Coordinating the Assembly System Based on Compensation Mechanism Under Supply Disruption

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Abstract: A well-coordinated assembly system plays an important role in an enterprise’s strategic management. As the uncertainty of the supply chain is increasing, coordinating the assembly system effectively under supply disruption becomes a critical success factor for a global supply chain system. In this study, we consider an assembly system with two suppliers and one manufacturer and formulate the model of each partner with bonus policy under supply disruption. The optimal decision of each partner is analyzed under decentralized decision. Then we optimize the total cost of assembly system under centralized decision which is regarded as the benchmark. Furthermore, to achieve this benchmark, the compensation mechanism is designed to coordinate the assembly system under supply disruption. At last, the sensitivity is analyzed and the numerical analysis shows that our compensation mechanism is reasonable and effective.

Key words: Assembly system, compensation mechanism, supply disruption, bonus policy

INTRODUCTION

In recent years, the uncertainty of assembly system in upstream supply chain increased significantly due to influence of natural disasters, strikes, terrorist attacks and political instability and other factors. In 2000 Philips Semiconductor Factory’s fire lead to Ericsson’s supply disruptions of the chip which caused the loss of 1.8 billion Ericsson and 4% of market share loss. In July 2010, Hitachi’s unexpected shortage of car engine control part resulted in Nissan’s plant shutdown for 3 days in Japan and the production of 1.5 million cars affected. In March 2011, Japan 9 earthquakes in northeast region devastated the area of industrial enterprises. Car production of three major Japanese automakers, Toyota, Honda and Nissan are affected by the disruption of supply chain and some joint ventures in China also had different levels of supply disruptions. These examples illustrate that, as supply chains are extended by outsourcing and stretched by globalization, disruption risks and lack of visibility into a supplier’s status can both worsen.

Supply chain risk management has attracted interest from both researchers and practitioners in operations management. Sodhi and Chopra (2004) provided a diverse set of supply disruption examples. Various operational tools that deal with supply disruptions have been studied: multisourcing (Ariyipudi and Akella, 1993; Tomlin, 2009; Babich et al., 2007), alternative supply sources and backup production options (Serel et al., 2001; Kouvelis and Milner, 2002; Babich, 2006), flexibility (Van Mieghem, 2003; Tomlin and Wang, 2005) and supplier selection (Deng and Elmaghraby, 2005). For a recent review of supply-risk literature (Tang, 2006).

These and the majority of other papers in the supply-risk literature assume that the occurrence of supply disruptions is known to both the suppliers and the manufacturer. In contrast, we assume that occurrence of supply disruption partially asymmetric between the suppliers and the manufacturer. Tomlin (2009) studied a model where the manufacturer faces two suppliers, one with known and the other with unknown reliability. The manufacturer learns about the latter supplier’s reliability through Bayesian updating. In our model, information is also revealed, but through a contract choice rather than through repeated interactions. Gurnani and Shi (2006), a buyer and supplier had differing estimates of the supplier’s reliability. Unlike our setting, in assembly system with two suppliers and one manufacturer, the supplier and the manufacturer know the disruption time but the other supplier don’t.

In the operations contracting literature, Parlar and Berkin (1991), Moinzadeh and Aggarwal (1997), Ozekici and Parlar (1999). Rosenthal (2008) and other scholars has studied the uncertain delivery time caused by supply disruption. However, the above literatures don’t consider how to coordinate the assembly system in case of supply

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disruption. To address these gaps in the current literature, we investigate the interaction between supplier’s crashing decision and collaborative policies in case of supply disruption. We address the following questions:

- What are suppliers’ optimal decisions for each partner in this assembly system in case of supply disruption?
- What is the best solution under supply disruption for the assembly system?
- How would the manufacturer eliminate the effect of supply disruption, achieve supply coordination and optimize its operational cost?

In answering these questions, we limit our consideration within two-suppliers and one-manufacturer system in case of one supplier’s disruption. We construct suppliers’ and manufacturer’s model that the supplier in supply disruption make the decision of crashing time to optimize its operational cost. Then we set the benchmark that optimal crashing will be derived from aspect of the whole assembly system. In order to achieve the benchmark, we offer the compensation policies and examine how the manufacturer uses this policy to coordinate the suppliers under supply disruption. Finally, numerical and sensitive analysis is provided to illustrate our useful model.

THE MODEL DESCRIPTION

Consider a two-echelon assembly system with two suppliers and a single manufacturer, while final product of manufacturer is assembled from the two kind of key components provided by the two suppliers. The initial inventories of suppliers’ components are both zero. The agreed delivery time from the components production to the delivery time point, when the manufacturer receives the components, is determined which is called agreed delivery time \( T_i \) (\( i = 1,2 \)). The suppliers’ actual delivery time \( t_i \) is random because of certain supply emergence, so \( t_i \) and \( t_i \) stand for the actual delivery time. Their probability distributions are respectively \( f(t_i) \) and \( g(t_i) \).

The manufacturer’s delivery time from its beginning of production to delivery point of final product is determined which is defined as \( T_m \). The manufacturer’s beginning time of its production is the actual delivery time point of two supplier’s components. When the manufacturer both receives the matching quantity of component 1 and 2, it begins to assemble. If either delivery of the two suppliers is delayed, the manufacturer’s assembly time will be postponed, (Fig. 1).

Under bonus policy, two suppliers have determined their agreed delivery time \( T_1 \) and \( T_2 \) and started production. But in the production process, a certain supplier (supplier 1 taken as an example in this paper) is disrupted which is lasting for period \( k (k < T_1) \) (Fig. 2).

As illustrated in Fig. 2, the interval of point \( F \) and \( J \) represents the disruption period \( k \) of the supplier. The sum of period \( t_i \) and \( t_i \) is the normal delivery time \( t_i \) without disruption. Point \( A \) stands for the starting time point of the supplier and point \( A \) is the delivery time point specified by the manufacturer. The interval of point \( A \) and \( A \) is \( T_1 \) which the agreed delivery time of the supplier.

To compensate for the losses caused by production disruptions, supplier 1 will crash the delivery time. Let crashing cost per unit time is \( \gamma \).To make the problem meaningful, we assume \( \gamma \leq \rho \), without loss of generality. Before the disruption time point \( I \), supplier 1 has taken production for period \( t_i \) and \( t_i+k<T_1 \) which means that reproduction time point of supplier 1 is ahead of the delivery time point \( A \) specified by the manufacturer. Let the actual delivery time of supplier 1 after disruption is \( T_1' \), which obeys the probability distribution of \( f(t_1') \) which is illustrated (Fig. 3).

As shown in Fig. 3, Point \( A \) stands for the starting time point of the supplier and after period \( t_1 \) the supplier
OPTIMAL SOLUTION UNDER DECENTRALIZED DECISION WITH BONUS POLICY

We first study the choice of supplier 1 under decentralized decision. The supplier will determine optimal \( t'_1 \) to minimize its total cost. After disruption the delivery time of supplier 1 becomes \( t'_1 \), and through the crashing time of \( t'_1 \) the actual delivery time of supplier 1 after disruption becomes \( t'_1 - t' \). Then the cost function is:

\[
TC'_1(\tau_0, t'_1) = \int_{\tau_0}^{T'} f(t'_1) \left( (t'_1 - k - t'_1 - r) - \tau_0 \right) dt'_1' \\
+ b_1 \int_{\tau_0}^{T'} f(t'_1) \left( k - t'_1 - t' + r \right) dt'_1' \\
+ b_2 \int_{\tau_0}^{T'} f(t'_1) \left( (t'_1 - k - t - t'_1 + r) - k \right) dt'_1' \\
- b_1 \int_{\tau_0}^{T'} f(t'_1) \left( k - t'_1 - t' + r \right) dt'_1' + \gamma s + k\delta
\]

(3)

Where, the first term stands for the penalty cost of supplier 1 under crashing condition and the second, third and fourth term represent inventory holding cost of supplier 1 with crashing. The fifth term is bonus received from the manufacturer when the delivery time is ahead of time. The sixth term means the crashing cost of supplier 1. The final term is the loss of supplier 1 when the disruption happens. The expressions of two suppliers’ actual delivery time which obey exponential distribution, can be substituted into Eq. 3 and the equation is simplified as follows.

\[
TC'_1(\tau_0) = \frac{1}{\lambda_2} \left( \frac{(T' - k - t'_1 + r)}{\alpha_1} + h_1(\tau_0 - k - t'_1 + r - \tau_0) \\
+ \frac{1}{\lambda_2} \left( \frac{(T' - k - t - t'_1 + r)}{\alpha_1} + h_2(\tau_0 - k - t - t'_1 + r - \tau_0) \\
- \frac{1}{\lambda_2} \left( \frac{(T' - k - t'_1 + r)}{\alpha_1} + h_2(\tau_0 - k - t'_1 + r - \tau_0) \\
+ \gamma s + k\delta
\]

(4)

To obtain the value of \( t'_1 \), take the first derivative of \( t'_1 \) and set the equation equal to zero. Then the following equation can be obtained:

\[
(\rho_1 + h_1 - b_1 - \frac{h_1}{\lambda_2} \left( \frac{(T' - k - t'_1 + r)}{\alpha_1} + h_2(\tau_0 - k - t'_1 + r - \tau_0) = \rho_1 - b_1 + \gamma
\]

(5)

Therefore, under decentralized decision the optimal crashing time \( t'_1 \) of supplier 1 is:

\[
t'_1 = \frac{1}{\lambda_2} \left( \frac{(\rho_1 + h_1 - b_1)(\alpha_1 + \lambda_2) - h_1 \lambda_2 e^{\lambda_1 T}}{(h_1 - b_1 + \gamma)(\alpha_1 + \lambda_2)} \right) - (T' - k - t'_1)
\]

(6)

If \( t'_1 \) in the above equation is no more than zero, then \( t'_1 = 0 \) which means that supplier 1 will not crash the delivery time. Take the second derivative of \( t'_1 \) in Eq. 4, then:
\[
\frac{\partial^2 T_{C_n}}{\partial \delta^2} = (p_1 \lambda_1 - b_1 \lambda_1 + h_1 \lambda_1 - b_1^2 \lambda_1 + h_1 \lambda_1 - \frac{b_1^2}{\lambda_1} \lambda_1) e^{\lambda_1(T_1 + \lambda_1)} > (h_1 \lambda_1 - b_1 \lambda_1 + h_1 \lambda_1 - \frac{b_1^2}{\lambda_1} \lambda_1) e^{\lambda_1(T_1 + \lambda_1)} > 0
\]

Consequently, \( T_{C_n}(t) \) is convex in \( t \), so \( t^*_c \) is the optimal value of supplier 1 under decentralized decision.

The cost of supplier 2 and the manufacturer under decentralized decision are formulated and simplified as follows, respectively:

\[
T_{C_2} = \frac{1}{\lambda_2} p_2 e^{\lambda_2 t_2} + \frac{1}{\lambda_2} \left( \lambda_2 T_2 - \frac{b_2^2}{\lambda_2^2} \right) e^{\lambda_2 T_2} - b_2 (T_2 + \frac{1}{\lambda_2} e^{\lambda_2 T_2} - \frac{1}{\lambda_2})
\]

\[
T_{C_n} = p_n \left( \frac{1}{\lambda_n} e^{\lambda_n T_n} - \frac{1}{\lambda_n} \right) + \left( h_n + b_n \right) \left( \lambda_n T_n - \frac{b_n^2}{\lambda_n^2} \right) e^{\lambda_n T_n} - b_n (T_n + \frac{1}{\lambda_n} e^{\lambda_n T_n} - \frac{1}{\lambda_n})
\]

OPTIMAL ANALYSIS AND CONTROL UNDER CENTRALIZED DECISION

As to centralized decision, the goal is to find the optimal crashing time \( t^*_c \) and the total cost of assembly system is:

\[
T_C = \sum_{n=1}^{N} T_{C_n} = \sum_{n=1}^{N} \left[ \frac{1}{\lambda_n} p_n e^{\lambda_n t_n} + \frac{1}{\lambda_n} \left( \lambda_n T_n - \frac{b_n^2}{\lambda_n^2} \right) e^{\lambda_n T_n} - b_n (T_n + \frac{1}{\lambda_n} e^{\lambda_n T_n} - \frac{1}{\lambda_n}) \right]
\]

Where, the first and second term, respectively stand for inventory holding cost of supplier 1 and 2. The third term is the manufacturer's penalty cost. The forth term means the crashing cost and the fifth term is the loss of supplier 1 when the disruption happens. The expression of two suppliers' actual delivery time can be substituted into Eq. 10 and the equation is simplified as follows:

\[
T_C = \left[ \frac{1}{\lambda_1} p_1 e^{\lambda_1 (t_1 + \lambda_1)} + h_1 \lambda_1 T_1 - h_1 T_1 - \left( \frac{b_1^2}{\lambda_1} \right) \lambda_1 e^{\lambda_1 (t_1 + \lambda_1)} + b_1 (T_1 + \frac{1}{\lambda_1} e^{\lambda_1 T_1} - \frac{1}{\lambda_1}) \right] + \left( \frac{1}{\lambda_2} p_2 e^{\lambda_2 (t_2 + \lambda_2)} + h_2 \lambda_2 T_2 - h_2 T_2 - \left( \frac{b_2^2}{\lambda_2} \right) \lambda_2 e^{\lambda_2 (t_2 + \lambda_2)} + b_2 (T_2 + \frac{1}{\lambda_2} e^{\lambda_2 T_2} - \frac{1}{\lambda_2}) \right) + \left( \frac{1}{\lambda_n} p_n e^{\lambda_n (t_n + \lambda_n)} + h_n \lambda_n T_n - h_n T_n - \left( \frac{b_n^2}{\lambda_n} \right) \lambda_n e^{\lambda_n (t_n + \lambda_n)} + b_n (T_n + \frac{1}{\lambda_n} e^{\lambda_n T_n} - \frac{1}{\lambda_n}) \right)
\]

Take first derivative of \( t_1 \), in Eq. 13 and set it equal zero, then we get:

\[
\left( h_1 + b_2 + p_2 \right) - \left( h_1 + b_2 + p_2 \right) \frac{b_1^2}{\lambda_1} e^{\lambda_1 (t_1 + \lambda_1)} = h_1 + \gamma
\]

The above equation can be solved as follows:

\[
t_1^* = \frac{1}{\lambda_1} \ln \frac{\left( h_1 + b_2 + p_2 \right) \left( \lambda_1 + \lambda_n \right) e^{\lambda_1 (t_1 + \lambda_1)} - \lambda_1}{(h_1 + \gamma) \left( \lambda_1 + \lambda_n \right) e^{\lambda_1 T_1}} - (T_1 + \lambda_n)
\]

According to Eq. 15, if \( t_1^* \) is larger than \( k \), let \( t_1^* = k \) which means supplier 1 will crash the delivery time no more than \( k \). Take second derivative of \( t_1 \), in Eq. 11, then:

\[
\frac{\partial^2 T_C}{\partial \delta^2} = \left( h_1 + b_2 + p_2 \right) \left( 1 - \frac{b_1^2}{\lambda_1^2} \right) e^{\lambda_1 (t_1 + \lambda_1)} > 0
\]

Therefore, the total cost of assembly system is convex in \( t_1 \), which can make the assembly system minimum under centralized decision.

THE COMPENSATION MECHANISM UNDER SUPPLY DISRUPTION

Since, \( p_n > p_1 \), then \( t_1^* > t_1^c \), which can be explained that the manufacturer transfers a higher penalty cost to supplier1 under centralized decision than under decentralized decision. This means under centralized decision supplier 1 faces a larger penalty cost and therefore will spend a greater cost to crash the delivery time.

However, through the above analysis the crashing time \( t_1^c \) of supplier 1 is best for assembly system under disruption. To incentive the supplier 1 to crash more delivery time, the manufacturer will coordinate the assembly system. Here we design a collaborative mechanism. The manufacturer will pay compensation for supplier 1’s crashing and the compensation coefficient per unit time is \( \beta \). As to the cost saved, the three partners in assembly system can share the saving cost according to a certain agreement. Under this compensation mechanism the cost function of supplier 1 becomes:

\[
T_C = \frac{1}{\lambda_1} p_1 e^{\lambda_1 (t_1 + \lambda_1)} + h_1 \lambda_1 T_1 - h_1 T_1 - \left( \frac{b_1^2}{\lambda_1} \right) \lambda_1 e^{\lambda_1 (t_1 + \lambda_1)} + b_1 (T_1 + \frac{1}{\lambda_1} e^{\lambda_1 T_1} - \frac{1}{\lambda_1}) + \left( \frac{1}{\lambda_2} p_2 e^{\lambda_2 \left( T_2 + \lambda_2 \right)} + h_2 \lambda_2 T_2 - h_2 T_2 - \left( \frac{b_2^2}{\lambda_2} \right) \lambda_2 e^{\lambda_2 \left( T_2 + \lambda_2 \right)} + b_2 (T_2 + \frac{1}{\lambda_2} e^{\lambda_2 T_2} - \frac{1}{\lambda_2}) + \left( \frac{1}{\lambda_n} p_n e^{\lambda_n \left( T_n + \lambda_n \right)} + h_n \lambda_n T_n - h_n T_n - \left( \frac{b_n^2}{\lambda_n} \right) \lambda_n e^{\lambda_n \left( T_n + \lambda_n \right)} + b_n (T_n + \frac{1}{\lambda_n} e^{\lambda_n T_n} - \frac{1}{\lambda_n}) \right)
\]

Take the fist derivative of \( t_1 \), in Eq. 13 and let it be zero. Then the optimal \( t_1 \) under compensation mechanism can be obtained. The optimal value of \( t_1 \) under compensation mechanism is:

\[
t_1^* = \frac{1}{\lambda_1} \ln \frac{\left[ \left( h_1 + b_2 + p_2 \right) \left( \lambda_1 + \lambda_n \right) e^{\lambda_1 (t_1 + \lambda_1)} - \lambda_1 \right]}{(h_1 + \gamma - \beta) \left( \lambda_1 + \lambda_n \right) e^{\lambda_1 T_1}} - (T_1 + \lambda_n)
\]
Set $\tau_c = \tau_c$, the compensation coefficient $\beta$ can be got. Then the conclusion can be drawn.

Proposition 1 If the supplier's delivery is disrupted, the manufacturer can take the compensation mechanism to coordinate the assembly system. The compensation coefficient $\beta$ can be solved through $\tau_c = \tau_c'$. Under compensation mechanism, the cost function of supplier 2 is the same as under decentralized decision but the cost function of manufacturer has changed to:

$$
\begin{align*}
TC_m^e &= p_2 \left( \frac{1}{2} e^{-\lambda_2(T_2 + \alpha_2 - 1/T_2)} - \frac{1}{2} e^{-\lambda_2 T_2} \right) + \frac{1}{2} e^{-\lambda_2 T_2}
+ \frac{1}{2} e^{-\lambda_2 T_2} \left( \frac{1}{2} e^{-\lambda_2 T_2} + \frac{1}{2} e^{-\lambda_2 T_2} \right) + \beta e^{-\lambda_2 T_2}
\end{align*}
$$

NUMERICAL ANALYSIS

To illustrate regulation effect of compensation effect in the previous section and disruption period $\tau_c$'s influence on parameters of assembly system. The numerical analysis will be given in Table 1 and 2.

Related parameters are assumed as follows: $\alpha_1 = 50$, $\alpha_2 = 10$, $\alpha_3 = 8$, $\alpha_4 = 5$, $\alpha_5 = 4$, $\lambda_1 = 1/50$, $\lambda_2 = 1/60$, $\lambda_3 = 30$, $\delta = 9$ and the following result can be obtained.

From the above numerical analysis we can draw the following conclusions:

- Under compensation mechanism the total cost of assembly system equal the cost under centralized decision, while the crashing time is the same under these two situations. This indicates that compensation mechanism can coordinate the assembly system which can make the total cost under disruption optimal.
- When $\tau_c$ small, supplier 1 is will not determine to crash delivery time, because supplier 1's crashing is equivalent to extending the delivery time. However, when the disruption occurs, the two suppliers have produced for a period and at this time whether supplier 1 crashes the delivery time or not is a new decision. At this moment supplier 1 has known the delivery time of supplier 2 and the new delivery time under disruption will be smaller than the original. To avoid suppliers laying off deliberately, the manufacturer should monitor the production of two suppliers dynamically. If the supplier lies off deliberately or for a long time, it should be definitely be punished. When production time $\tau_c$ before disruption is larger than a certain value, supplier 1 will decide crashing. The crashing time is increasing with $\tau_c$ because supplier 1 wants to complete the rest time of delivery earlier than the original.
- Under centralized decision, the optimal crashing time of supplier 1 increases with $\tau_c$ at first. When $\tau_c$,

| Table 1: Comparison between decentralized decision and centralized decision |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| $\tau_c$ | $\tau_c'$ | $TC_{m1}$ | $TC_{m2}$ | $TC_{m3}$ | $TC_{m4}$ | $TC_{m5}$ | $\tau_c$ | $TC_{m6}$ |
| 5   | 0      | 420.449 | 191.272 | 590.021 | 1609.744 | 11.499 | 1550.304 |
| 10  | 0      | 425.814 | 194.862 | 1009.014 | 1629.691 | 16.499 | 1605.304 |
| 15  | 0      | 432.233 | 198.137 | 1032.143 | 1663.206 | 21.499 | 1620.304 |
| 20  | 0      | 439.817 | 203.213 | 1049.845 | 1702.876 | 26.499 | 1635.304 |
| 25  | 0      | 448.668 | 208.059 | 1092.599 | 1749.347 | 30     | 1650.486 |
| 30  | 0      | 458.983 | 213.414 | 1130.937 | 1803.335 | 30     | 1668.835 |
| 35  | 0      | 470.850 | 219.320 | 1175.446 | 1865.650 | 30     | 1691.774 |
| 40  | 0      | 484.455 | 225.873 | 1226.776 | 1957.165 | 30     | 1719.691 |
| 50  | 8.799  | 514.339 | 227.543 | 1240.194 | 1982.137 | 30     | 1792.876 |
| 60  | 18.799 | 544.399 | 227.543 | 1240.194 | 2023.137 | 30     | 1893.135 |

| Table 2: Sensitivity analysis under compensation mechanism |
|------------------|------------------|------------------|------------------|------------------|------------------|
| $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\lambda_1$ | $\lambda_2$ |
| 5   | 2.4170 | 11.499 | 418.284 | 184.259 | 987.759 | 1590.304 |
| 10  | 2.4170 | 16.499 | 421.197 | 184.259 | 999.846 | 1605.304 |
| 15  | 2.4170 | 21.499 | 424.111 | 184.259 | 1011.933 | 1620.304 |
| 20  | 2.4170 | 26.499 | 427.025 | 184.259 | 1024.019 | 1635.304 |
| 25  | 2.3710 | 30     | 431.356 | 185.085 | 1034.043 | 1650.486 |
| 30  | 2.2070 | 30     | 439.828 | 188.024 | 1040.982 | 1668.835 |
| 35  | 2.0250 | 30     | 449.681 | 191.272 | 1050.790 | 1691.744 |
| 40  | 1.8250 | 30     | 461.059 | 194.802 | 1063.769 | 1719.691 |
| 45  | 1.6030 | 30     | 474.125 | 198.829 | 1080.252 | 1735.206 |
| 50  | 1.3587 | 30     | 489.055 | 203.213 | 1100.607 | 1792.876 |
| 55  | 1.0081 | 30     | 506.044 | 208.059 | 1125.243 | 1839.347 |
| 60  | 0.7891 | 30     | 525.311 | 213.414 | 1154.609 | 1893.335 |
postponement of supplier 1's disruption. Thus, supplier 1 has a greater incentive to crash the delivery time and the manufacturer can reduce the compensation.

- The disruption point of supplier 1 influences each side of supply chain as shown in Fig. 5.

Figure 5 clearly shows that compared to decentralized decision under compensation mechanism, the cost of two suppliers, the manufacturer and the assembly system are reduced which proves the compensation mechanism is effective. As $t_c$ is increasing, the cost of each side in assembly system is increasing, indicating that the later the supplier 1's disruption occur, the greater impact the disruption has on assembly system.

**CONCLUSION**

In this study, we formulate the coordination model under supply disruption and achieve the supply coordination with compensation mechanism. The model under decentralized decision and under centralized decision are analyzed and compared and the compensation mechanism is proposed to coordinate the supply chain. Numerical analysis shows the collaborative mechanism is effective. Besides, the result shows when $t_c$ is small, supplier 1 will not determine to crash delivery time, because supplier 1's crashing is equivalent to extending the delivery time. However, when the disruption occurs, the two suppliers have produced for a period and at this time whether supplier 1 crashes the delivery time or not is a new decision. At this moment supplier 1 has known the delivery time of supplier 2 and the new delivery time under disruption will be smaller than the original. To avoid suppliers' laying off deliberately, the manufacturer should monitor the production of two suppliers dynamically. If the supplier lies off deliberately or for a long time, it should be definitely be punished. Interestingly, when production time $t_c$ before disruption is larger than a certain value, supplier 1 will decide crashing. The crashing time is increasing with $t_c$ because supplier 1 wants to complete the rest time of delivery earlier than the original.

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