index in the early stages, a company should concentrate on improving its 'senior management support' (SMS). The results are shown in "Fig. 10," With an assumed 10% extra SMS Enabler is added to the model. As "Fig. 10," shows, after the SMS takes extra action increase 10%, first, the SMS score increases. Then, it increases the Enablers score follows by effecting to other enablers. Finally, it affects on CPFR index.

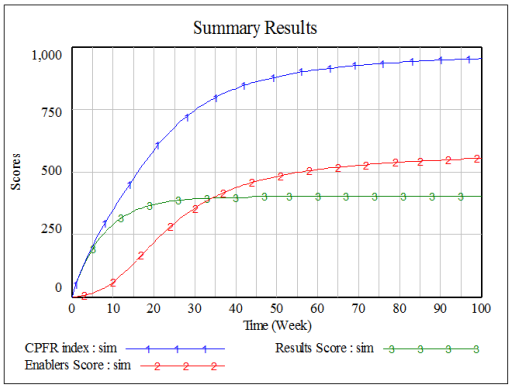
From "Fig. 6," (enablers score), after week 60, it was difficult for the company to increase the enablers' scores. Therefore, extra efforts are needed to improve CPFR implementation. In other words, reaching a perfect CPFR implementation is a challenging task for firms. As it is shown in Table IV, it takes nine months for an organization to reach the early stages of the fifth maturity

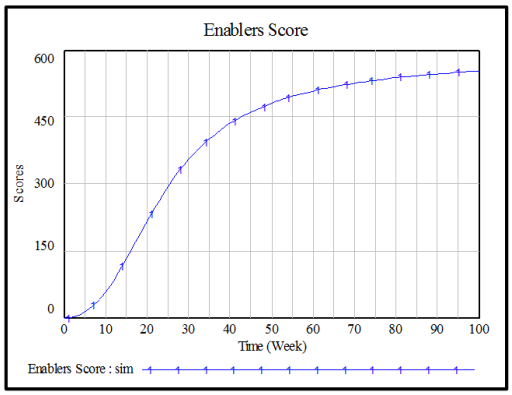
level and with a CPFR index of 804.5 at the end of month 9 (See Table IV). Moreover, the example simulation scenario of three different competition pressures shows the usefulness of the model, which can be used to analyse the result quickly and clearly understanding the situation.

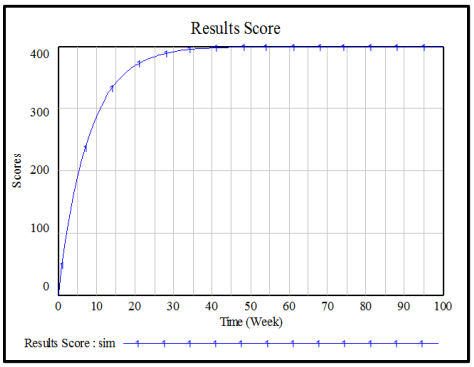
"Fig. 11" and Table V show the comparison of three competition pressure scenarios. The high competition pressure scenario (H_COP) resulted in most rapid CPFR index increases in the early phases, but not much difference in the result with the medium competition pressure scenario (M_COP) at the end of the simulation period. Finally, the low competition pressure scenario (L_COP) slowed down the CPFR index.

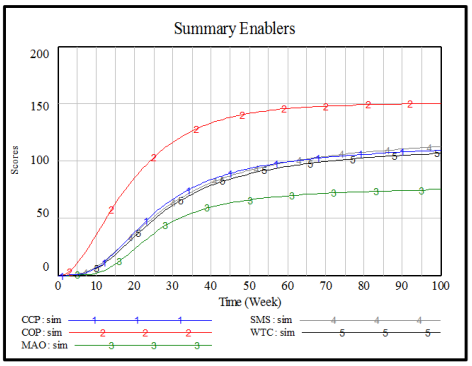
VI. Discussion and Conclusions

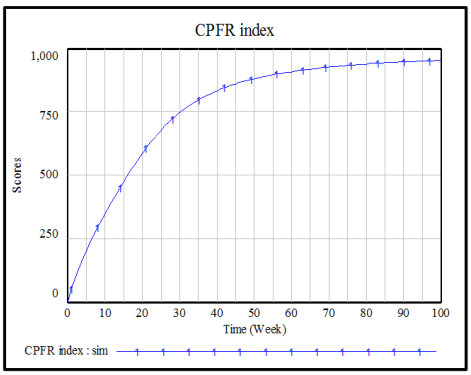
The main objective of this study was twofold: (1) to investigate the interactions and causal relationships among the five enablers and results of the CPFR implementation; and (2) to propose a system dynamics model to understand the potential impact of each enabler on successful implementation of CPFR. Based on the results of a previous study, five of the most important enablers of CPFR implementation are selected to further study in this research. Based on the system dynamic approach, this paper developed casual relationships among the different CPFR sub-systems. A system dynamics model ("Fig. 6,") was developed to examine identified interactions among CPFR index factors. This model will be extended in the future studies to include an in depth analysis of the system behaviour of the CPFR index sub-systems.











Figures 5-9. The simulation results

The CPFR implementation enablers and results identified in this research can serve as a roadmap to CPFR implementation. The enablers help both managers and policy makers when they are faced with limited resources. The system dynamics model can also help firms to continuously monitor their CPFR performance and take suitable policy decisions arising from the dynamic nature of the system to improve its performance.

The results from the base run revealed that a strategic enabler like 'competition pressure' implies a higher driving power. In other words, the management should place high priority in the allocation of resources for these dominant enablers which have a high-driving power and thus possessing the capability to significantly influence other enablers.

The results of this study clearly show that when the rate of increase for enablers, results and the CPFR index are highest, the 'competition pressure' score was 118.6 out of 150 scores and the 'senior management support' rate was 65.4 out of 130 representing 79 % and 50.3% of the maximum possible rate, respectively. Therefore, to boost the enablers' scores, and achieve the highest CPFR index in the early stages, a company should concentrate

the majority of its efforts on improving its 'senior management support'. Companies should primarily focus on enhancing the 'senior management support to successfully progress through to higher maturity levels in the future. It is assumed that higher "competition pressure" as an external enabler in markets and effective "senior management support" modulates CPFR implementation and thus enhances the CPFR index. The results also show that 'competition pressure' was the strongest and 'senior management support' was the weakest enabler in boosting the CPFR index. Therefore, to boost the enablers' scores, and achieve the highest CPFR index in the early stages, a company should concentrate on improving its 'senior management support'.

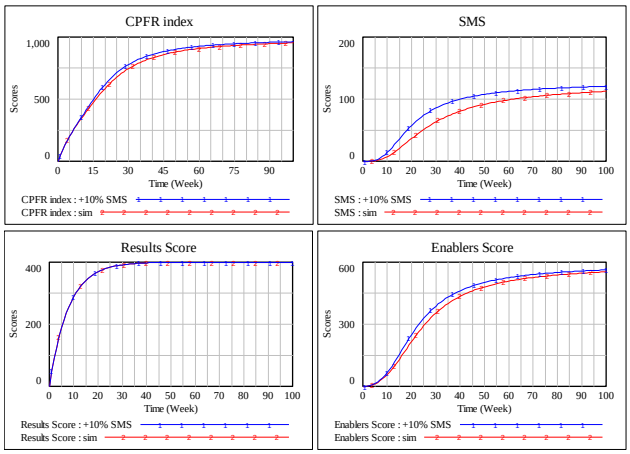


Figure 10. The simulation results with 10% extra SMS

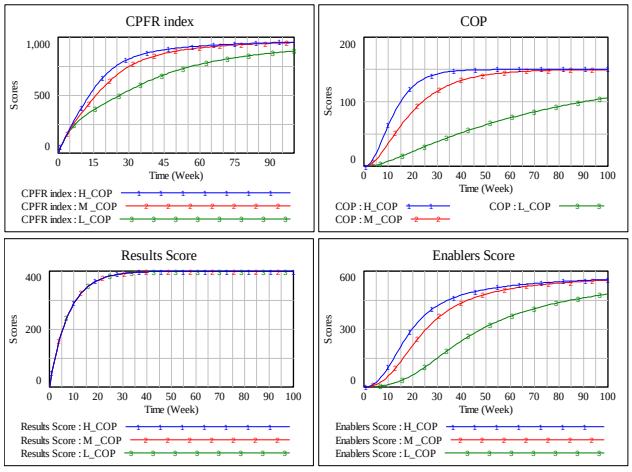


Figure 11. The simulation results with three competition pressure scenarios

A major contribution of this research lies in imposing direction to various enablers of CPFR implementation, which helps focus decision makers on the more important enablers.

Finally, the development of the CPFR index model, which help to understand the relationship with the group of CPFR enablers and CPFR results. This is a success of the first step of the development CPFR index model by applying system dynamics theory and modelling and Vensim Software, which focussing on the relationship of variable in CPFR enablers such as, competition pressure (COP), Senior Management Support (SMS), etc. Further development will be integrated all parameters of CPFR enablers and CPFR results into the detail of interrelationship.

TABLE V. RESULTS OF THREE DIFFERENT COMPETITION PRESSURE LEVEL

Time (Week)	CPFR index		
	H_COP	M _COP	L_COP
4	174.69	167.50	161.61
8	322.64	291.71	263.66
12	458.65	398.01	332.91
16	578.21	496.20	385.80
20	673.19	585.06	431.92
24	743.02	660.40	475.97
28	792.78	720.88	519.25
32	828.30	768.06	561.14
36	854.14	804.56	600.55
40	873.43	832.92	636.66
44	888.23	855.17	669.12
48	899.89	872.84	697.99
52	909.30	887.06	723.52
56	917.06	898.64	746.07
60	923.57	908.21	766.02
64	929.11	916.20	783.71
68	933.90	922.95	799.45
72	938.08	928.72	813.52
76	941.75	933.68	826.14
80	945.02	938.00	837.51
84	947.94	941.79	847.79
88	950.57	945.13	857.13
92	952.94	948.11	865.63
96	955.10	950.77	873.41
100	957.07	953.17	880.53

ACKNOWLEDGEMENT

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.

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