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The theory of constraints' thinking process approach to developing strategies in supply chains

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Abstract *Many attempts have been made to study factors influencing the performance of supply chains. These studies are generally quantitative and involve rigorous statistical analyses. This paper describes an application of a systems approach known as the thinking process of the theory of constraints not only to identify critical success factors in supply chain management, but also to understand causal relationships between these factors. The study was conducted in a group-based model building environment with a group of students who specialised either in logistics management or e-commerce. The results suggest that understanding the dynamic nature of supply chains through cause and effect relationships is critical to the formulation of supply chain growth strategies.*

Introduction

Over the last four decades implementation of operations management principles and strategies, such as materials requirements planning (MRPI and MRPII) (Orlicky, 1975), just-in-time (JIT) (Monden, 1981), total quality management (TQM) (Deming, 1986; Juran, 1992), lean manufacturing (Womack and Jones, 1996), and theory of constraints (TOC) (Goldratt, 1988), have helped companies to reduce manufacturing costs as much as practically possible. As the CEO of Hong Kong-based company Li & Fung highlighted:

> . . . you can try to squeeze the cost of production down 10 cents or 20 cents per product, but today you have to be a genius to do that because everybody has been working on that for years and there's not a lot of fat left. It's better to look at the cost that is spread throughout the distribution channels (Magretta, 1998, p. 108).

It is only recently that management of business enterprises have realised that effective supply chain management is the competitive strategy that now has the most potential to reduce costs further (Dyer, 1994, 1996; Lee *et al.*, 1993).

Although the interest in supply chain management, both in industry and in academia, has grown rapidly over the past few years, the concept can be traced as far back as Forrester (1958, 1961). Using industrial dynamics techniques, Forrester tracked the effects of delays (material flow lead time and information flow lead time) and decision policies within a simple but representative supply chain consisting of a manufacturing plant and its warehouse, distributors, and retailers. In this seminal work, Forrester (1961) demonstrated the importance of

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sharing information with partner organizations in the supply chain, strategic alliances and supply base management, vendor-managed inventory, and the impacts of delays across the supply chain at a time when these vocabularies were not part of the business literature.

To date many attempts have been made to identify critical success factors in supply chain management (Holmes, 1995; Power *et al.*, 2001), investigate the relationship between logistics strategy and business processes (Brewer and Hensher, 2001), identify drivers behind successful strategic supplier alliances (Monczka *et al.*, 1998), assess the impact of TQM practices on logistics and supply chain performance (Anderson *et al.*, 1998; Tan *et al.*, 1999), measure the effect of supply management orientation on supplier performance (Shin *et al.*, 2000), examine the role of communication in supply chain management (Ellinger *et al.*, 1999), and investigate the impact of information technology on logistics capability (Cross *et al.*, 1997). These are quantitative studies that have applied rigorous statistical analysis including factor analysis (Power *et al.*, 2001; Tan *et al.*, 1999; Anderson *et al.*, 1998), structural equation modelling (Shin *et al.*, 2000; Anderson *et al.*, 1998) and canonical correlation analysis (Brewer and Hensher, 2001).

In this study, a system approach known as thinking process (TP) was applied to identify critical factors of effective supply chain management, determine the causal relationships between these factors and investigate their interrelationship with supply chain performance. These relationships would help managers to analyse and develop growth strategies in supply chains.

Theory of constraints and its TP

This section provides an overview of the TOC and its TP. For a complete description, readers can refer to Goldratt (1990) and Cox and Spenser (1998). Rahman (1998) provides a detailed description of the TOC methodology including its concepts, principles, tools and performance measures and presents a comprehensive review of the TOC literature.

Developed by Goldratt (1988) in the mid-1980s, TOC evolved from the Optimized Production Timetables (OPT) system (Goldratt, 1980) and was later known under the commercial name of Optimized Production Technology (OPT®). As part of a marketing tool for the OPT system, Goldratt illustrated the concepts of OPT in the form of a novel, *The Goal* (Goldratt and Cox, 1984), in which the theory is gradually unravelled through the context of an everyday production situation. A second book, titled *The Race* (Goldratt and Fox, 1986), was written to overcome difficulties encountered in the implementations and, gradually, the focus of the concept has moved from the production floor to encompass all aspects of business. By 1987, the overall concept became known as TOC, which Goldratt (1988, p. 453) viewed as "an overall theory for running an organisation".

The TOC has two major components. First, a philosophy which underpins the working principles of TOC. This is often referred to as TOC's "logistics paradigm" and consists of five steps for on-going improvement, the drum-buffer-rope (DBR) scheduling methodology, and the buffer management information system. This philosophy suggests that the main constraint in most organizations may not be physical, but in fact managerial-policy related. To address the policy constraints and effectively implement the process of on-going improvement, Goldratt (1990, 1994) developed a generic approach called the TP. This is the second component of TOC. Experts believe that it is the TP which will ultimately have the most lasting impact on business. The working principles of TOC and the application procedure of the TP are discussed in the following two subsections.

Philosophy of TOC

The working principle of TOC provides a focus for a continuous improvement process. The principle consists of five focusing steps (Goldratt, 1990, p. 5) which are summarised in Figure 1. The steps are:

(1) *Identify the system's constraint(s).* These may be physical (e.g. materials, machines, people, demand level) or managerial. It is important to identify these constraints and also necessary to prioritise them according to their impact on the goal(s) of the organization.

(2) *Decide how to exploit the system's constraint(s).* If the constraint is physical, then the objective should be to make the constraint as effective as possible. A managerial constraint should not be exploited but should be eliminated and replaced with a policy which will support increased throughput.

(3) *Subordinate everything else to the above decision.* This means that every other component of the system (non-constraints) must be adjusted to support the maximum effectiveness of the constraint. Because constraints dictate a firm's throughput, resource synchronisation with the constraint will lead to more effective resource utilisation.

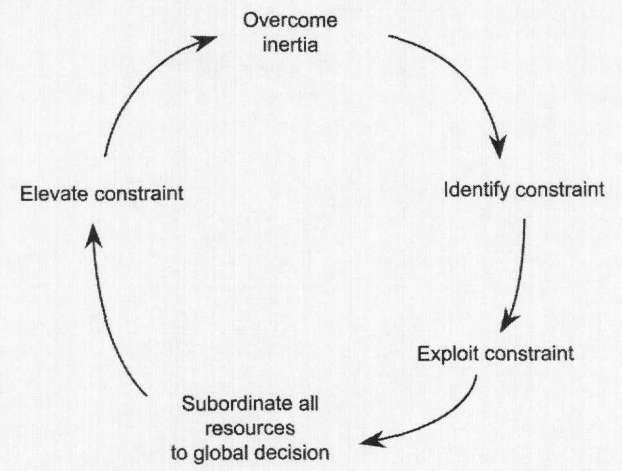


Figure 1.
Process of on-going improvement

(4) *Elevate the system's constraint(s).* If existing constraints are still the most critical in the system, rigorous improvement efforts on these constraints will improve their performance. As the performance of the constraints improves, the potential of nonconstraint resources can be better realised, leading to improvements in overall system performance. Eventually the system will encounter a new constraint.

(5) *If in any of the previous steps a constraint is broken, go back to step 1. Do not let inertia become the next constraint.* TOC is a continuous process and no policy (or solution) will be appropriate (or correct) for all time or in every situation. It is critical for the organization to recognise that as the business environment changes, business policy has to be refined to take account of those changes.

The implementation of the five focusing steps to a typical production environment can yield rapid and substantial improvements in operations as well as profits (Noreen *et al.*, 1995). However, this process of continuous improvement will eventually shift constraints from factory floor to the market. Insufficient demand is a managerial or policy constraint rather than a physical constraint. Policy constraints are generally difficult to identify and evaluate, and frequently require involvement and cooperation across functional areas. Goldratt (1994) developed the TP methodology to address policy constraints and create breakthrough solutions using common sense, intuitive knowledge and logic.

The thinking process

According to Goldratt (1990), managers are required to make three generic decisions while dealing with constraints. These are:

(1) decide what to change;

(2) decide what to change to;

(3) decide how to cause the change.

To address these questions, the TP prescribes a set of five tools in the form of cause-and-effect diagrams. The questions, associated tools and their purposes are summarised in Table I. The TP process starts with the first decision question, "What to change?", i.e to identify core problems. Current reality tree (CRT) is used for this purpose. Dettmer (1997) defined a CRT as a logical

Table I.
Thinking process tools and their roles

Generic questions	Purpose	TP tools
What to change?	Identify core problems	Current reality tree
What to change to?	Develop simple, practical solutions	Evaporative cloud
How to cause the change?	Implement solutions	Future reality tree
		Prerequisite tree
		Transition tree

structure that depicts the state of reality as it currently exists in a given system. Once a core problem has been identified, the next question becomes "What to change to". The second step in the process is therefore to search for a plausible solution to the core problem. This requires other tools such as evaporating cloud (EC) and future reality tree (FRT). According to Dettmer (1997) FRT is a strategic tool used to plan major changes. The implementation of these changes is likely to improve a system. Once the "what to change to" question is decided, the organization is left with the question "How to do it" or "how to change". The prerequisite tree (PRT) and transition tree (TT) diagrams are used to identify obstacles to implementation and devise detailed plans for overcoming these obstacles.

It is not the purpose of this paper to discuss these tools in great detail. For a detailed discussion readers are referred to Goldratt (1994), Noreen *et al.* (1995) and Kendall (1998). The purpose of this study is to address the first question: what to change, i.e to identify core problems which reduce the effectiveness and efficiency of supply chains. The CRT tool was used for this purpose.

Guidelines for constructing CRT

The CRT identifies cause-and-effect relationships in a system. It is constructed from the top-down by identifying undesirable effects (UDEs), and depicting probable causes for those effects (effect-cause). It is, however, read from bottom-up (cause-effect), when the construction is complete. The following steps should be taken to develop a CRT (Noreen *et al.*, 1995, p. 156):

(1) Identify a list of UDEs that describe the area being analysed. It is recommended to begin with a list of five to ten UDEs.

(2) Connect one or more UDEs to other UDEs if they are causally related. Depict cause-and-effect relationships with an arrow as shown in the categories of legitimate reservations (CLR) (see Appendix, Figure A1).

(3) Connect all other UDEs to the result of step 2. Scrutinise each entry and arrow along the way via the CLR. Stop when all the UDEs have been connected.

(4) Read the tree from bottom up, scrutinising again each arrow and entry along the way via the CLR. Make any necessary corrections.

(5) Ask yourself if the tree as a whole reflects your intuition about the area being analysed. If not, check for each arrow for additional cause reservations (point 6 in the Appendix, Figure A1).

(6) Do not hesitate to expand the tree to connect other UDEs that exist but were not included in the original UDE list.

(7) Present the tree to someone or a group who will help you surface and challenge the assumptions captured within.

(8) Decide that the CRT is complete. Identify the core problem or problems.

A simple example. A simple storage problem is chosen to illustrate how a CRT is constructed. The UDEs of the problem (adapted from Noreen *et al.* (1995) are presented below:

(1) Note enough space in the store.

(2) Too much make-to-stock inventory.

(3) Items piled up waiting to be stored.

(4) Cycle times are longer than necessary.

The corresponding CRT is presented in Figure 2.

Suppose the management of a company is concerned with problems in a warehouse and have identified four UDEs. These UDEs can be used to construct a CRT in order to deduce possible causes. The management believes that the lack of space in the warehouse (UDE1) is due to excess inventories that resulted from making parts to stock (UDE2) and items being stockpiled prior to storage (UDE3). So, UDE2 and UDE3 were connected to UDE1. The reason for UDE3 happening is suggested to be due to parts being delivered to the warehouse in large quantities as well as a result of delivery schedules not matching the rate of usage. (This has been identified in Figure 2 as R1, which is simply a reference number and has no significance). R1 is, therefore, connected to UDE3 and is read "if R1 then UDE3". Management suggested that the main reason why parts were delivered in too large quantities (R1) was that work orders were larger than division's needs (R2). It was also suggested that cycle

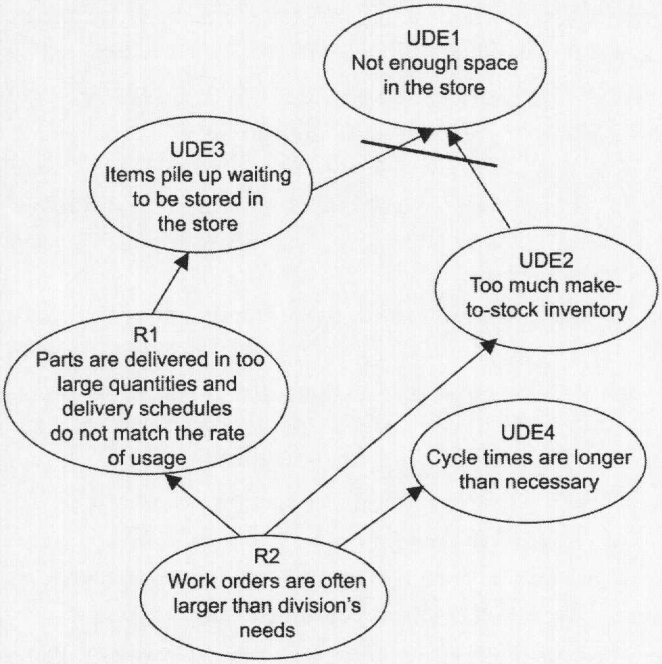


Figure 2.
A current reality tree

times were longer than necessary (UDE4) and that UDE2 was related to the size of the work order (R2). Therefore, R2 was connected to R1, UDE2 and UDE4. Note that of all the UDEs and Rs only UDE1 is linked to two UDEs (UDE2 and UDE3). This must be read with a "logical AND". Thus, the relationship between UDE1, UDE2, and UDE3 should be read as follows: if there are excess inventories that result from making parts to stock (UDE2) and items that are piled up waiting to be stored (UDE3), then there is not enough space in the warehouse (UDE1).

The tree was constructed starting with the UDEs and working down (Figure 2). However, the tree should be read "bottom-up". The management confirmed that the tree (Figure 2) represented the issue at hand and identified R2 (work orders are often larger than division's needs) as the core problem.

In this example the process of building the CRT was illustrated using a simple problem. It has to be remembered that TP should be applied only in a complex problem situation where a solution is not intuitive and the relationships between effects and causes are not clear.

Developing strategies in supply chains using TP

Group model building process

Today's global business environment is characterised by expanding foreign markets, comprehensive information networks, improved transportation, higher customer expectations, and high wage-rates. Effective and efficient supply chain management offers a means of gaining competitive advantage in an environment increasingly characterised by fierce competition and uncertainty. Shimchi-Levi *et al.* (2000, p. 1) defined supply chain management as:

> . . . a set of approaches utilised to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimise system-wide costs while satisfying service level requirements.

Thus the objective of supply chain management is to increase efficiency and minimise costs across the entire supply chain. Identification and application of appropriate supply chain performance metrics are critical to the success of supply chains.

Students undertaking a course in international logistics management at the Institute of Transport Studies (ITS), University of Sydney, were invited to participate in a group-based model building exercise in supply chains. The purpose of this exercise was to:

- identify the consequences (effects) of failing to organise and run efficient supply chains;
- determine possible causes of these consequences; and
- develop causal relationships between causes and effects.

The course was offered in February 2001 and was taught by the author of this paper in an intensive mode. A total of 44 students who enrolled in this course were pursuing masters degrees in either logistics management or e-commerce at the University of Sydney. About 35 percent were international students and the rest were local students. Some 15 percent of the students had very little or no experience, 40 percent had two to five years experience and about 45 percent had more than five years of experience. Two students had more than 20 years of experience. About 35 percent of the students had experience with logistics companies. About 30 percent of the students took a logistics management course prior to taking the international logistics management course.

Six groups were formed. Although it was difficult, a conscious attempt was made to ensure that groups were composed of both local and international students, with moderate and extensive experience as well experience with logistics organizations.

The group-based model building exercise was run in two sessions. In the first session, students used nominal group technique (NGT) to brainstorm the problem and identify five to ten UDEs of failing to organise and run an efficient supply chain. Groups then identified factors most likely to cause such effects and developed cause-effect relationships in the form of a casual diagram.

The actual models were developed in the second session. The TP was applied to develop the casual relationship between causes and effects. Since the students had no prior knowledge of TP and its analytical tools such as the CRT, the author of this paper developed the causal trees on white board with feedbacks and suggestions agreed by the groups.

Results of the brainstorming sessions

The number of UDEs identified by these groups in the first session of the exercise ranged between four and eight. The first task in the second session was to decide which UDEs were to be considered for the model building process. The groups agreed on the following UDEs:

- long cycle time;
- high cost of managing inventory;
- low customer service;
- high distribution cost;
- high cost of supply chain.

It is interesting to notice that the list of identified UDEs can be considered as the main performance metrics of supply chains and include both cost and non-cost measures. Many authors have suggested these items as measures of performance in supply chain models (Lee and Billington, 1992; Christopher, 1998; Mason-Jones and Towill, 1999).

The branches of the CRT were developed choosing one UDE at a time at random and following the guidelines mentioned earlier. When all the UDEs were considered and branches were constructed, these branches were put together and developed into a CRT for the entire supply chain system. The following paragraphs discuss the construction of each of the branches.

High inventory management cost

The groups identified high inventory management costs as one of the major consequences of failing to organise and execute an efficient supply chain. Overstock and understock of inventory were considered to be the root causes of this problem. Inventory management costs generally account for a significant percentage of total business costs. For a typical retail company, inventory can account for 10 to 20 percent of product cost. Given these high costs, production technologies and strategies developed over the last four decades, such as MRP, JIT and TOC, have been heavily focused on managing inventory. The major causes for high inventory cost were identified in the second session to be lack of communication, long cycle times and low usage of information technologies (IT). The CRT is shown in Figure 3.

Long cycle time

The criticality of cycle time or delay in a supply chain (including both product flow time and information flow time) was highlighted by Forrester (1958) some 40 years ago. Recently, Stalk and Hout (1990) and Mason-Jones and Towill (1999) have emphasised the importance of reduction of total cycle time. In order to avoid what is now called "bullwhip effect" (Lee *et al.*, 1997) or "Forrester effect" (Hines *et al.*, 2000), total cycle time must be reduced by improved

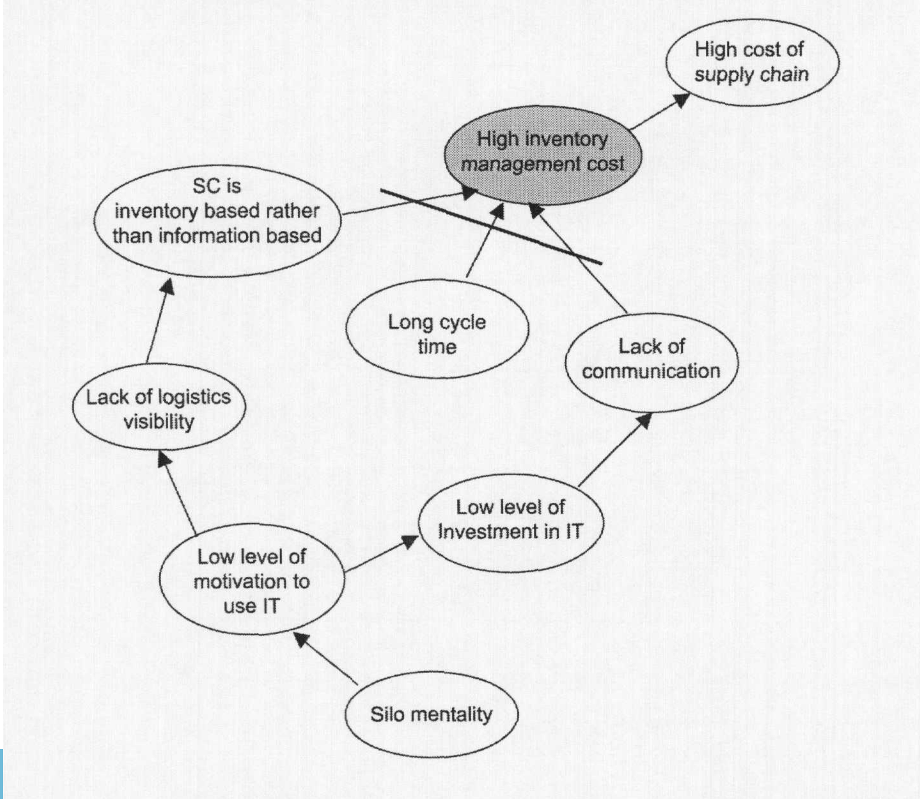


Figure 3. Causal relationships based on inventory management cost

coordination and communication among supply chain partners and by aligning product-process design with appropriate supply chain structure (see Figure 4).

Low customer satisfaction

Although cost is the performance measure of choice for many supply chains, one must realise that cost alone might not be adequate to describe system performance. During the second session, the group identified low level of customer satisfaction, a non-cost type of supply chain performance measure, as one of the UDEs. There are several ways to measure customer satisfaction in supply chains, such as responsiveness (Lee and Billington, 1993) and flexibility (Voudouris, 1996). Long cycle times adversely affect responsiveness and flexibility in a supply chain and this ultimately affects customer satisfaction (see Figure 5).

Management may define customer service as inadequate due to a lack of appreciation of the performance of the supply chain as a whole, which in turn may affect customer satisfaction (Lee and Billington, 1992). Lack of environmental appreciation on the part of the companies can also lead to customer dissatisfaction (see Figure 6).

High distribution cost

Lack of coordination contributes to low levels of integration across supply chains, which in turn affects distribution costs (see Figure 7).

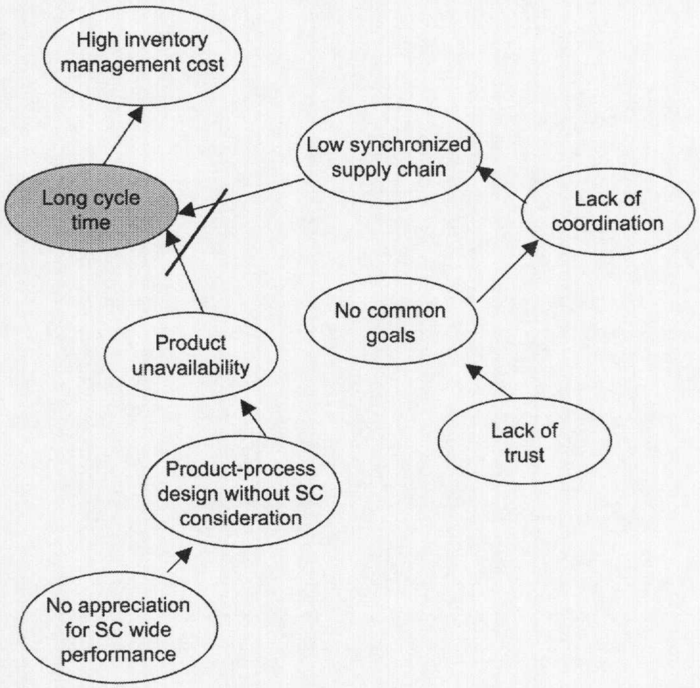


Figure 4.
Causal relationships based on cycle time

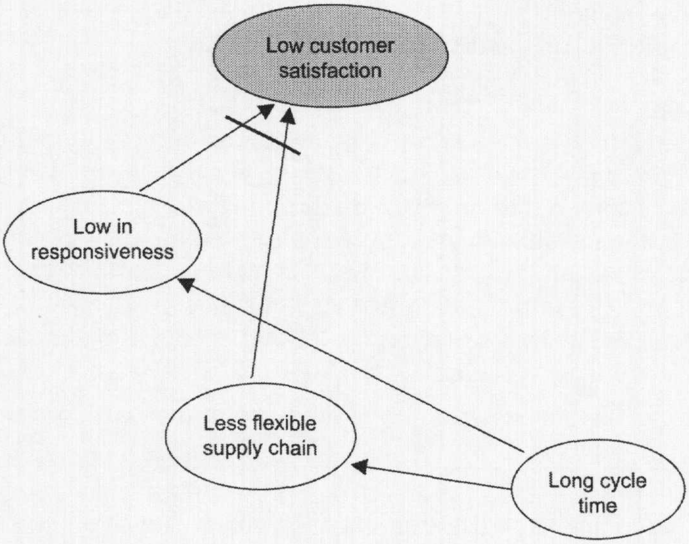


Figure 5. Causal relationships based on customer satisfaction

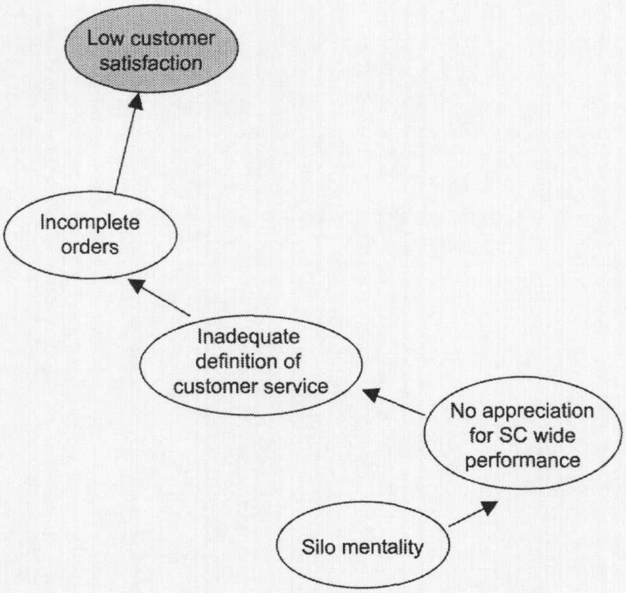


Figure 6. Causal relationships based on customer satisfaction

High cost of supply chain

The cost of supply chains is an aggregation of inventory management cost, distribution cost, and costs resulting from lack of environmental policies (see Figure 8). Inventory costs can be reduced by compressing lead times, appropriately adopting IT, and improving communication with the partners of the supply chain. A synchronised supply chain based on common goals among partner organizations ensures lower distribution cost, whereas lack of product retake policy contributes to expenses through increasing resource costs and losses in market share (Vandermerwe and Oliff, 1990).

Discussion

This research not only identified elements of successful SCM but also developed the causal relationships between these elements. Understanding the dynamic nature of the supply chain through cause and effect relationships is critical to the formulation of supply chain growth strategies. For instance, consider the case of "long cycle times" shown in Figure 4. The cause and effect diagram in Figure 4 identified cycle time as an element of successful SCM and the following two factors or "paths" show the main causes of this problem:

- *Path I.* No appreciation for SC-wide performance → product-process design without SC consideration → product unavailability → long cycle time.
- *Path II.* Lack of trust → no common goals → lack of coordination → low synchronised supply chain → long cycle time.

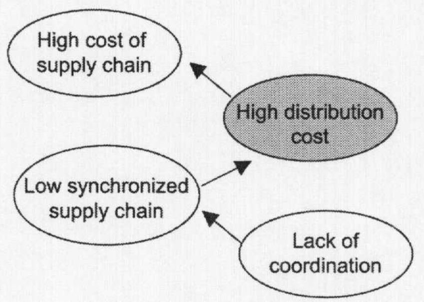


Figure 7.
Causal relationships based on distribution cost

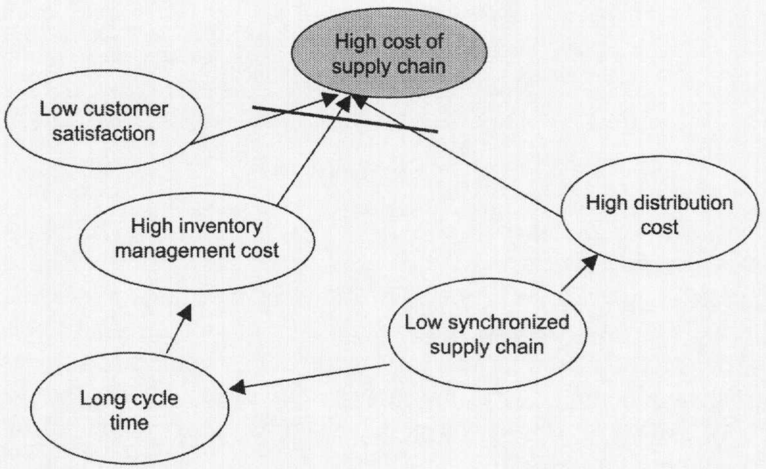


Figure 8.
Causal relationships based on cost of supply chain

Problems like long cycle times are influenced by complex inter-relationships between many factors. With a better understanding of these relationships, managers would be able to devise strategies for further improvement and growth in supply chains.

During the second session of the group-based model building exercise, two important aspects of SCM emerged which were not identified during the nominal group discussions. These are supply base management and environmental policy. The following subsections will describe the impact of these two aspects of SCM and develop branches for the CRT.

Supply base management

Low supply base management is the result of lack of common goals among the partner organizations in supply chains. Mistrust is likely to be a result of not sharing information as well as unwillingness to share risks and rewards (see Figure 9). The importance of supply base management on supply chain performance has been reported for many companies. Recently, Shin *et al.* (2000) suggested that better supply base orientation improves both the suppliers' and buyers' performance. The critical elements that improve the supply base management among organizations are long-term partnerships with channel participants (Choi and Hartley, 1996; De Toni and Nassimbeni, 1999), reducing the number of suppliers (Dyer, 1996; Hahn *et al.*, 1983; Kekre *et al.*, 1995), sharing risks and rewards (Handfield and Nicholas, 1999), involving suppliers in product development (Dyer, 1994), developing trust among channel partners (Newman, 1988).

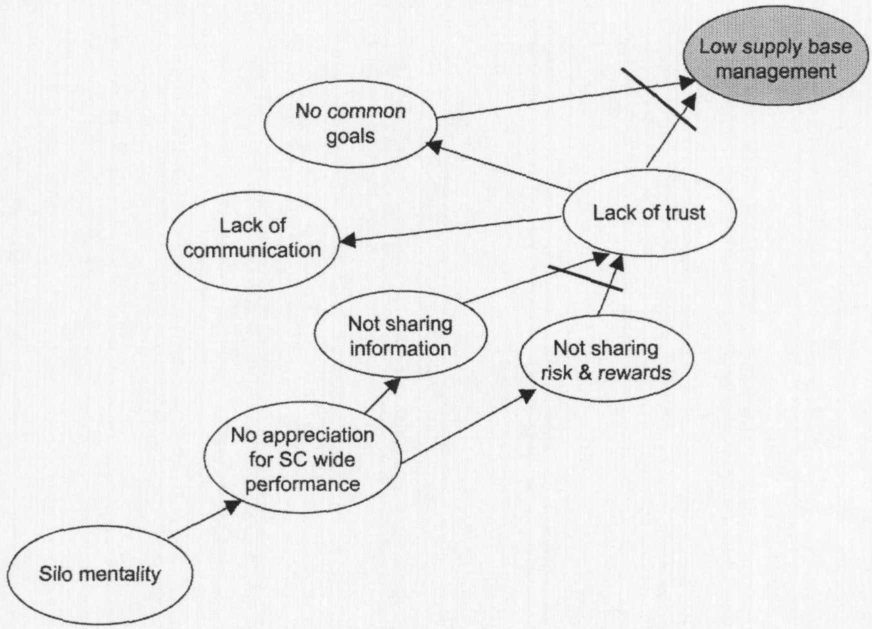


Figure 9.
Causal relationships based on supply base management

Environmental policy

Inadequate environmental policy can result in a number of adverse effects. These can include direct effects on costs of running businesses through low usage of recycled resources and indirect effects of degrading the local and global environment on customer satisfaction and market share (see Figure 10). Today, many researchers are in agreement that the environment makes good business sense and is an opportunity rather than a threat (Porter and Van der Linde, 1995; Shivastava, 1995; Hutchinson, 1996). A number of case studies have demonstrated that that there is compatibility between environmental and business goals (see Eden, 1994). By considering the environment in the design stage of its products, Xerox improved its ability to recover and reuse parts for future equipment. Implementing an end-of-life equipment take-back policy, Xerox's European operations saved over $80 million in 1997 (Maslennikova and Foley, 2000). Recently, several European countries have enforced environmental legislation, making producers responsible to take back products at the end of their life cycles (Cairncross, 1992).

Pressure to consider environmental aspects from legislation is not the only concern for companies. A "green" image has become an important marketing opportunity. Thus, it is imperative for companies to revisit their supply chain performance metrics in response to growing external institutional pressure and customers' environmental requirements.

The big picture

The conceptual CRT map developed during the group model building exercise is shown in Figure 11. In addition to the five UDEs identified by the groups,

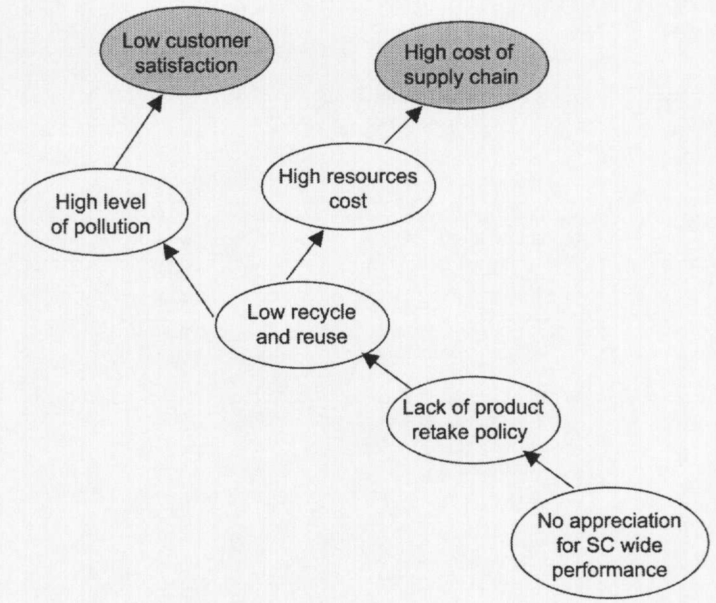


Figure 10.
Causality due to lack of product retake policy

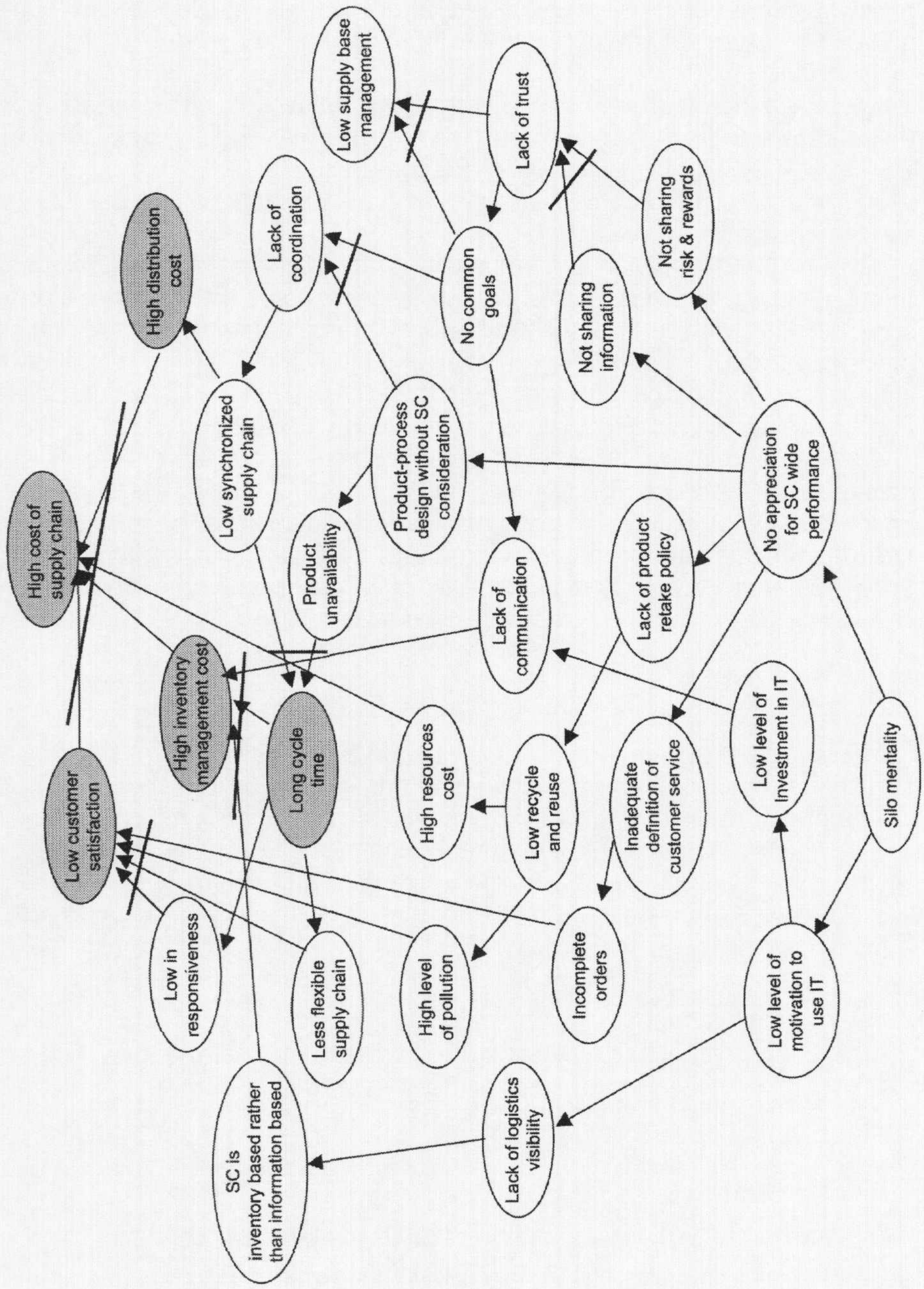


Figure 11.
A CRT for a supply chain system

four other UDEs were identified during the model building exercise. These are responsiveness, flexibility in the supply chain, incomplete orders, and percentage of products recovered, recycled and reused. All four measures are non-cost measures of supply chain performance and are related to customer satisfaction.

Responsiveness and incomplete orders have frequently been suggested in the literature as measures for supply chain performance (Altiok and Ranjan, 1995; Cook and Rogowski, 1996). Responsiveness can be considered as response time and on-time delivery, whereas incomplete orders can be considered as fill rate (Beamon, 1999).

Measures such as flexibility, and recovery and reuse rates are seldom used in supply chain analysis. Flexibility can measure a supply chain's ability to accommodate variety, volume and schedule fluctuations from the chain participants such as suppliers, producers, and customers. Since the supply chain exists in an uncertain environment, Beamon (1999, p. 284) emphasised that "flexibility is vital to the success of the supply chain". The use of recovery and reuse rate as a measure of supply chain performance is a recent phenomenon (Maslennikova and Foley, 2000). The EU Producers Responsibility Obligations (packaging waste) Regulation, 1996, is required to ensure that companies recover 60 percent of packaging waste by 2001 (McIntyre *et al.*, 1998). Researchers identified two types of motivation for companies to engage in product take-back process:

(1) economical; and

(2) environmental (Fleischmann *et al.*, 1997).

These issues are intertwined, as "increasing disposal costs make waste reduction more economical, and environmentally conscious customers represent new market opportunities" (Fleischmann *et al.*, 1997, p. 3).

The core problem appears to be with management (Figure 11). Owing to their limited vision, the management of many organizations fails to see and appreciate the importance of system-wide performance measures. Several other factors (causes) which may affect the performance of supply chains are:

- communication;
- trust among channel participants;
- investment and usage of IT;
- common goals;
- coordination;
- product-process design without supply chain consideration;
- lack of appreciation for supply chain wide performance measures;
- sharing risks and rewards;
- supply base orientation, inadequate definition of customer service.

Many empirical and case studies have identified these factors. For instance, Power *et al.* (2001) found that "more agile" supply chains are more customer focused, have greater involvement with suppliers and better utilise IT compared to the "less agile" supply chains. Many have suggested channel-wide management of inventories, coordination, shared visions, reduced supplier base (Cooper and Ellram, 1993; Shin *et al.*, 2000), and fair sharing of risks and rewards (Handfield and Nichols, 1999) as characteristics of integrated supply chain management.

Conclusion

To date, most of the studies undertaken on supply chain management have focused on a wide range of issues and are generally quantitative in nature. This research applied a qualitative approach not only to identify the critical success factors in a supply chain, but also the causal relationships between these factors. Management can use these relationships to develop growth strategies for their companies. However, these relationships need to be tested by large-scale empirical studies.

References

Altiok, T. and Ranjan, R. (1995), "Multi-stage, pull-type production/inventory systems", *IIE Transactions*, Vol. 27 No. 2, pp. 190-200.

Anderson, R.D., Jerman, R.E. and Crum, M.R. (1998), "Quality management influences on logistics performance", *Transportation Research Part E*, Vol. 34 No. 2, pp. 137-48.

Beamon, B.M. (1999), "Measuring supply chain performance", *International Journal of Operations and Production Management*, Vol. 19 No. 3, pp. 275-92.

Brewer, A. and Hensher, D. (2001), "Identifying the overarching logistics strategy of business processes: an exploratory analysis", *International Journal of Logistics: Research and Applications*, Vol. 4 No. 1, pp. 1-41.

Cairncross, F. (1992), "How Europe's companies reposition to recycle", *Harvard Business Review*, March-April, pp. 34-45.

Choi, T.Y. and Hartley, J.L. (1996), "Supplier development: customers as a catalyst of process change", *Business Horizons*, July-August, pp. 37-44.

Christopher, M. (1998), *Logistics and Supply Chain Management: Strategies for Reducing Cost and Improving Service*, 2nd ed., Prentice-Hall, London.

Cook, R.L. and Rogowski, R.A. (1996), "Applying JIT principles to continuous process manufacturing supply chains", *Production and Inventory Management Journal*, First Quarter, pp. 12-17.

Cooper, M.C. and Ellram, L.M. (1993), "Characteristics for supply chain management and the implications for purchasing and logistics strategy", *Journal of Logistics Management*, Vol. 4 No. 2, pp. 13-24.

Cox, J.F. and Spenser, M.S. (1998), *The Constraints Handbook*, St Lucie Press/APICS Series on Constraints Management, Boca Raton, FL.

Cross, D.J., Goldsby, T. and Clinton, S.R. (1997), "Information technology influences on world class logistics capability", *International Journal of Physical Distribution & Logistics Management*, Vol. 27 No. 1, pp. 4-17.

Deming, E. (1986), *Out of the Crisis*, MIT, Cambridge, MA.

De Toni, A. and Nassimbeni, G. (1999) "Just-in-time purchasing: an empirical study of operational practices, supplier development and performance", *Omega*, Vol. 28 No. 6, pp. 631-51.

Dettmer, H.W. (1997), *Goldratt's Theory of Constraints: A System Approach to Continuous Improvement*, ASQC Quality Press, Milwaukee, WI.

Dyer, J.H. (1994), "Dedicated assets: Japan's manufacturing edge", *Harvard Business Review*, November-December, pp. 174-8.

Dyer, J.H. (1996), "How Chrysler created an American keiretsu", *Harvard Business Review*, July-August, pp. 42-56.

Eden, S.E. (1994), "Using sustainable development – the business case", *Global Environment Change*, Vol. 4 No. 2, pp. 160-7.

Ellinger, A.E., Daugherty, P.J. and Plair, Q.J. (1999), "Customer satisfaction and loyalty in supply chain: the role of communication", *Transport Research Part E*, Vol. 35, pp. 121-34.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E., Van Nunen, J.A.E.E. and Van Wassenhove, L.N. (1997), "Quantitative models for reverse logistics: a review", *European Journal of Operational Research*, Vol. 103, pp. 1-17.

Forrester, J. (1958), "Industrial dynamics: a major breakthrough for decision makers", *Harvard Business Review*, July August, pp. 37-66.

Forrester, J. (1961), *Industrial Dynamics*, MIT Press, Cambridge, MA.

Goldratt, E.M. (1980), "Optimized production timetable: beyond MRP: something better is finally here", paper presented at APICS 23rd Annual International Conference Proceedings.

Goldratt, E.M. (1988), "Computerized shop floor scheduling", *International Journal of Production Research*, Vol. 26 No. 3, pp. 443-55.

Goldratt, E.M. (1990), *What Is this Thing Called Theory of Constraints and How Should It Be Implemented?*, North River Press, New York, NY.

Goldratt, E.M. (1994), *It's Not Luck*, Gower, Aldershot.

Goldratt, E.M. and Cox, J. (1984), *The Goal: An Ongoing Improvement Process*, Gower, Aldershot.

Goldratt, E.M. and Fox, J. (1986), *The Race*, North River Press, New York, NY.

Hahn, C.K., Pinto, P.A. and Bragg, D.J. (1983), "'Just-in-time' production and purchasing", *Journal of Purchasing and Materials Management*, Vol. 19 No. 3, pp. 2-10.

Handfield, R. and Nichols, E. Jr (1999), *Introduction to Supply Chain Management*, Prentice-Hall, Englewood Cliffs, NJ.

Hines, P., Lamming, R., Jones, D., Cousins, P. and Rich, N. (2000), *Value Stream Management: Strategy and Excellence in the Supply Chain*, Prentice-Hall, London.

Holmes, G. (1995), *Supply Chain Management: Europe's New Competitive Battleground*, EIU Research Report.

Hutchinson, C. (1996), "Integrating environment policy with business strategy", *Long Range Planning*, Vol. 29 No. 1, pp. 11-26.

Juran, J.M. (1992), *Juran on Quality by Design*, Free Press, New York, NY.

Kekre, S., Murthi, B.P.S. and Srinivasan, K. (1995), "Operating decisions, supplier availability and quality: an empirical study", *Journal of Operations Management*, Vol. 12 No. 3/4, pp. 387-96.

Kendall, G.I. (1998), *Securing the Future: Strategies for Exponential Growth Using the Theory of Constraints*, St Lucie Press/APICS Series on Constraints Management, Boca Raton, FL.

Lee, H.L. and Billington, C. (1992), "Managing supply chain inventory: pitfalls and opportunities", *Sloan Management Review*, Vol. 33, pp. 65-73.

Lee, H.L. and Billington, C. (1993), "Material management in decentralized supply chains", *Operations Research*, Vol. 41 No. 5, pp. 835-47.

Lee, H.L., Billington, C. and Carter, B. (1993), "Hewlett Packard gains control of inventory and service through design for localisation", *Interfaces*, Vol. 23, July-August, pp. 1-11.

Lee, H.L., Padmannabhan, V. and Whang, S. (1997), "The bullwhip effect in supply chains", *Sloan Management Review*, Vol. 38 No. 3, pp. 93-102.

McIntyre, K., Smith, H.A., Henham, A. and Pretlove, J. (1998), "Logistics performance measurement and greening supply chains: diverging mindsets", *International Journal of Logistics Management*, Vol. 9 No. 1, pp. 57-68.

Magretta, J. (1998), "Fast, global, and entrepreneurial: supply chain management, Hong Kong style: an interview with Victor Fung", *Harvard Business Review*, September-October, pp. 103-14.

Maslennikova, I. and Foley, D. (2000), "Xerox's approach to sustainability", *Interfaces*, Vol. 30 No. 3, pp. 226-33.

Mason-Jones, R. and Towill, D.R. (1999), "Total cycle time compression and the agile supply chain", *International Journal of Production Economics*, Vol. 62, pp. 61-73.

Monczka, R., Peterson, K., Handfield, R. and Ragatz, G. (1998), "Determinants of successful vs non-successful strategic supplier alliances", *Decision Sciences*, Vol. 29 No. 3, pp. 553-77.

Monden, Y. (1981), "What makes the Toyota production system really tick", *Journal of Industrial Engineering*, January, pp. 36-46.

Newman, R.G. (1988), "The buyer-supplier relationship under just-in-time", *Production and Inventory Management Journal*, Vol. 29 No. 3, pp. 45-50.

Noreen, E., Smith, D. and Mackey, J. (1995), *The Theory of Constraints and Its Implications for Management Accounting*, North River Press, MA.

Orlicky, J. (1975), *Material Requirement Planning*, McGraw-Hill, New York, NY.

Porter, M. and Van der Linde, C. (1995), "Green and competitive: ending the stalemate", *Harvard Business Review*, September, pp. 120-34.

Power, D., Sohal, A.S. and Rahman, S. (2001), "Critical success factors in agile supply chain management: an empirical study", *International Journal of Physical Distribution & Logistics Management*, Vol. 31 No. 4, pp. 247-65.

Rahman, S. (1998), "Theory of constraints – a review of the philosophy and its application", *International Journal of Operations and Production Management*, Vol. 18 No. 4, pp. 336-55.

Shin, H., Collier, D.A. and Wilson, D.D. (2000), "Supply management orientation and supply/buyer performance", *Journal of Operations Management*, Vol. 18, pp. 317-33.

Shrivastava, P. (1995), "Environmental technologies and competitive advantage", *Strategic Management Journal*, Vol. 16, pp. 183-200.

Shimchi-Levi, D., Kaminsky, P. and Shimchi-Levi, E. (2000), *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*, McGraw-Hill International Edition, Singapore.

Stalk, G. and Hout, T. (1990), *Competing against Time*, Free Press, London.

Tan, K., Kannan, V.R., Handfield, R.B. and Ghosh, S. (1999), "Supply chain management: an empirical study of its impact on performance", *International Journal of Operations and Production Management*, Vol. 19 No. 10, pp. 1034-52.

Vandermerewe, S. and Oliff, M.D. (1990), "Customer drive corporations green", *Long Range Planning*, Vol. 23 No. 6, pp. 10-16.

Voudouris, V.T. (1996), "Mathematical programming techniques to debotteneck the supply chain of fine chemical industries", *Computers and Chemical Engineering*, Vol. 20, Part B, pp. 1269-74.

Womack, J.P. and Jones, D.T. (1996), *Lean Thinking*, Simon and Schuster, New York, NY.

Appendix

A legitimate reservation exists when the logic presented does not make sense. The cause-effect relationship must always be stated as: IF C THEN E. There are two primary reasons for the observer to voice legitimate reservations when one presents a cause-effect relationship: ENTITY EXISTENCE and CAUSAL EXISTENCE. The observer can add to the explanation of his reservation by using 3 through 6 below to explain the scientific nature of the reservation.

1. ENTITY EXISTENCE: Questioning the existence of the entity (cause or effect) by explaining that the cause or the effect does not actually exist.

2. CAUSALITY EXISTENCE: Questioning the existence of the causal link between the cause and the effect by use of the IF.. THEN statement; by explaining that although we agree that both C and E exist, there is no stated link between the stated cause and the observed effect.

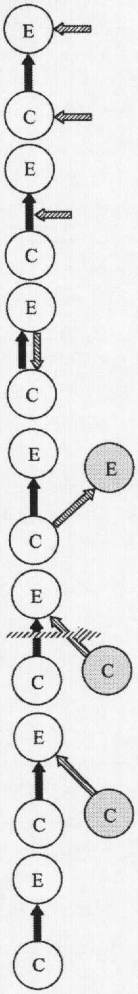
3. TAUTOLOGY: Being redundant in stating the cause-effect relationship. cause is actually a rewording of the effect, thus being redundant. If a tautology exists, you can state the cause as being the effect and the effect as being the cause (e.g. the arrow could point in either direction). Therefore, the cause does not lead to the effect.

4. PREDICTED EFFECT (ENTITY) EXISTENCE: Using another effect (E') to show that the hypothesized cause (C) does not result in the initially observed effect (E). On the other hand, if the original cause does not result in the additional effect, then this supports the original cause-effect relationship.

5. CAUSE INSUFFICIENCY: Explaining that an additional non-trivial cause must exist to explain the existence of the observed effect. If either of the hypothesized causes does not exist, then the observed effect will also not exist. IF C' AND IF C, THEN E.

6. ADDITIONAL CAUSE: Explaining that an additional cause that adds to the size of the observed effect must exist. The causes magnify the size of the observed effect and neither cause by itself can totally explain the size or extent of the effect. The IF… THEN statement is worded as follows: IF C' AND C, THEN E.

7. CLARITY: Not fully understanding the cause effect relationship or the entity. Requesting an additional explanation of the cause-effect relationship or the entity.



LEGEND: ○ and ➡ = Original hypothesis

● and ⇨ = Legitimate reservations

Source: Avraham Y. Goldratt Institute

Figure A1.
Categories for legitimate reservations