Aligning Reliability Improvement Strategies in an Assembly System

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Aligning strategies has become an imperative mean for members of a supply chain to achieve competitiveness in today's market (Xiao and Yang, 2008; Handfield et al., 2000). However, it can be more cumbersome in an assembly system in which a manufacturer builds the final product by assembling a set of components produced by different suppliers. In such a situation, although suppliers are not directly connected, they have a reciprocal effect on each other. Therefore, a supplier must consider the strategies of other suppliers, as well as of the manufacturer, in its decision making. Another factor that sophisticates the coordination of a supply chain is supply uncertainty. There is vast body of literature in the context of managing supply risk (Yano and Lee, 1995; Snyder et al., 2010; Dolgui et al., 2013). Nevertheless, managing and improving reliability in decentralized supply chains have been largely overlooked in the current literature.

In this research, we study how different members of a supply chain can align their production and reliability improvement decisions in an assembly system. In particular, we explore the relation of a manufacturer and two suppliers in a decentralized assembly system under uncertainty of supply and demand. The suppliers produce complementary components and the manufacturer assembles the final product. The suppliers' production systems are unreliable which affects their production capacity. This unreliability can be caused by different factors, such as machine breakdowns, unscheduled maintenance, unavailability of human resources, and disruptions. The suppliers can improve their reliability through investment. We study the case in which the manufacturer decides on the order quantities, whereas the suppliers determine the production quantities and investment amounts. In this study, we focus on two main questions: (1) *"how the manufacturer and the suppliers should align their decisions with other players' strategies to maximize their profits?"* and (2) *"How timing of the decisions affect the optimal behaviors of the manufacturer and the suppliers?"*

In order to explore the effect of timing of the decisions and availability of information on the behaviors of the players, we investigate the problem under four settings:

1. **Simultaneous ordering and investment (SOI):** In this scenario, we assume that the players make their decisions simultaneously and analyze the problem under static game setting. This scenario can occur in pull production systems in which the improvement process of the suppliers' production system is not relatively long.
2. **Ordering after observation of capacities (OAC):** In this scenario, we investigate the dynamic formation of the problem in which the suppliers are leaders and the manufacturer decides on the order quantities once the suppliers' capacities are observed. This situation usually occurs when

the manufacturer's orders are posterior to the production phase of the suppliers. This case is common in agribusiness supply chains and push production systems. In this case, initially, the suppliers decide on the investment amount. Each supplier makes the investment decision considering the uncertainties of his capacity and the manufacturer's demand. Having observed the suppliers' capacities, the manufacturer decides on the order quantities of the components. Subsequently, the components are delivered and the manufacturer assembles the final products. The production quantity of the final product equals the minimum of the suppliers' delivered quantities. Finally, the demand is observed and satisfied by the manufacturer.

3. **Ordering before realization of capacities (OBC):** In this scenario, we explore the case in which the suppliers are the leaders and the manufacturer, as the follower, decides on the order quantities before realization of the capacity. This situation is common in pull manufacturing systems, which have a relatively long production improvement and maintenance process. In this scenario, initially the suppliers invest in their reliability. Subsequently, the manufacturer decides on the number of components that she wants to purchase from the suppliers. Then, the capacities of the suppliers are observed and the components are delivered to the manufacturer. Finally, the manufacturer assembles the final products and sells them in the market.
4. **Ordering before investment (OBI):** In this scenario, we investigate the case in which the manufacturer is the leader of the game. This is a common situation in pull production systems in which the system improvements and maintenance are relatively short processes. Consequently, the suppliers have enough time to enhance their production systems after the manufacturer places her order. It is also common when the manufacturer commits in advance to a certain order quantity. In this case, initially, the manufacturer determines her order quantities. Then, given these order quantities, the suppliers invest in their production systems. Subsequently, the capacities of the suppliers are observed and the components are delivered to the manufacturer. Finally, the manufacturer assembles the final product and sells it on the basis of the observed demand.

Under all four scenarios, we prove, although the equilibrium may not be unique, there is a unique Pareto optimal equilibrium under which the profit functions of all the players are maximized. In addition, we show that in all the scenarios, the suppliers can encourage each other to exert a greater effort on the reliability improvement.

In OAC scenario, we show that, when the suppliers terminate their production, if their production quantities are sufficiently high, it is beneficial for the suppliers to inform the manufacturer about their outputs to escalate the manufacturer's order quantity. In general, if we consider the suppliers individually, sharing the output information will not have any negative effect on their profit. However, one supplier may impair the other supplier's profit through information sharing. In particular, if the outputs of the suppliers are not equal, the supplier with the lower production has a negative effect on the second supplier's profit, if his output is sufficiently low.

When the manufacturer postpones her ordering decision until after the suppliers' investment decisions (OBC), the suppliers can use investments as a tool to affect the manufacturer's ordering decision. In this situation, the suppliers artificially increase their investments to induce the manufacturer to place a larger order. As a result, the investment amounts of the suppliers, and subsequently, the manufacturer's order quantity, in this scenario are larger relative to the SOI case. Postponement of the ordering decision has a positive effect on the optimal profits of the players. In this situation, the suppliers have the opportunity to manipulate the ordering quantities of the manufacturer, which leads to a higher profit for suppliers. In contrast, given an investment inflation strategy, the delivered quantity to the manufacturer increases, which results in a higher profit for the manufacturer. Therefore, it is lucrative for the manufacturer, as well as the suppliers, to postpone the ordering decision until after the suppliers' investment. In addition, because the postponement of an ordering decision results in higher ordering quantity and investments, it enhances the customer service level as well.

In the last scenario (OBI), the postponement of investments gives the manufacturer the opportunity to manipulate the suppliers' decisions through ordering quantity. In this situation, the manufacturer artificially increases her ordering quantities to motivate the suppliers to have larger investments. Therefore, in this scenario, the ordering quantity of the manufacturer is larger than that of the SOI case. The order inflation strategy of the manufacturer leads the suppliers to increase their investments in comparison to the SOI case. As a result, both the suppliers and the manufacturer yield a higher profit. The manufacturer has the ability to moderately control the investment decisions of the suppliers, and the suppliers enjoy the higher order quantities of the manufacturer. Consequently, similar to the previous case, the entire supply chain benefits from the postponement of the decisions.

In conclusion, in this study we explored the relationship of a manufacturer and two suppliers with endogenous reliabilities in a decentralized assembly system. We analyzed the system under four different settings to clarify the effects of timing of the decisions on players' optimal behaviours. We found that in the first three cases, the manufacturer's optimal order quantities from the suppliers are always equal. In addition, we showed that the sequential decision making has a positive effect on the supply chain and the players' profits.

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