A System Dynamics Model of Evolving Supply Chain Relationships and Inter-firm Trust

Yatsai Tseng
Department of Business Administration, Tunghai University, Taiwan

Weiyang Wang,
Department of Information Management, National Kaohsiung University of Applied Sciences, Taiwan

Mengjue Wang
Department of Information Management, National Kaohsiung University of Applied Sciences, Taiwan

Abstract

Inter-firm trust is an essential element in supplier relationship that shapes the collaboration and coordination between suppliers and buyers. In this paper, we use system dynamics as an approach and perspective to analyze the evolutionary process of supply chain collaboration. Use a valve manufacturing firm as an illustrative case, this paper illustrates how a buyer firm in a networked supply chain unexpectedly harmed the inter-firm trust between the buyer and its suppliers that further resulted in the collapse of collaborative relationships. Based on the quantitative system dynamics model developed, this paper argues and shows that supply chain relationships may be more complex than the consideration of transaction costs. Path dependency of the make or buy decision may exist and drive a supply chain to evolve over time. Buyers and suppliers' rational decisions to reduce their own risks and to optimize efficiency may not only interfere with the benefits of the other side but also entrap a long existed supply chain to collapse. From the economic perspective, how to balance the time required for capacity expansion and the time for suppliers to develop new customers is of the essence in such a vulnerable supply chain setting.

1. Introduction

Inter-firm trust is an essential element in supplier relationship that shapes the collaboration and coordination between suppliers and buyers (Akkermans et al., 2004;

Laaksonen et al., 2009; Das and Teng, 1998; Zaheer et al., 1998; Blois, 1999; Dyer and Chu, 2003). Supply chain collaboration requires a high level of trust on all sides. Inter-firm trust has been empirically and theoretically recognized to be beneficial in supply chain coordination and collaboration (Barney and Hansen, 1994; Gulati, 195; Zaheer et al., 1998; Krishnan et al., 2006; Laaksonen et al., 2009). However, differences may exist in buyer's and supplier's perspectives of supply chain collaboration (Nyaga, et al., 2010). The trusting firm in an inter-organizational relationship may be vulnerable to the local optimization decisions made by a partner who looks for more competitive advantages. Hence, in spite of the significant role of supply chain collaboration in increasing the performance of supply chain and decreasing in the amount of transaction costs (Dyer and Chu, 2003), supply chain collaboration is practically vulnerable by its nature.

In this paper, we use system dynamics as an approach and perspective to analyze the evolutionary process of supply chain collaboration. Different from Akkermans, et al. (2004) that focuses on the reinforcing feedback loop of trust, transparency, and habituation, this paper illustrates that how a buyer firm in a networked supply chain unexpectedly harmed the inter-firm trust with its suppliers, leading to the collapse of the relationships among them. Use the valve firm as an illustrative case, this paper argues and shows that supply chain relationships may be more complex than the consideration of transaction costs (Williamson, 1979, 1985). Path dependency of the make or buy decision may drive a supply chain to evolve over time. Buyers and suppliers' rational decisions to reduce their own risks and to optimize efficiency may not only interfere with the benefits of the other side but also entrap a long existed supply chain to collapse. A quantitative system dynamics model is built to explore the evolutionary process of a supply chain relationship. Three different management attitudes towards supplier relationships, *collaborative*, *complimentary source,* and *substitution* are examined and experimented. How a firm like the valve firm under study should manage its supply chain where a vulnerable supply chain trust exists is further discussed.

The rest of the paper is organized as follows: Section 2 describes the background information of the valve firm and its networked supply chain. Section 3 illustrates the model overview. In Section 4 we present the causal feedback diagram simplified from the quantitative model and the simulation result analysis. Accordingly, policy designs are further discussed in Section 5. Finally, discussion of research implications is provided as well as limitations and suggestions for future research.

2. Background Information of the Illustrative Case

Valve industry in Taiwan is an export-oriented industry to fulfill OEM orders from abroad. Though most valve manufacturers in Taiwan are small and medium enterprises, they have successfully attracted international valve orders with high flexibility, high quality, responsiveness, and low price. However, in recent years, Chinese companies have been making the competition environment more severe with their low production costs. More and more firms in the valve supply chain, upstream or downstream, are now moving their plants to China. KMV Company, the valve manufacturer under study, is one of them.

KMV Company was established in 1987 by a branded valve manufacturer in the United States. As a subsidiary of the parent valve manufacturer, KMV produces OEM valves majorly for its parent company. However, orders from the parent company are not guaranteed. Price, order to delivery time, and quality are critical factors for the parent company to determine whether and how much to order. If KMV Company cannot fulfill valve orders in time, order cancellation may also occur. In 2006, KMV Company planned to move its low profit margin products to China to take advantages of low production costs. The plant was expected to manufacture low profit valves and critical materials to support valve productions. In valve manufacturing, valve castings are the most essential parts in valve products. Valve casting occupies about sixty percents of product costs and impacts a lot in the quality of finished valve products. KMV Company had five major valve castings suppliers and they had collaborated for many years in Taiwan. Hence, as illustrated in Figure 1, KMV Company kept the manufacturing activities of existed high-profit margin and high-quality valve products to remain in Taiwan.

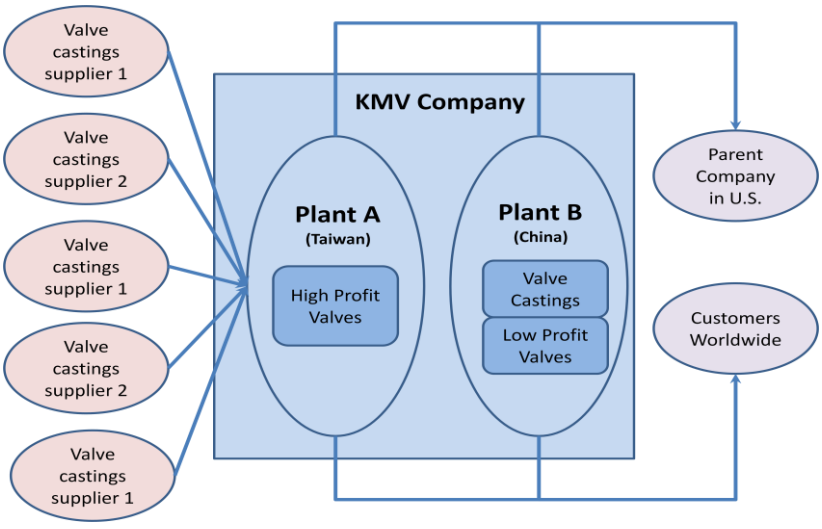

Figure 1 Supply chain of KMV Company

However, since KMV's subsidiary plant in China started its pilot run in 2008, castings supply from KMV's collaborated suppliers began to drop while the percentage of valve castings from KMV's subsidiary plant in China arose. KMV's subsidiary plant even started to offer valve castings for high-profit-margin valves that are manufactured in Taiwan. In 2010, supply of valve castings from KMV's subsidiary achieved one-third of total valve castings to support high profit-margin products. Delivery delay from suppliers to KMV Company was lengthened than ever before. In confrontation of possible shortage of supply, KMV Company transferred a greater portion of casting orders to its subsidiary plant in China, even though the quality was not good enough and the yield rate was low. KMV Company is now considering moving most manufacturing activities to China in a consideration of the part supply.

3. A dynamics model of the evolved supply chain relationship

To explore how KMV's supply china relationship evolves over time, twenty-nine interviews (approximately one and half an hour to thirty minutes each) were conducted. Operational and middle managers in production and planning department were interviewed. The secondary sources included, for example, company materials as well as industrial reports. The purpose of the interviews was to clarify KMV's present and prior decisions and actions, as valve castings order allocation policy, attitude towards supply chain relationship, plant investment, etc. Accordingly, we built a system dynamics model that is focused on KMV's supply chain model. The simulation time unit is measured in months and the time horizon of simulation is set to run from March, 2006, the time when KMV Company started its investment in new plant, to February, 2010. Based on the model validation process proposed by Forrester and Senge (1980), validations have been performed to ensure model validity, including the structural verification test, unit consistency test, boundary test, parameter test, and behavior reproduction test. The results of behavior reproduction test are as shown in Figure 2. Using a simplified qualitative causal loop diagram, how the relationship between KMV and its suppliers evolves over time is analyzed step by step according to the sequence of *KMV's Order fulfillment process, KMV's reallocation of orders from suppliers to plant in China*, and the *rapid collapse of KMV's supplier relationships.*

Figure 2 Behavior reproduction test

Order fulfillment process in KMV Company

As shown as the balancing loop denoted as *loop 1* in Figure 3, KMV Company's production rate is determined based on the amount of order backlog on hand. However, insufficient inventory of valve castings, the most critical part of valves, may impact the actual volume of production rate. When KMV's order backlog are accumulated and time to delivery is lengthened, the parent company in U.S. and other customers worldwide reduce the amount of orders to KMV Company and may even cancel prior orders that have been confirmed. Hence, how to ensure the availability of valve castings has been a critical issue for KMV Company.

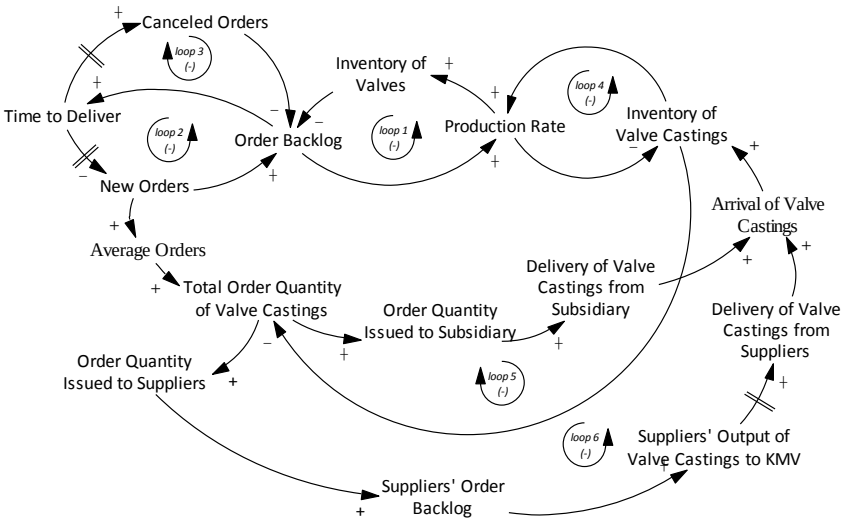

Figure 3 Order fulfillment process in KMV Company

In KMV Company, valve orders are fulfilled by build-to-order and valve castings are procured when customer orders are confirmed. The actual amount of valve casting orders is determined by average valve orders of past three months. KMV Company also keeps a certain level of safety stock of valve castings to avoid shortage problem of supply. Though KMV replenishes valve castings mainly from collaborated suppliers, lengthened delivery delays from suppliers may lead KMV to release valve casting orders to its subsidiary plant. As shown in Figure 3, the depletion of *Inventory of Valve Castings* is denoted as *loop 4*, and the replenishment of valve castings from KMV's subsidiary plant and suppliers are denoted as *loop 5* and *loop 6*, respectively.

Reallocation policy of valve castings orders

Valve castings suppliers usually manufacture valve castings when orders are received from KMV. However, when KMV releases replenishment orders that exceeds the production capacity that suppliers have allocated for KMV, a lengthened delivery delay of valve castings from suppliers may occur. To acquire valve castings in time to fulfill customer orders, KMV Company adjusts its quantity of casting orders to suppliers, as illustrated by the loop, *loop 8*, in Figure 4. KMV reallocates those replenishment orders to its subsidiary plant, as the loop denoted as *loop 5*, even though the yield rate of subsidiary plant may be as high as expected. As illustrated in *loop 9*, in Figure 4, KMV may even increase its investment in its subsidiary in China when the subsidiary plant received more and more transferred replenishment orders.

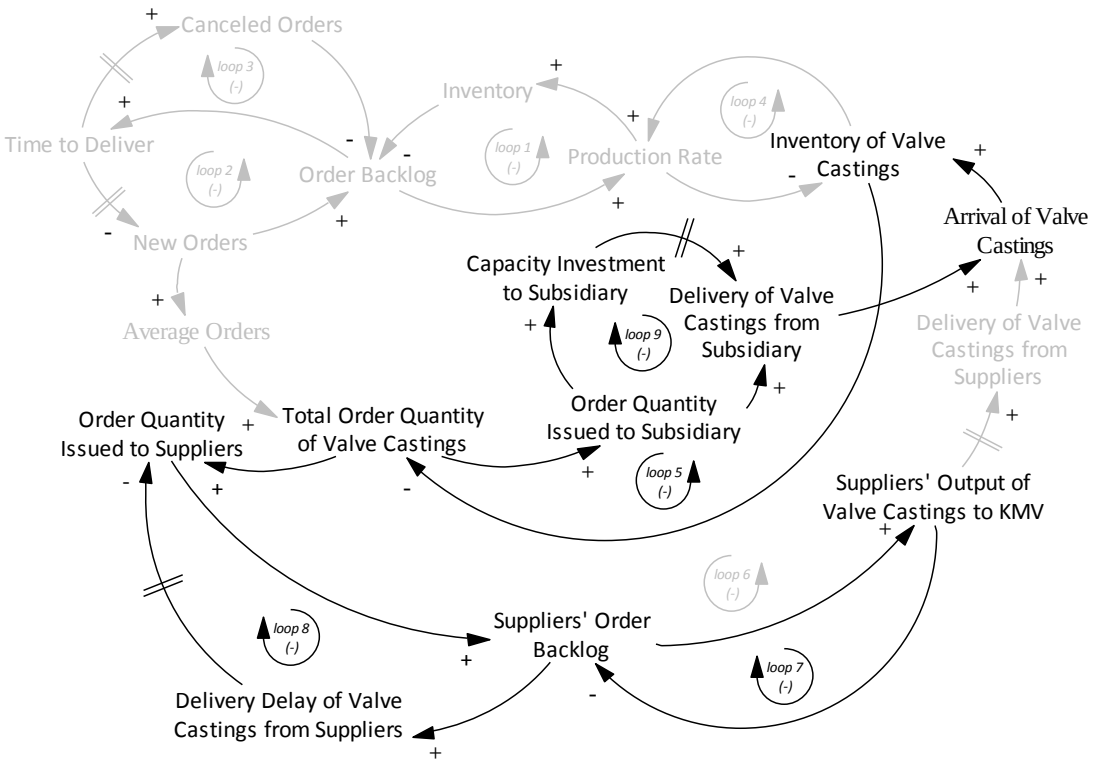

Figure 4 Order Reallocation

Vicious loops leading to the collapse of Inter-firm trust

KMV's order transfers and capacity investment in subsidiary plant annoy its collaborated suppliers. Suppliers start doubting whether KMV is moving manufacturing activities of high profit valve products to China, just like other domestic companies in Taiwan. As illustrated in Figure 5, even not knowing the exact quantity of orders that KMV is releasing to subsidiary plant, the information gradually harms suppliers' trust in their collaboration relationship with KMV. Valve casting suppliers respond to this by looking for new customers to substitute KMV Company. After a period of time, suppliers are having more and more new customers and new orders. To KMV Company and its suppliers, their long existed collaboration relationship is rapidly collapsing. As shown in Figure 5, the vicious loop denoted as *Loop 10* illustrates the breaking down process of KMV's supplier relationships. The more casting orders suppliers receive from new customers, the lower percentage of KMV's orders in suppliers' total casting orders, leading to suppliers' higher tendency to expand new customer base. Suppliers' production capacity allocation decision also accelerates the collapse of collaboration relationships. To attract and serve new customers, suppliers reallocate production capacity that was allocated for KMV to other potential customers, leading to a lengthened delivery delay of valve castings from suppliers to KMV.

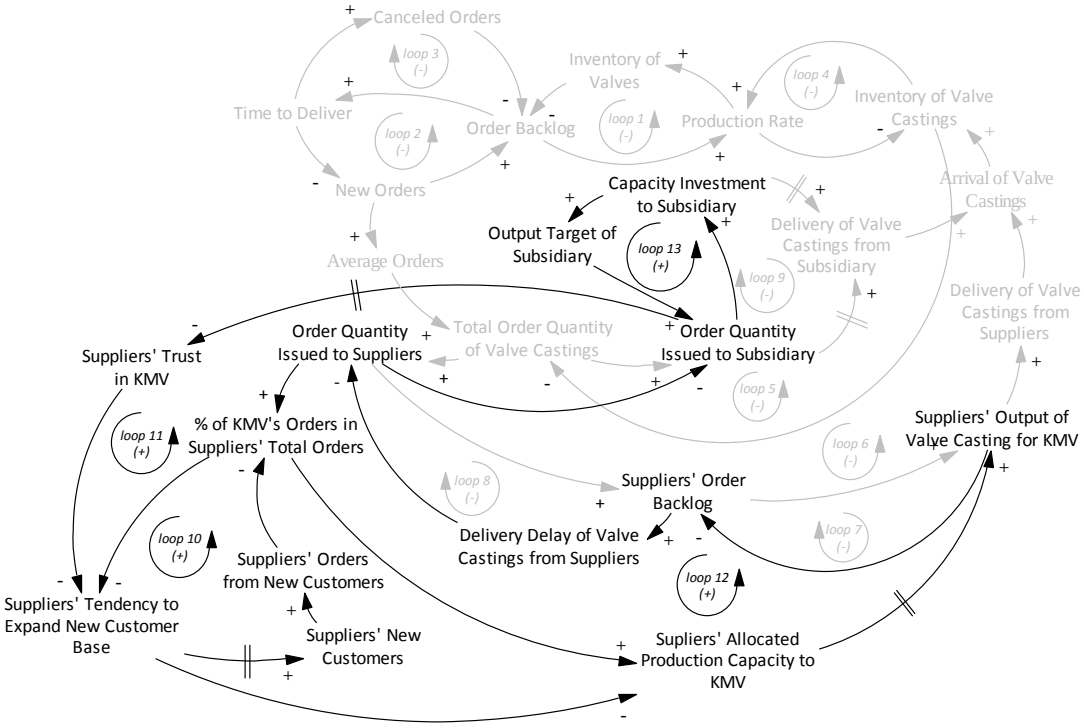

Figure 5 *Vicious loops leading to the collapse of Inter-firm trust*

In response to the lengthened delay, KMV reduces the amount of order quantity to suppliers and turns to its subsidiary plant in China. Another two vicious feedback loops emerge as a result. First, as illustrated by the vicious denoted as *loop 11* in Figure 5, suppliers' trust in KMV is further destroyed, suppliers' production capacity allocated for KMV gets fewer, and the delivery delay of valve castings is further lengthened. Second, the smaller percentage of KMV orders in suppliers' total orders implies the less and less importance of KMV orders to suppliers. As illustrated by *loop 12* in Figure 5, as KMV transfers orders to subsidiary plant in order to ensure the availability of valve casting supply, the less importance of KMV orders to suppliers leads to fewer production capacity allocated to KMV and worsens the shortage problem of valve castings from suppliers. In confrontation of such a circumstance, KMV expands the production capacity investment of its subsidiary plant in China for valve castings. Since the subsidiary plant has its own performance target as most companies are, to achieve the targeted production efficiency and corresponding output target, subsidiary plant in China asks for more valve castings orders from Taiwan, intensifying the order transfer action, strengthening the impacts of the aforementioned vicious loop, and accelerate the collapse of supply chain relationship.

4. Simulation and policy design

The aforementioned dynamically evolved supply chain relationship is illustrated in Figure 6, Figure 7 and Figure 8. Using the real data of customer valve orders that KMV Company offered, as illustrated by the blue line in Figure 6, the simulation horizon is set to forty-eight months. By build-to-order production, KMV Company manufactures valves (denoted by the red line) and issues procurement orders of valve castings orders (denoted as the green line) to support production. However, when KMV's investment of new subsidiary in China began and gradually increased at the end of 2007 (about the 16th month in simulations), suppliers' trust in KMV started to drop. As shown in Figure 7, delivery delay of valve castings from suppliers is lengthened than ever before. As a result, KMV Company issues transferred a portion of valve casting orders to its subsidiary plant in a response to possible shortage problem of valve castings. Even when suppliers' delivery delay is shorten during the period of the 41st to the 48th month, the amount of orders transferred to subsidiary still grows because of subsidiary plant's targeted production efficiency and corresponding output target. Consequently, as illustrated in Figure 8, the amount of orders to suppliers is decreasing while more orders are transferred to KMV's subsidiary. The collaboration relationship between KMV and its suppliers is collapsing as suppliers' trust in KMV kept falling.

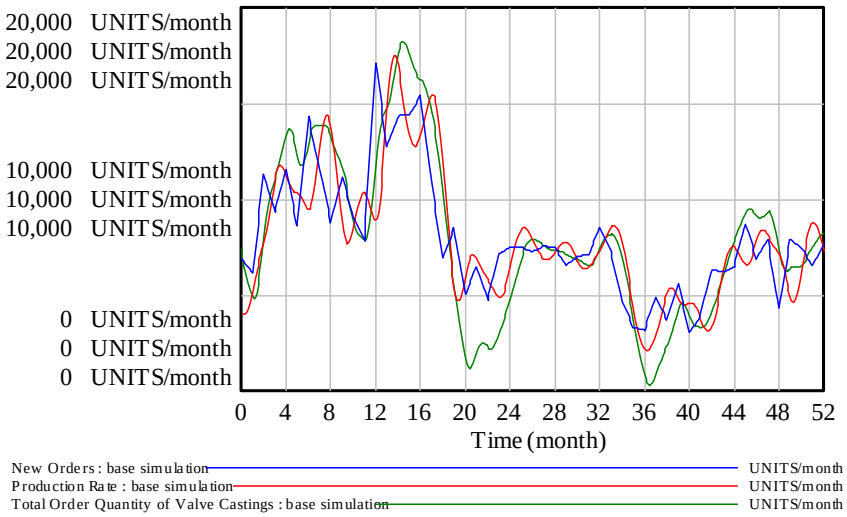

Figure 6 Simulation results (1)

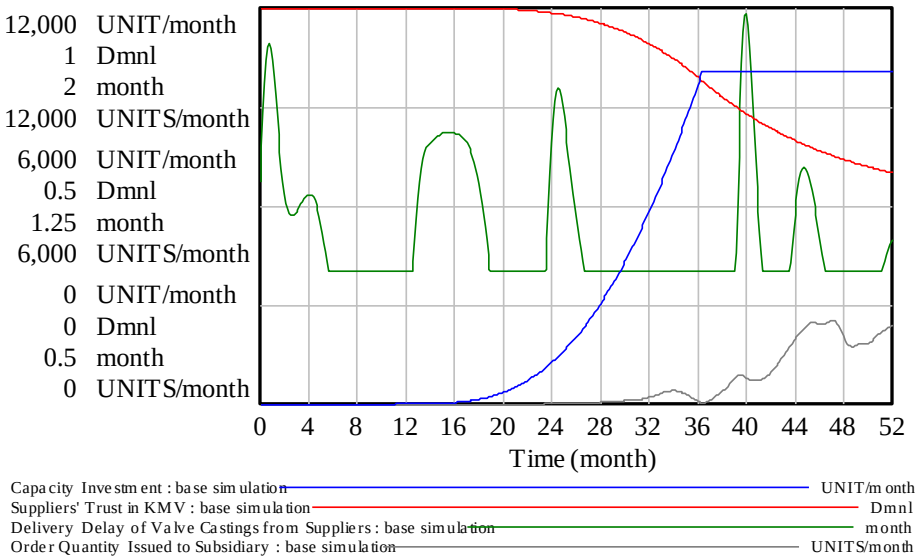

Figure 7 Simulation results (2)

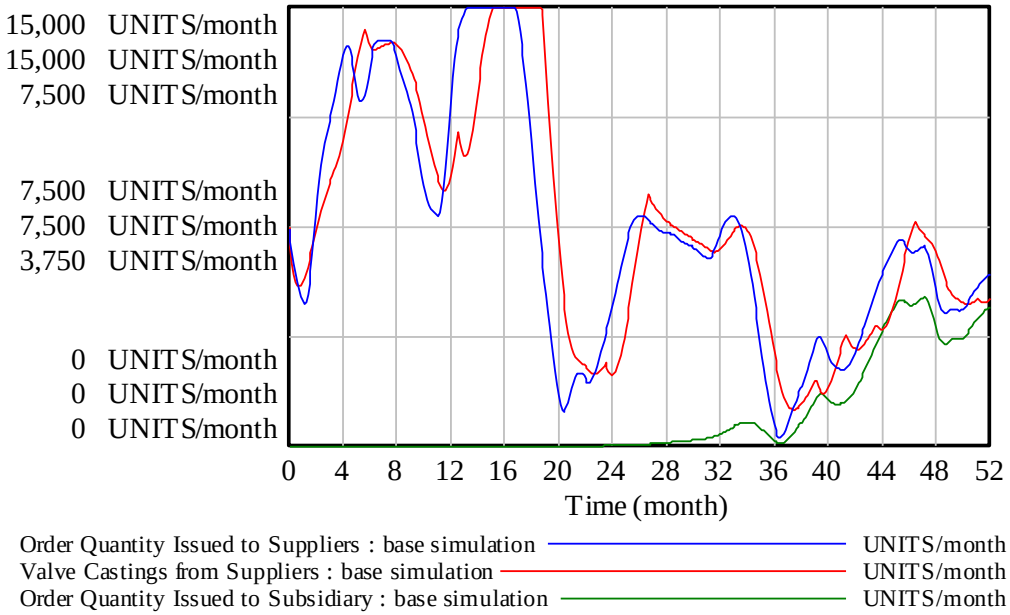

Figure 8 Simulation results (3)

In a supply chain relationship where vulnerable trust exists, how should a firm like KMV Company should to do to ensure supply availability? To explore possible resolutions, a series of simulation for better policy designs is conducted. Since valve orders are greatly influenced by chemical industry for liquid control and a seven-year cycle is often seen in chemical industry, an assumed data set of customer demand of valve products, as shown in Figure 9, is used to simplify the analysis. Besides, time

horizon of simulation is set to extend from 48 months to 100 months to reveal the impacts of different policy designs in managing the supply chain.

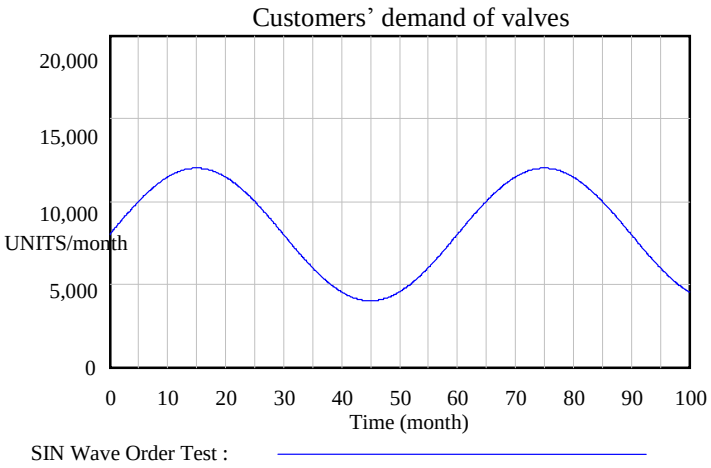

Figure 9 Assumed customer demand of valves

Three different KVMV's attitude towards its supplier relationships, *collaborative*, *complimentary source*, and *substitution* are examined and experimented. The differences between each supplier relationship attitude are reflected in the procurement and investment policies. Table 1 gives the summary of the three supplier relationship policies.

(1) Policy A: maintains collaborative supply chain relationships by allocating 70% percent of total valve castings orders to suppliers. Investment in subsidiary plant (an output of 10,000 units of valve castings/month per investment) is based mainly on the perception of decreasing revenues when shortage problem of valve castings occurs.

(2) Policy B: treats suppliers as complimentary sources to supply about 20% percents of KMV's total valve castings requirements to suppliers. Production capacity investment of subsidiary plant is more aggressive than policy A (an output of 20,000 units of valve castings/month per investment) when shortage problem of valve castings and supplier relationship problem are perceived.

(3) Policy C: aggressively expands the production capacity of subsidiary plants from the start of simulation to substitute original collaborated suppliers to prevent shortage of supply. At least 80% percent of valve casting orders is allocated to subsidiary plant when the plant is ready for production.

Table 1 Supplier relationship management policies

Policy	Attitude towards suppliers	Orders to suppliers	Investment of subsidiary
Policy A	Collaboration	70% at least	10,000 units /month when shortage problem occurs
Policy B	Complimentary sources	20%	20,000 units /month when shortage problem occurs
Policy C	Substitution	20% at maximum	20,000 units /month from the beginning

Impacts of the three supplier relationship policies are illustrated in Figure 10. In Figure 10, lines in blue, red, and green denote the simulation results of *Collaborative*, *Complimentary sources*, and *Substitution* policies, respectively. Compare simulation results of the three designed policies, one can make several critical observations. First, as shown in the figure, simulated pattern *Suppliers Trust in KMV* drop in all the three policies, illustrating the vulnerable supply chain trust that KMV has faced. Second, though the *Collaborative* policy (policy A) has a higher degree of *Suppliers' Trust in KMV*, the falling suppliers trust unavoidably leads suppliers to develop new customers, resulted in the decreasing *% of KMV's Orders in Suppliers' Total Orders*. Third, simulated *Inventory of Valve Castings* in *Complimentary sources* and *Substitution* policies drop quickly while the one in *Collaborative* policy reaches another peak. In

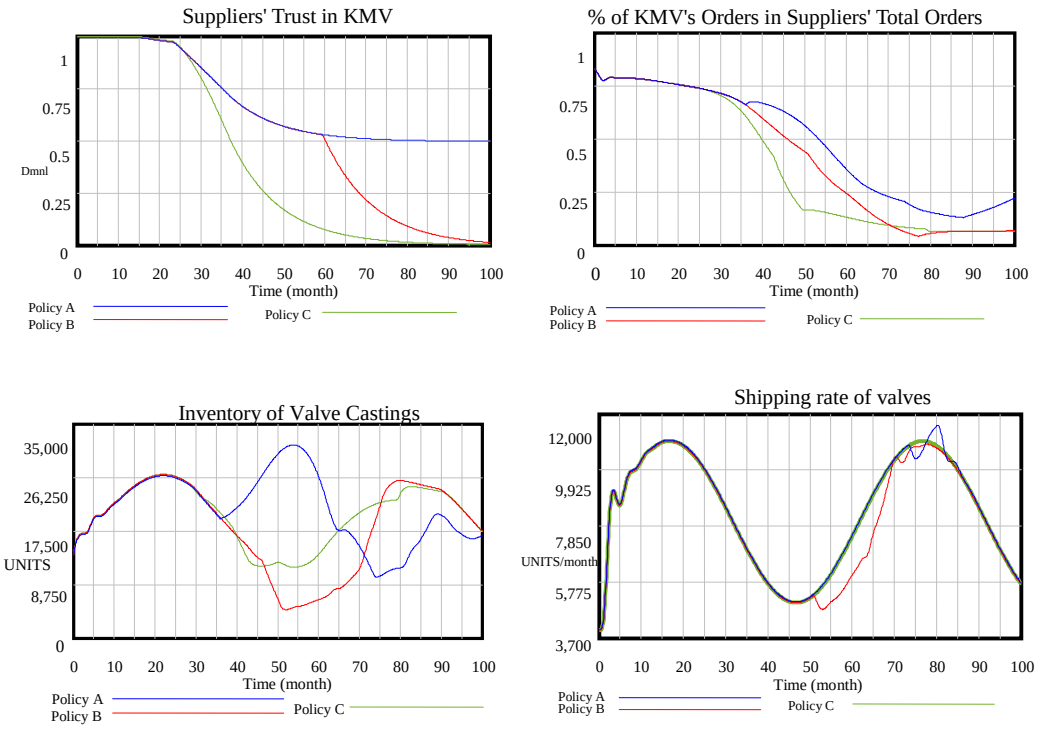

Figure 10 Simulation results of different supplier relationship policies

the *Substitution* policy, though the simulated *% of KMV's Orders in Suppliers' Total Orders* drops rapidly, the earlier investment of subsidiary plant makes the company ready to manufacture valve castings by its own. As to the greater amount of *Inventory of Valve Castings* in the *Collaborative* policy, guaranteed procurement orders to suppliers when valve orders and corresponding casting requirement are decreasing is the main cause. However, the inventory of valve casting in the *Collaborative* policy still falls when suppliers gains more orders from newly developed customers.

Finally, the forth observation and the most important finding is the *Shipping rate of valves* in *Collaborative* and *Substitution* policies are almost the same, implying that shortage of valve castings, if there's any, does not influence manufacturing and order fulfillment activities to customers. Compared to *Collaborative* policy, the *Substitution* policy protects the company from insufficient supply of valve castings with a lower level of casting stocks. Accordingly, the *Substitution* policy, that is, aggressively expand subsidiary plant in advance, is suggested to be a better policy to manage supply chain relationship if suppliers' trust is vulnerable. The policy ensures the availability of material supply from subsidiary plant before suppliers develop enough new customers. Capturing the dynamic relationship between the time required for capacity expansion and the time for suppliers to develop new customers is of the essence in managing such a supply chain relationship is vulnerable. Accordingly, we would not suggest the policy that views suppliers as a complimentary source and invests in subsidiary plant only when shortage problem occurs.

5. Concluding remarks and future research directions

Supply chain collaboration is more important than ever. Critical details, such as selecting the right partner, matching inter-organizational needs and capabilities, clearly defining standards and goals, and numerous operational decisions such as the allocation of the order quantity among multiple suppliers are often overlooked (Daugherty, et al., 2006). Business environment that expectedly and unexpectedly changes over time, also make supplier relationship hardly to stay static. A collaborated supply chain can be destroyed unintentionally when vicious feedback loops are activated to collapse the trust among buyer and seller. From the economic perspective, we suggest that an aggressively expansion or investment policy may be a better policy to manage the dynamic supply chain relationship. How to balance the time required for capacity expansion and the time for suppliers to develop new customers is the most important in the evolving supply chain relationship. However, from supply chain collaboration perspective, we suggest that firms should have a more thorough plan and consideration from a systemic perspective when making an economic decision.

Otherwise, the rational decision may result in uncontrollable impacts that are beyond expectations, such as the collapse of supply chain relationships as KMV Company experiences. Based on the an evolutionary process of supply chain relationship discussed in this paper, we encourage further research examining more supply chains and studying the essential mechanisms underlying each case to build a more complete theory about supply chain evolutions.

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