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ABSTRACT

Supply Chain Management is a critically important approach toward producing and delivering goods and services in a cost-effective, timely manner. However, many SCM systems in practice exhibit the bullwhip effect, a tendency towards increasing variability in demand as this type of information migrates downwards in the producing supply chain. We argue that one can reduce the size of the bullwhip effect through the judicious use of knowledge management technologies. We have advanced our arguments through several propositions, and we have derived a set of testable hypotheses from two of these propositions in order to demonstrate how one would go about verifying these arguments. We have identified two different general research methodologies in order to provide a multiple methodological approach to gaining greater confidence in the propositions. It now remains to carry out this plan of research.

1. INTRODUCTION

Supply Chain Management (SCM) is an approach to coordinating the functions and processes associated with the order fulfillment cycle, with the objective of delivering what the final customer wants at the time and place the customer desires it, in a manner that minimizes total costs for the organizations linked together in the chain. A supply chain can include a number of functional areas within a firm–such as production, distribution and marketing. The supply chain also typically includes other firms–such as suppliers, transportation carriers, warehouses, retailers as well as the end customers themselves (Chopra and Meindl, 2001). From a process viewpoint, SCM can coordinate order management; production and inventory management; materials management; distribution and transportation; and product design.

Knowledge Management (KM) is concerned with the creation, storage, dissemination, and application of organizational knowledge. Successful KM rests upon an organization possessing a supportive culture characterized by high trust and the ready sharing of needed information (Davenport and Prusak, 1998; Shaw, 1997), sufficient technological sophistication (Tuggle and Shaw, 2000), and appropriate attitudes and motivation towards organizational success (Pfeffer, 1994).

To achieve success at SCM, an organization must possess--and share--knowledge about many different facets of this process. The knowledge sources are both internal to the organization (e.g., knowledge of the whereabouts of subassemblies, knowledge of sources of manufacturing delays) and external to the organization (e.g., knowledge of the final customer's expectations, knowledge of where en-route components are and when they are expected to arrive at their destinations). To be truly effective, an organization must achieve knowledge sharing and coordination along the entire supply chain network.

Lack of information sharing between members of the supply chain has been shown to significantly affect total profitability (e.g., Armistead and Mapes, 1993; Anderson and Fine, 1999). As such, we argue that KM can enhance the degree of success of existing SCM efforts as well as increase the likelihood of success of new SCM undertakings. While many SCM projects have resulted in improved performance (e.g., Lin et al., 2000; Arntzen et al., 1997; Camm et al., 1997), we believe that higher levels of performance improvement are possible by coupling KM initiatives with SCM programs.

2. LITERATURE REVIEW

2.1 Overview of Supply Chain Management

A supply chain consists of material, cash, and information flows that are relevant to the planning and operational activities at both successive and preceding tiers. In Figure 1, we illustrate a simple supply chain associated with the manufacturing and distribution of a single product. Manufacturing, supplier, and retail processes are represented by boxes and the transportation process is represented by arrows. In this construct, materials and end products move from left to right toward the customer.

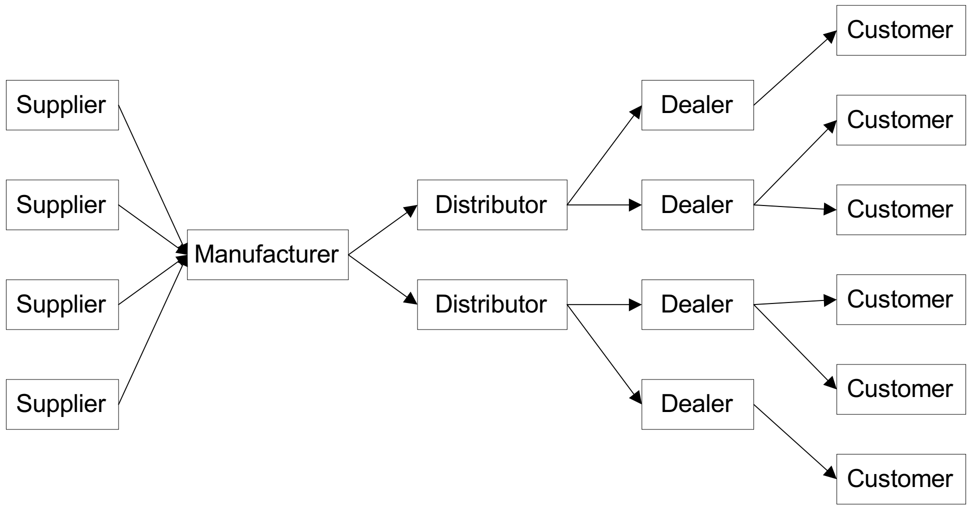

Figure 1. Representative Supply Chain

A somewhat more abstract view of the supply chain is presented in Figure 2, which illustrates some properties of information transfer in a supply chain. Three types of information that can be transferred in the chain are demand, internal costs, and system constraints. Demand quantities at successive tiers in the chain depend on the demand at earlier tiers–note that demand at tier k is dependent on demand at tier k-1, and so on throughout the chain.

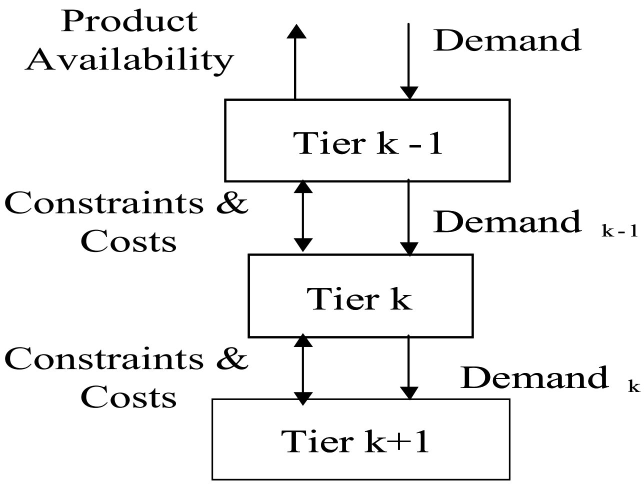

Figure 2: Information Transfer in a Supply Chain

SCM involves designing the supply chain network, planning the supply chain processes, and then executing the operation in a manner consistent with the overall strategy. Network configuration determines the number, location and function of each facility at each stage in the transformation process. The processes that drive SC performance include order processing (e.g. determining where and when the order will be produced and shipped), production planning (e.g. how many should be produced in each production period, how many subassemblies should be ordered to support the production plan), selecting and managing suppliers (e.g. which suppliers and components need to be included in the supply network), product design (e.g. of the product and its components), and problem solving (e.g. what should be done with parts that are too numerous to fit in the space assigned).

Information systems and the transfer of information between functions and stages are key ingredients in SCM initiatives. For example, manufacturers in a supply chain often share forecasts of material requirements with their immediate suppliers. The suppliers then use this demand information to generate their own production plans, and then share forecasted material requirements with the next supply tier.

The major attributes of supply chain performance are cost (inventory, expedited transportation, and capacity in terms of plant, property, and equipment) and customer responsiveness (reliability, flexibility, lead time). The Supply-Chain Operations Reference model (Supply Chain Council, 2001) discusses these attributes and measures for different types of supply chains. In order to capture an aggregate effect on performance across a number of cost and responsiveness attributes, surrogate measures have been used to illustrate the behavior and performance of supply chains. Here, we are interested in examining the effect of KM initiatives on one of these surrogate measures--the bullwhip effect along a supply chain. We explore the bullwhip effect in depth in a later section.

2.2 Overview of Knowledge Management

The study of KM includes a variety of viewpoints and approaches. For example, the recent literature reflects several different perspectives on KM: a categorization of types of knowledge activity (Davenport et al., 1998), methods to assess a firm's stage of knowledge management (Bohn, 1994), classification of knowledge (Nonaka, 1994), and a discussion of the capabilities of different Knowledge Based Systems (Nissen, 1999). In this discussion, we focus upon KM that is technologically enabled, recognizing that firms can practice many of the precepts of KM without having to resort to the use of computer-based technologies.

The fundamental capabilities of Knowledge Based Systems can be categorized into five areas: knowledge capture, knowledge organization, knowledge formalization, knowledge distribution, and problem solving application (Nissen, 1999). Each capability requires a specific technique or technology.

One approach to discussing KM is to divide it into separate stages: knowledge creation, knowledge capture, knowledge storage, knowledge dissemination, and knowledge application. Not all KM efforts include all five stages. Different approaches are applicable at each stage.

During knowledge creation, one wants to facilitate the exchange of complicated ideas and tentative proposals by Subject Matter Experts (SMEs--i.e., individuals who have amassed expertise in one domain). One approach is to create collaboration spaces where SMEs can electronically pose questions, report results, offer suggestions, formulate ideas, and, if need be, sketch on an electronic whiteboard or even communicate via a videoconference facility.

In the context of the supply chain, knowledge creation is relevant, for example, in the process redesign associated with the implementation of supply chain planning systems. Each supply chain entity knows part of the process, but until the initiative brings these disparate pieces together, the complete knowledge of the SC process doesn't exist.

Knowledge storage entails the design of mechanisms to easily store, search for, and retrieve knowledge in different forms. It is one thing to store and index explicit knowledge (knowledge that can be readily documented in some form). It is quite another to try to do the same with tacit knowledge: hands-on skills, special know-how, experiences, beliefs, mental models, perspectives, and intuitions (Nonaka, 1994). For tacit knowledge in particular, knowledge capture is a phase that precedes knowledge storage.

In the context of supply chain management, a knowledge base stores information on best practices that have been successful in one supply chain environment in such a way so that the knowledge can be easily located. Supply chain management is broad in scope, involving many processes, so taxonomies like the one presented in Ganeshan et al. (1999) may be helpful for organizing knowledge bases.

Knowledge dissemination focuses upon the issues of getting the right knowledge to the right user at the right time. Externalization is the process of making tacit knowledge explicit so that knowledge sharing is facilitated. Internalization is the process of making explicit knowledge tacit, so that it is seamlessly integrated into one's work routine. Socialization is the process of one person conveying tacit knowledge to a second person, so the second person absorbs the nuances of that knowledge. Combination is the process of weaving together explicit knowledge so it is available as needed.

In the supply chain, dissemination issues address both explicit and tacit knowledge– coordinating the supply chain often requires development of explicit techniques and procedures (e.g., the CPFR users guide for Collaborative Planning, Forecasting and Replenishment). SCM may also involve tacit knowledge, as in understanding the internal policies regarding the management of shortages, for example.

Knowledge application is the process of using knowledge to improve the operation of some organizational process. Bringing knowledge to bear on a process (when it was not used beforehand) usually results in one or more of the following results: reduced errors (e.g., by not repeating mistakes), improved quality (e.g., by using best of breed practices), speeding up decision making (e.g., by getting better cross-functional coordination), lower costs (by quickly identifying expertise), and by speeding up training (e.g., by attending to common mistakes and learning from best practices).

In a supply chain, best practices are sometimes adopted, but more typically adapted to suit a different supply chain environment. Best practices are often identified from benchmarking studies, and in many cases the benchmarks are world-class operations. Importantly, the best practice needs to be relevant in the context of the firm's operational strategy–an often overlooked issue in the sharing of best practices in companies.

2.3 Supply Chain Performance and the Bullwhip Effect

Traditional information flow along a supply chain can be incomplete and not timely, driving costs via the "bullwhip effect". The bullwhip effect is a term used to describe how variation in order size grows as demand translates through the tiers in a supply chain. It is a fundamental characteristic and a primary performance driver in supply chains (Lee, et al., 1997; Sterman, 1989). The bullwhip effect influences responsiveness in terms of delivery performance, as well as cost and asset utilization throughout the supply chain. The bullwhip effect influences inventory in the chain, but may also result in production overtime, expedited transportation costs, and missed due dates. Especially in a build-to-order, tightly-controlled supply chain, if orders are processed with regard to the costs and constraints across the supply chain, the performance of the chain and all its members on both internal and customer-facing metrics can be improved.

The selection of a measure for the bullwhip effect depends partly on the type of improvement expected from the SC initiative. For example, the following measure (from Meixell and Wu, 1998) describes the degree to which demand varies over tiers for a single release of the time-sequenced material requirement schedule:

Definition (Single Release Demand Amplification, DA^s_{ij}) *For an item i in supply tier k, single release demand amplification,* DA^s_{ij} *is the amplification between the demands for item i at tier k and the demand for its component j at tier k+1, as measured across a single release over time periods t= L_i+1,…,T at a specific time epoch. Specifically,*

$$DA^s_{ij} = CV(x^{k+1}_{j,t-L_i}, t = 1,...,T - L_i) - CV(r^k_{it}, t = L_i + 1,...,T) \quad (1)$$

where CV(·) is the coefficient of variation across a time array (·), item demands r_{it} over periods t= L_i+1,…,T, are translated through the supply tier using some lot sizing policy and impose an internal demand x_{jt} on its component j, over periods t= 1,…,T-L_i.

Thus, DA^s measures the demand amplification along a chain within a single schedule release. Demand amplification, then, pertains to the difference in order size variation between tiers across the time periods in the planning horizon of a single schedule release. So, for example, if a level schedule is generated and then propagates through a supply chain as a level schedule, the demand quantities would be constant over all *t* at all *k* and the *CV's* for all items will be 0. Any other policy carries some level of variation, and if the CV changes across the tiers, some level of amplification.

There are several causes of the bullwhip effect--order batching, price fluctuations, shortage gaming/inflated orders, demand forecast updates (Lee, et al., 1997; Sterman, 1989), long lead-time (Chen, et al., 1999), and capacity utilization policy (Meixell, 1998). The effects from each of these factors may be mitigated by appropriate use of KM and knowledge transfer methodologies. Long lead-time, for example, makes it difficult to create knowledge in the case of demand forecast generation. Shortage gaming is a cultural issue that addresses the motivation of the supply chain partners to share honest information–when this type of gaming exists, customers benefit by overstating their demand needs in future periods. The supply chain operates less effectively when the bullwhip effect occurs, and each of these factors has been shown to contribute to its occurrence. In some cases, models exist that explain the relationship between the causes and the effect. These factors are important because a study of the KM factors requires the inclusion or control of these factors, or the results may display so much variance as to render the results un-usable, due to these significant uncontrolled factors.

In addition to these more quantifiable factors, however, are the cultural factors, including trust and an attitude and motivation towards organizational and supply chain success. These too impact on supply chain performance in general, and in some cases on the bullwhip effect specifically. For example, a supplier may hesitate to notify its customer that it cannot meet the published production plan, fearing punitive action on the part of the customer, and hoping that another supplier may notify the customer of its inabilities first. When this happens, the customer's production plan will nonetheless need to be updated at some time (since the material shortage is inevitable) but when it occurs at a point in time closer to the production date, the bullwhip effect is more severe.

3. RESEARCH PROBLEM

3.1 Integrating KM and SCM

Our overarching thesis is that applying KM methodologies and practices in a supply chain system will reduce the bullwhip effect. The following propositions focus on what benefits KM should be expected to bring to the practice of SCM, how those effects are expected to manifest themselves, and where in the supply chain those benefits are expected to occur. As an illustration of how one would test these propositions, we drill down on propositions 1.2 and 2.1 to specify a set of testable hypotheses. We conclude with an examination of two different research methodologies that may be used to explore the empirical viability of the hypotheses. For each of these propositions and hypotheses, we posit ceteris paribus conditions.

3.2 Propositions

Proposition 1: Implementing KM practices that increase the transfer of knowledge will reduce the bullwhip effect.

Proposition 1.1: By creating best practices knowledge bases, an operating SCM should approach theoretically optimal levels of performance.

Proposition 1.2: By creating lessons learned knowledge bases, it should be possible to improve the transfer of knowledge between all pairs of tiers (k, k-1).

Proposition 1.3: By creating collaboration spaces, the processes of design and planning should be expedited.

Proposition 2: Implementing KM practices that increase the level of trust between partners will reduce the bullwhip effect.

Proposition 2.1: A power based relationship preceding a supply chain initiative leads to either failed supply chain initiative or long implementation times.

Proposition 2.2: SCM initiatives under-perform because of poor teamwork in the supply chain process re-design stages.

Proposition 2.3: Using well founded and appropriate knowledge creation techniques leads to faster and more effective SC process redesign and improved SC performance.

Proposition 3: By having KM methodologies implemented, the SCM system should (a) solve novel nonrecurring problems faster, (b) should adapt more rapidly to unpredictable change, (c) allow for shorter training times for new workers with fewer errors.

3.3 Hypotheses

Proposition 1.2: By creating lessons learned knowledge bases, it should be possible to improve the transfer of knowledge between all pairs of tiers (k, k-1).

Consider an arbitrary pair of tiers, *k* and *k-1*, in a supply chain. The information that flows from *k-1* to *k* is the demand for materials and products that *k* is supposed to supply, along with supplementary information such as desired delivery date, bill of material quantities, lot-sizing information, quality of product desired, expected costs, and the like. There are a variety of schemas that may be used to communicate this information, e. g., oral, written, electronic, expectations based upon the most recent past experiences, etc. Proposition 1.2 speaks to the efficacy of using lessons learned knowledge bases in improving the quality of the flow of information between these two tiers. This proposition spawns a number of testable hypotheses, specifically,

Hypothesis 1: By using lessons learned knowledge bases to transfer information between tier *k-1* and *k*, fewer errors are committed in terms of the quantity *k* supplies to *k-1*.

Hypothesis 2: By using lessons learned knowledge bases to transfer information between tier *k-1* and *k*, there are more on-time deliveries of product.

Hypothesis 3: By using lessons learned knowledge bases to transfer information between tier *k-1* and *k*, quality of product delivered to tier *k-1* improves as compared with that tier's expectations, and as measured in the number of returns.

Hypothesis 4: By using lessons learned knowledge bases to transfer information between tier *k-1* and *k*, extraordinary charges in excess of costs anticipated by tier *k* in the negotiation process are reduced.

In each case, the null hypothesis is that lessons learned knowledge bases are not in use. One may wish to compare the use of lessons learned knowledge bases against each of the other communications mechanisms, but it will suffice for us to compare against any other communications mechanism. The hypotheses are to be tested comparatively, comparing the situation of using a lessons learned knowledge base against using some other communications mechanism and counting the number of errors that occur in delivered quantity, time to make the delivery, relative qualities of delivered product, and relative costs of delivered product. Ideally, the comparisons would be performed over all pairs of tiers (k-1, k) for the firms in the sample. Again, each of the hypotheses presumes conditions of ceteris paribus.

Proposition 2.1: A power based relationship preceding a supply chain initiative leads to either failed supply chain initiative or long implementation times. Implementing organizational practices that increase the level of trust between partners (thereby enabling the implementation of KM techniques) will reduce the bullwhip effect. Such practices include measurements of and rewards for sharing information, formation of cross-functional/cross-organizational teams, and empowerment to the team to make important decisions.

Proposition 2.1 addresses the importance of the power distribution between firms in a supply chain, its impact on trust, and how this influences the quality of the flow of information between these two tiers. This proposition motivates testable hypotheses that include the following:

Hypothesis 1: When a power imbalance exists between tiers in a supply chain, less information is transferred between tier *k-1* and *k*, causing more errors in terms of the quantity k supplies to k-1.

Hypothesis 2: When a power imbalance exists between tiers in a supply chain, less information is transferred between tier *k-1* and *k*, causing fewer on-time deliveries of product.

Hypothesis 3: When a power imbalance exists between tiers in a supply chain, less information is transferred between tier *k-1* and *k*, causing poorer quality of product delivered to tier k-1 as compared with that tier's expectations, and as measured in the number of returns.

Hypothesis 4: When a power imbalance exists between tiers in a supply chain, less information is transferred between tier *k-1* and *k*, causing extraordinary charges in excess of costs anticipated by tier k in the negotiation process.

In each case, the null hypothesis is that a situation of balanced power exists in the supply chain. The hypotheses are to be tested comparatively, assessing the degree to which an imbalance in power exists, and then counting the number of errors that occur in delivered quantity, time to make the delivery, relative qualities of delivered product, and relative costs of delivered product. Ideally, the comparisons would be performed over all pairs of tiers (k-1, k) for the firms in the sample. Again, each of the hypotheses presumes conditions of ceteris paribus.

4. PROPOSED METHODOLOGY

Two general approaches may be taken towards empirically testing these hypotheses. We suggest that it may be helpful to carry out each where applicable, and ideally both when possible. Multiple research methods provide different insights into the strengths and weaknesses of propositions. The first general approach would be to develop case studies of firms in the field. Two alternative strategies are available using the case study method: (A) Pre and posttests of a firm that integrated one or more KM methodologies into their existing SCM system. (B) Comparison of two firms--ideally one could identify two otherwise matched firms, one of which is adopting SCM, and the other of which is adopting an integrated SCM-KM package. One would want to ensure in either case that the firm not using KM methodologies in fact exhibits the bullwhip effect to some degree. Empirically, this should not be difficult to find or establish. Then, as suggested by the four hypotheses, comparisons would be made between pairs of firms over all pairs of tiers within each firm.

The second general approach would be to use a simulation model to first, produce a credible model of a firm using SCM such that it is possible to exhibit the bullwhip effect, and second, to take that baseline simulated firm and demonstrate how the bullwhip effect is ameliorated by the introduction of KM practices in the firm's behavioral repertoire. An optimization-based simulation model of the supply chain as described in Meixell and Wu, 1998, serves as the basis for this model of the bullwhip effect. Again, one would want to examine behavior over all pairs of tiers within each simulated firm.

In terms of testing hypotheses emanating from the other propositions, irrespective of which research approach is adopted, one will want to measure a variety of variables in the behavior of the firms studied. This would cover variables such as time to complete a transaction, cost to complete a transaction, number of errors, customer satisfaction, training time, training cost, number of problems that occur, time to resolve problems, number of meetings required, and time to complete meetings.

We are currently evaluating the use of validated instruments that could be used to assess power balance (Heide and John, 1988) and trust (Mayer et al., 1995; Pierce et al., 1992) in a supply chain.

5. CONCLUSIONS

Supply chain management is a critically important approach toward producing and delivering goods and services in a cost-effective, timely manner. However, many SCM systems in practice exhibit the bullwhip effect, a tendency towards increasing variability in information uncertainty as information migrates downwards in the producing organization. We argue in this paper that one can reduce the size of the bullwhip effect through the judicious use of knowledge management technologies. We advance our arguments through several propositions, and we derive a set of testable hypotheses from one of these propositions in order to demonstrate how one would go about verifying our argument. We identify two different general research methodologies in order to provide a multiple method approach to gaining greater confidence in the propositions we advance. It now remains to carry out this plan of research.

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