Investigation Through System Dynamics for the Benefits of ICT Intervention in Distribution

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Abstract

The objective of the paper was to investigate through Systems Dynamics (SD) methodology, the impact and benefits of information and communication technology (ICT) tools' intervention in the supply chain process of distribution. Accessing information in a timely and actionable manner as also negotiating and managing relationships within and between organizations in the supply chain has become a source of competitive advantage for businesses. ICT deployments and interventions across the supply chain have become a performance enabler and determinant of competitive advantage for many corporations. These improve supply chain visibility, collaboration, coordination and integration, and thereby dramatically improve the supply chain performance. One process in supply chain management, namely distribution, was described using SD. Introduction of a parameter, ICT capability dramatically changed the status quo and gave rise to new positive balancing or reinforcing loops. This parameter was measured in terms of an index, ICT capability index, which depends on knowledge, social, and economic dimensions.

Keywords : system dynamics, causal loop diagram, distribution, information and communication technology, supply chain management

JEL Classification : C61, C63, D24

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Enterprises are constantly facing volatility in the business environment due to competition, pricing pressures, e-commerce, and globalization. Accessing information in a timely and actionable manner as also negotiating and managing relationships within and between organizations in the supply chain has become a source of competitive advantage for businesses. ICT deployments and interventions across the supply chain have become a performance enabler and determinant of competitive advantage for many corporations. These provide timely information, improve supply chain visibility, collaboration, coordination, and integration and thereby dramatically improve the supply chain performance. This is not only within the enterprise intranet but also within the enterprise extranet consisting of various stakeholders such as shippers and suppliers.

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Benefits of Information and Communication Technology (ICT) Interventions in Supply Chain Management (SCM) Processes

ICT interventions in SCM processes bring about a transition from physical linkage between processes such as inventory, transportation, or storage to information-based processes. ICT deployment brings seamless access and transparency of information, which results in supply chain process integration and visibility. Collaboration and coordination among various stakeholders also improve, this results in better operational efficiency, competitive advantage, and performance.

ICT deployment facilitates better agility, coordination, collaboration, dialogue, engagement, decision-making, integration, and collaboration between various processes and actors in the supply chain (Auramo, Kauremaa, & Tanskanen, 2005). Seamless access, visibility, and transparency of information improves supply chain integration. Deployment of ICT for various processes can bring about spectacular improvements in efficiency. Auto-ID technologies such as bar coding and RFID have brought about better and effective inventory visibility and management ; automated shipping systems have optimized routes for transporters ; web-enabled services have brought about better collaboration and dialogue among supply chain stakeholders (Nair, 2014).

Cisco reported savings of U.S. $500 million using web-services for its supply-chain integration. Major suppliers of Wal-Mart such as Proctor & Gamble (P&G) have direct access to Point of Sale (POS) information from Wal-Mart retail outlets (Anderson, Britt, & Favre, 1997). By migrating placing of orders to an online application, Intel could eliminate hundreds of order clerk positions (Schramm, Nogueira, & Jones, 2011). Celestica, one of the world's largest electronic manufacturing services companies, has applied a web-based ICT tool to manage its network of suppliers across the globe. Thereby, the company could improve its customer-responsiveness, primarily helping its customer, Dell to maintain its delivery promise to end-users(Shore, 2001).

Other advantages include cost savings, customer-connect, innovation, and differentiation of products or services (Barros, Ishikiriyama, Cordeiro, & Peres, 2015). Many of the buzz words in SCM such as vendor managed inventory, collaborative planning, forecasting and replenishment, and ERP have ICT as the backbone. The next wave in enterprise computing is expected to be applications and systems based on the social mobile analytics cloud (SMAC) stack. In this stack, these ICT tools, each of whom are used in various supply chain processes, intersect together and deliver a force-multipier effect for the enterprise (Nair, & Anbuudayasankar, 2016). With the recent trend of proliferation of bring your own device (BYOD), mobile and cloud technologies can seamlessly integrate these heterogeneous legacy applications and systems resident among various stakeholders in the supply chain. Social media can facilitate instant and seamless, real-time communication and collaboration. Business analytics can be used to mine the enterprise big data available through several channels. Mobile transactions using platforms like PayPal and cashless payments through smart phones render easy transactions.

In spite of the wide-ranging benefits of ICT deployment in SCM, there are adoption issues for enterprises such as legacy applications, lack of capabilities for their suppliers to upgrade their ICT infrastructure, resistance to change, people management, and disconnected enterprises(Nair, 2014).

System Dynamics (SD)

System Dynamics (SD) is an inter-disciplinary methodology based on systems thinking, non-linear dynamics, and feedback loops to study structure, performance, and behavior of complex and dynamic systems. SD origins are from Industrial Dynamics research at MIT in 1956 led by Professor Jay Wright Forrester. System Dynamics uses techniques and conceptual tools like causal loop diagrams (CLD) and stock flow diagrams (SFD) for modeling and simulations. These simulations and models help us to understand various abstractions and views also the behavioral patterns with respect to the interaction of variables and attributes of the system (Sterman, 2000). The basic premise is that systems tend to be dynamic and unpredictable due to its building blocks and structure as also causal relationships between these blocks or attributes.

System Dynamics throws light on the exchanges between the flows of information, cash, orders, supplies, staff, and equipment in any enterprise or country (Forrester, 1961). SD has made inroads into various disciplines like corporate governance, management, strategy, policy, economics, healthcare, communication systems, social and biological systems, software engineering, electrical engineering, etc. Some examples of application areas could include studying the spread of an infectious disease epidemic or a nose-diving stock market crash, introduction of i-pod, and the effect on Sony walkman sales, etc. We get a holistic view and strategic perspective of the system as also be able to interpret the system over a period of time. Enterprises can look inwards and place the lens on themselves to understand themselves better as also devise new strategies to survive and thrive in the complex and competitive business environment. One great advantage of this technique is the ability to measure and model intangible variables or factors, which were hitherto not quantifiable.

The reasons for policy resistance can be analyzed and addressed. For example, we sometimes perform actions to solve a problem, but these backfire on us. An interesting observation is that use of ICT tools for paperless office in some cases has actually increased per-capita consumption of paper. Of course, many of these things are beyond our control and the actions we perform bring about side effects. CLD help us understand the interactions between variables using feedback loops, while SFD helps us understand the status of a variable of interest at any given point of time and its traversal and transformation in the flow. In CLD, we are able to classify loops as positive and self-reinforcing or negative and self-correcting. Positive loops are generally at an unstable equilibrium, while negative loops tend to denote that the system is trying to reconfigure and goal-seek itself to an equilibrium state after a disruption. CLD gives us a working model with an idea of the causal relationships in the system, while SFD gives us an idea about the state and rate variables. User-friendly SD simulation packages with friendly GUI like iTthink, Vensim, and Powersim have contributed to the steady usage of this exciting technique.

System Dynamics in Supply Chain Management

Designing and managing supply chains comes with its share of challenges despite various innovative technology developments. Most of these challenges stem from the fact that there is a multiplicity of stakeholders, many of whom are autonomous or semi-autonomous and volatile or unpredictable. This is further complicated by interactions by these actors. Each of these actors has their own views of the system and their share of objectives. Using SD to study SCM processes can throw light on these (Sidola, Kumar, & Kumar, 2012). One common explanation of supply chain management (Stevens, 1989) is a system whose constituent parts include material suppliers, production facilities, distribution services, and customers linked together via the feed - forward flow of materials and the feedback flow of information. SD analyzes various feedback loops in supply chain processes such as inventory control, distribution, manufacturing, or procurement to study structure, behaviour, and performance of the systems. Various variables are classified as positive and self-reinforcing or negative & self-correcting. Effectively speaking, we can identify and study variables that facilitate or hamper supply chain performance. SD is an excellent tool that can be used to model SCM processes, which are increasingly becoming unpredictable and multi-faceted as a result of divergent interests of its stakeholders (Wu, Chen, & Tsai, 2006).

The SFD tool can be used to model the supply chain as an extended enterprise consisting of an interconnection of stakeholders such as customers, suppliers, storage depots, transporters, and retail establishments. The process flow and transformations can be effectively studied by analyzing various feedback loops. SD could assist us to make decisions with respect to factory, inventory, and storage depot location, workflow, and activities. Other processes that can be analyzed include material resource planning, distribution planning, forward and reverse logistics, sourcing, and outsourcing strategies.

SD has been applied in various SCM scenarios in industrial production for over five decades (Asif, Bianchi, Rashid, & Nicolescu, 2012). The pioneering SD research group led by Forrester at MIT have employed this technique to study supply chains. This group modelled the supply chain as six interacting flow systems, namely the supplies, cash, information, orders, human resources, and equipment with four tiers namely plant, store, distributor, and merchant. Topics of interest include impact of inventory fluctuations, demand magnification, distributed control, and ICT deployment for SCM process(Singh, Sharma, Barcellos, & Borella, 2015).

SD was applied to understand the causal relationships between various actors and processes in SCM. Elements could be divided into structural such as supplier or factory and control such as supply & demand signals and information flow (Jayashankar, Swaminathan, Smith, & Sadeh, 1998). Modelling the structural and control actors help us in understanding the decision-making process. A typical situation could be the dilemma of an inventory manager. How should the inventory manager balance the orders versus production and take decisions with respect to re-ordering or manufacturing.

Despite the initial interest in applying SD for SCM contexts, there was a pause in terms of research interest till mid 1990s after which things started picking up (Towill, 1997). The widely used textbook by Sterman showcases some case studies on SD application in SCM. There was a long slack period before research started picking up. Subsequently, SD application in SCM areas in inventory management, demand amplification, and supply chain design started picking up (Angerhofer & Angelides, 2000). One such study involved studying demand amplification in a super market setting and how to handle various scenarios (Ge, Yang, Proudlove, & Spring, 2004). SD also improves SCM integration, which results in better enterprise performance (Eldabi & Keramati, 2011). Various supply chain scenarios are faced with demand uncertainty, demand slack, or unreliable suppliers (Ozbayrak, Papadopoulou, & Akgun, 2007) as well as information sharing can be understood better (Feng, 2012) with SD modelling.

Causal Loop Diagram (CLD) for Benefits of ICT Intervention in Distribution

ICT intervention in SCM brings about a marked change and improvement in all processes of supply chain planning and execution such as inventory control, distribution, production, distribution, and shipping (Holistic Analytics, 2015). Here, we see the impact of ICT intervention in the process of distribution.

Distribution is the physical logistics of moving inventory along various channels of distribution. This involves designing, maintaining, and regulating channels to achieve the effective and efficient flow of raw materials, work-in-process, finished goods to meet the customer requirements. The activity involves engagement from production & manufacturing to customer & point of sale. In the distribution process, finished goods inventory is positively impacted by manufacturing and production capabilities. The finished goods inventory moves through various distribution channels such as air, water, or land.

The efficiency of distribution depends on the subtle relationship between orders shipped, order fulfilled, and order backlog. Distribution channels feed onto orders shipped. However, delays in delivery time could diminish the actual orders fulfilled from the shipped orders. The gap results in an order backlog which impacts the customer-relationship.

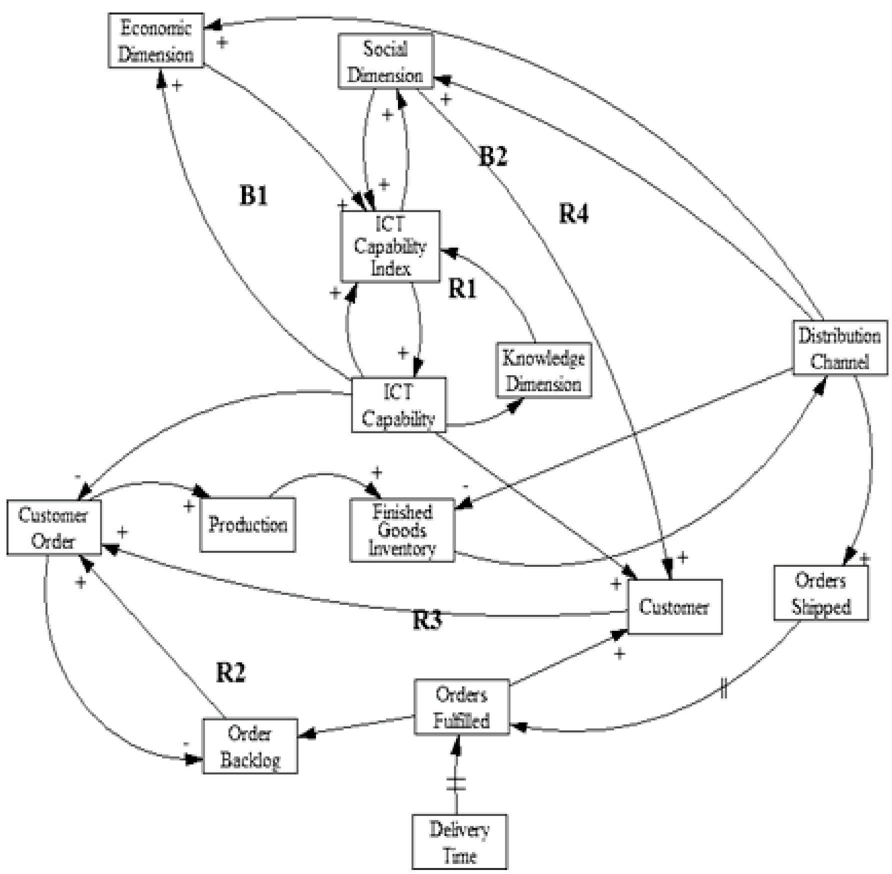
We introduced a variable, ICT capability. The action of this variable is very wide and impactful (Cedillo - Campos & Sánchez - Ramírez, 2013) and impacts many elements in the distribution process. Using a tool like RFID (Bollampally & Dzever, 2015), we are able to get better tracking of inventory at both storage and shipment levels. Using a tool like decision support systemsor web services or cloud or analytics (Nair & Anbuudayasankar, 2016), we have better engagement with customers and better access to orders received and also visibility of shipments.

This variable can be measured in terms of an ICT capability index. This is similar to the ICT development index (IDI) used by the United Nations for ranking nations based on ICT readiness, digital divide, etc. This index has economic, social, and knowledge dimensions (Kauffman & Kumar, 2005). In economic terms, the savings accrued as a result of ICT usage can be measured. The social impact is measured in relative improvement in speed, service, and quality of workflow and operations. The knowledge potential is in terms of relative improvement in access, quality, timeliness, and visibility of information. The index can be represented in any one of these three dimensions. However, one thing to be noted is that these dimensions could be interrelated as well. One added complexity is the difficulty in quantifying the knowledge and social dimensions of the index, unlike the economic dimension which can be easily quantified.

The ICT capability impacts the enterprise in all these dimensions. Economic dimension means better savings and earnings due to the ICT usage in improving the inventory management process and the like. ICT intervention improves engagement with customers as well as the interactions with various stakeholders resulting in better workflow, thereby impacting the social dimension. Inventory visibility is a tangible impact of the knowledge dimension. These three parameters of the index impact other operations as well. Distribution channel efficiency is closely related to the economic dimension ; whereas, the customer and the social dimension are interlinked with respect to customer engagement and relationship management. It is clear that the ICT capability intervention brings about disruption in the causal relationships in a positive manner, thereby resulting in benefits to the enterprise.

In Figure 1, the CLD has four reinforcing and two balancing loops all of whom are impacted by the ICT capability variable and its metric, ICT capability index. The reinforcing loop R1 describes the ICT capability

Figure 1. Distribution Causal Loop Diagram Using Vensim with ICT Capability



metric. The ICT capability metric has knowledge, social, and economic dimensions. In this loop, knowledge dimension is an important component of the ICT capability metric.

The reinforcing loop R2 describes the customer order fulfilment process. In the spirit of maintaining zero inventory or just in time (JIT) inventory, manufacturing is proactive to the customer orders received by the enterprise. The finished goods inventory (FGI) moves as orders shipped through the distribution channel which consists of movement of goods through air, water, and land. However, the full conversion of orders shipped to orders fulfilled need not happen due to various bottlenecks or unpredictable or surprise events in the channel. The gap in this conversion emerges as an order backlog. The ICT capability has the potential to close the gap between orders shipped and orders fulfilled. Efficient workflow, communication, and collaboration between stakeholders can address most bottlenecks and ensure a better response to surprise events.

The reinforcing loop R3 captures the customer satisfaction accrued as a result of orders fulfillment. Improved customer engagement results in repeat orders. The reinforcing loop R4 describes the knowledge influence in the distribution process. Knowledge dimension is an important component of the ICT capability metric. The knowledge dimension refers to the edge given by transparency and visibility of information as a result of ICT capability. This could be in terms of inventory visibility throughout the supply chain and how it avoids the bull-whip effect.

The following are the balancing or negative feedback loops :

The balancing loop, B1 highlights the economic benefit as a result of the ICT capability on the distribution process. Economic dimension results in the savings accrued as a result of ICT capability. This is another component of the ICT capability index. This capability provides visibiltiy, coordination, workflow, engagement, and collaboration for the distribution process where customer order is escalated to manufacturing and the finished goods flow through the distribution channel.

The balancing loop, B2 highlights the social impact of ICT capability on the distribution process. The social impact refers to improvements in speed, service, collaboration, and quality of workflow and operations. This improves relationships among the stakeholders in the distribution and supply chain. Improved engagement with stakeholders results in pro-active responses to surprise events. It is clear that all causal relationships have been disrupted by ICT capability in a positive fashion, which is clear from various balancing and reinforcing loops.

Managerial Implications

As described in this investigation, for every activity in supply chain planning and execution, ICT capabilities influence various actors, processes, and control flows. This could include inventory management, MRP, demand forecasting, production planning & scheduling, etc. From a managerial standpoint, the ICT advantage and impact on SCM processes as also its interplay with various actors and factors in the supply chain are highlighted and better understood so as to create business value for the enterprise. Various supply chain scenarios like just in time or bullwhip effect (Mehrad, & Akbari, 2015) or designing the supply chain network using mathematical or empirical models (Ghobadi, Darestani, & Shahroudi, 2015) can be understood better by using these techniques. The strong postitive association between ICT competence and organizational competence (Kang & Moon, 2015) is better understood. This complements the efforts for using SD modeling to study corporate performance and governance (Sahay & Kumar, 2015).

Supply chain managers desire the contrived flow of information which happens as a result of ICT deployment and this helps immensely in regulating the supply chain process umbrella (Mishra, 2010). Integration of firms in the face of coordinating materials and information flows within a procurement - production - distribution network is very important and is key to good supply chain performance (Muttalageri, & Chandrashekar, 2009). ICT deployment helps in both structural and functional integration of stakeholders in the supply chain process umbrella. Companies are now looking to develop new methods in areas such as manufacturing, flexibility, transportation, and information technologies in order to have a strategic superiority in their supply chain. Managers are key factors in the organizational performance and the success of the supply chains (Akdogan & Demirtas, 2014) and techniques like SD help managers to make better decisions in supply chain processes such as inventory management (Botha, Grobler, & Yadavalli, 2017). With better understanding of supply chain, managers can brainstorm and deliberate on decisions, strategy, issues, and policies by developing scenarios and extending the models using SD tools.

Conclusion

ICT deployments and interventions across the supply chain have become a performance enabler and determinant of competitive advantage for many corporations. System Dynamics is an excellent simulation and modeling technique based on systems thinking, non-linear dynamics, and feedback loops to study structure, performance, and behavior of complex and dynamic systems. A causal loop diagram, the primary SD approach, is used to investigate the influence of ICT intervention on the supply chain process of distribution. Using SD software package, Vensim, we are able to see that the introduction of an ICT capability variable in the CLD dramatically changes the status quo and impacts the causal relationships and dynamics of the process on all reinforcing or balancing loops. This ICT capability can be measured in terms of an ICT capability index which is dependent on three dimensions, namely knowledge, social, and economic. With better understanding of the actors, factors, and workflow, supply chain managers can brainstorm and deliberate on decisions, strategy, issues, and policies by developing scenarios and extending the models using SD tools.

Limitations of the Study and Scope for Further Research

This study analyzed the ICT impact on the SCM process of distribution using SD methodology and its CLD tool. Through SD, the process of distribution is analyzed with entities such as production, customer order, orders shipped, order backlog, finished goods inventory, etc., and the relationship of these entities with respect to ICT capability index and its knowledge, social, and economic dimensions. This study is limited to this generic process description of distribution. A different treatment would be needed for any specific enterprise's distribution process, which may have other complexities and other extraneous entities.

The paper investigated the ICT influence on SCM process of distribution using SD methodology and its CLD tool. This can be applied for any process in supply chain planning and execution. Investigation on the ICT impact on supply chain processes such as demand planning, supplier selection, purchasing decisions, inventory management, production planning, sequencing, scheduling, warehouse management, logistics and retailer management using SD are likely to open new vistas on how the process improvements have contributed to the competitive advantage for the enterprise. Management case studies with the influence of specific ICT tools like social mobile analytics cloud (SMAC) stack, radio frequency identification (RFID), decision support systems, and software systems are also possibilities for extending the study. Supply chain managers brainstorm and build consensus on decisions, strategy, issues, and policies by developing scenarios using SD methodologies like CLD and stock-flow diagrams.

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