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A Study of Multi-Stage Supply Chain Dynamics with Advanced Demand Insights

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Abstract

Before production starts in a system that uses advance demand information, the advance demand information is sent to a company further up the chain, and just before production starts, the firm-order information is sent. Unfortunately, upstream companies often have to deal with too much merchandise and supplies that are late. So, it's important to look at the impact of changing factors like changing demand and the difference between information on advance demand and information on set orders. The model was built on these three steps. First, let's look at a supply chain with four companies. Based on when the firm order and production happen, sellers can be divided into three groups. Second, the supply chain is made up of three different types of sellers, based on when the firm order is sent. Lastly, a model was made of the layout of production activities for each type of provider. After that, they were planned out and put into action as an analysis model. Several case studies were looked into using this software. In the end, it was proven that quick changes in demand made the bullwhip effect stronger, especially when demand went up. Also, the seller whose daily production numbers and stock levels changed a lot because of the difference between the information about expected demand and the firm order was found.

Keywords : Supply chain, Advance demand information, Bullwhip effect, Simulation, Modeling, Standard deviation ratio

1. Introduction

A production system that uses advance demand information, or "ADI," sends advance demand information to a company upstream for a certain amount of time before production starts. Just before production starts, firm-order information is sent. In make-to-order production, this system is a good way to cut down on both the wait time and the amount of supplies needed. However, the ADI is only a prediction of how much will be made. There is a delay between the ADI and the firm order because customer needs can change before the firm order is sent. There should not be a difference between the ADI and the firm order. If there is, small and medium-sized businesses in the supply chain will have to deal with late supplies if the firm order is higher than the ADI or too much merchandise if the firm order is lower than the ADI. To solve this issue, we need to figure out the characteristics of the production system's variability using ADI. However, these characteristics have not been spelt out yet because variability is caused by many different causes. Because of this, the study's goal is to create an ADI-based research model for a supply chain and to use ADI to look at the production system's behaviour and features.

In Japan, the ADI system is the only way to make things, and it has only been the subject of a few studies. So far as we know, no study has been done to find out what makes ADI systems variable and how to fix any problems that might be happening. Ueno et al. (2007) suggested a way to plan production and supplies for multiple items that would allow for mass customisation while taking into account the limits of daily manufacturing capacity. Ueno (2018) also did a study to find out what causes the bullwhip effect and how big it is by looking at how people buy things when demand is unclear in a two-stage supply chain using ADI. Karaesmen et al. (2004) looked into how useful ADI is in systems for production and accounting. They showed that centralising information about demand can lessen the bullwhip effect but not get rid of it completely. For their 2005 paper, Liberopoulos and Koukoumialos used numbers to look into the trade-offs between the best base stock levels, amount of kanbans, and expected supply lead times in single-stage and two-stage production/inventory systems using base-stock and mixed base-stock/kanban policies with ADI. Rostami-Tabar and Sahin (2015) looked at how well ADI works in production systems. They saw that using an ADI along with a base-stock strategy might make suppliers more efficient by lowering the costs of inventory and backorders. A supply chain model with an

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ADI-based production system was made for this study, and the bullwhip effect was used to test its usefulness. The model is correct if it gives the same results for the bullwhip effect as a study using real data (Ueno, 2018). This is a well-known problem that happens in the supply chain. There is a thing called the "bullwhip effect" that happens when changes in demand get worse as they move up the supply chain. This wastes goods and money for sellers further up the chain, which is a drag. A lot of research has been done on the bullwhip effect. Lee et al. (1997a, 1997b) studied and modelled the bullwhip effect conceptually and found that it was caused by information loss. A study by Chen et al. (2000) measured the bullwhip effect for simple two-stage supply lines with only one producer and store. Hasama and Song (2007) used a simple two-stage model to run tests and talk about the factors that affect the bullwhip effect. They said that sharing information is the best way to solve the problem. After studying the reasons of the negative bullwhip effect and the Wal-Mart case, Dai et al. (2017) created a mathematical programming model to make the supply chain as efficient as possible. This model offers a way to fix the bullwhip effect. The authors of Tanweer et al. (2014) wanted to lower the bullwhip effect in the supply chain. They came up with an optimisation model that uses exponential smoothing to predict the demand for many goods. Ali et al. (2020) used a discrete event modelling method to look into how wait time affected the bullwhip effect in a multi-product and multi-echelon supply chain with both decentralised and centralised information-sharing strategies. They said that lowering the difference in demand is important for lowering the bullwhip.

2. Modeling the supply chain

2.1 Classifying and constructing a production-activity model

This research looked at an ADI supply chain with three producers, a final assembly maker, and a buyer and seller who are directly connected. When a final assembly maker places an order, the timing of production changes because more upstream providers have to make the product faster. According to when they get a clear order and start making things, wholesalers can be divided into three groups. Names for these three kinds are Type A, Type B, and Type C. Figur 1 displays the times of the ADI, the firm order, and the production of a single provider. Fig. 1 shows how the relative link between the company order (red line) and output determines the type of provider. FIGURE 1a: Type A suppliers get the firm order before production starts; Type B suppliers get the firm order during production; Type C suppliers get the firm order after the shipment is finished; and Type A suppliers get the firm order after the shipment is finished.
The production-activity model's layout for the three types of providers is shown in Fig. 2. The top section shows how the ADI flows, the middle section shows how the business order flows, and the bottom section shows how the product actually flows. The two types of lines—solid and dashed—show how the goods and information move through the system.
According to Fig. 2a, the ADI is sent from downstream providers to the Type A source first. On the basis of the received ADI, plans for production and stocking were made. As an ADI, the plan's order amount is then sent to the main provider. Finally, the firm order from the downstream provider is sent right before production begins. The system updates a previously made plan based on the firm order and inventory data it receives. The firm order is then sent to the upstream provider using the new plan, just like the ADI. Lastly, the parts provided by the main provider are stored briefly in parts inventory. The goods are then made using the parts inventory. Additionally, the produced goods are kept in stock for a short time before being sent to sellers further down the supply chain. Figur 2b shows Type B provider. During production, a clear order comes in, so the plan doesn't change and production is based on the ADI. For shipping, on the other hand, clear orders are needed. The Type C provider in Fig. 2c bases both production and shipment on the ADI because the shipment is only complete when the firm order is received.

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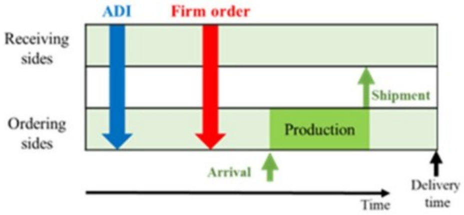
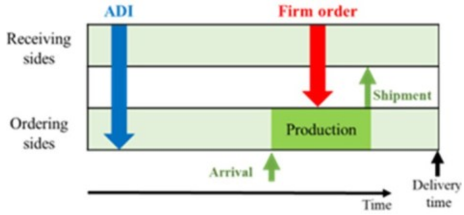
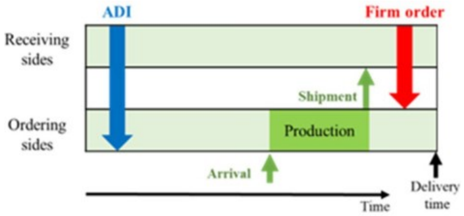


(a) Type A : Firm order is received before the start of production



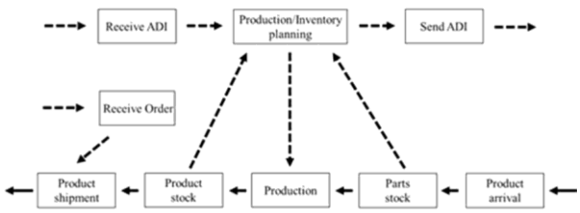
(b) Type B : Firm order is received during production



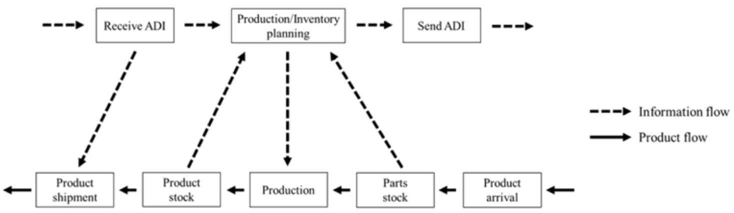
(c) Type C : Shipment completed before the firm order is received

Fig. 1 Timing of the ADI, firm order, production, parts arrival, and product shipment for each type.

(a) Type A supplier



(b) Type B supplier



(c) Type C supplier

Fig. 2 Structure of the production-activity model for the classified three types of suppliers.

2.2 Formulation

The above elements of the model of production and action were made. The following describes the characters used in this study: t stands for "time" and "days" are used as a measure. The source's place is shown by m. The higher the number, the further back the provider is. In the next part, we'll talk about the basic math for a Type A provider.

This study used formulae to look at the structure of the production-activity model of a Type A provider. They are shown in Figure 3. In Fig. 3, the numbers show the equation numbers that are explained below.

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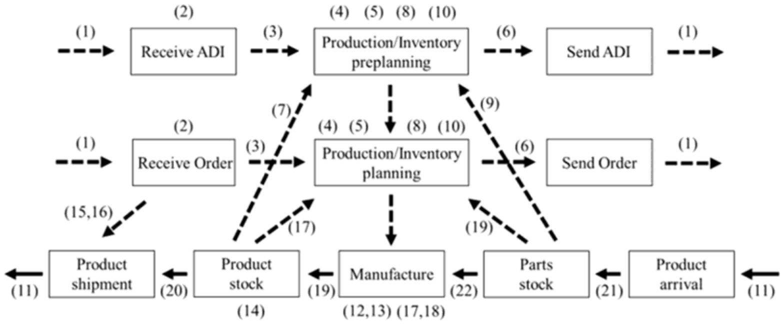

Fig. 3 Relationship between equations and structure of the Type A production-activity model

2.2.1 Flow of the information

The symbols used in this section are defined as follows, where *t* is the time index, and the unit is days. *m* is the index of the supplier's position, and the larger the number, the farther upstream the supplier. In the following section, the basic equation for a Type A supplier is explained. The information flow is represented by the same equation for both the ADI and firm order and is distinguished by the initial letter. The initial letter "A" represents ADI, and "C" represents the firm order.

$A\_NS_{m,t}$:	Quantity needed to ship downstream in ADI	$A\_PRE_{m,t}$:	Quantity of production stock at the end of operation in ADI
$A\_MO_{m,t}$:	Modified order quantity in ADI	$A\_PAS_{m,t}$:	Quantity of parts inventory at the start of operation in ADI
$DIF_{m,t}$:	Compensation quantity of planned and actual performances		
$A\_NP_{m,t}$:	Quantity needed to be produced in ADI	$A\_PAE_{m,t}$:	Quantity of parts inventory at the end of operation in ADI
$A\_CP_{m,t}$:	Quantity that can be produced in ADI	C_m :	Suppliers' production capacity
$A\_SHO_{m,t}$:	Quantity of surplus or shortage in ADI (treat a shortage as positive)	σ :	Moving standard deviation of demand quantity
$A\_ORD_{m,t}$:	Order quantity to upstream in ADI	k :	Safety factor (2.236 with a 1% out-of-stock rate)
$A\_SS_{m,t}$:	Safety stock in ADI	μ :	Moving average of demand quantity
$A\_PRS_{m,t}$:	Quantity of production stock at the start of operation in ADI	c :	Rate of shutdowns during a day operation

Every Friday, a week's ADI for the following week is sent, which includes the date and quantity of the delivery. Equation (1) shows the ADI sent downstream. Since downstream suppliers' orders must be delivered, the quantity needed to ship is expressed by Eq. (1).

$$A\_NS_{m,t} = A\_ORD_{m-1,t} \tag{1}$$

Equation (2) describes the determination of the safety stock. In Eq. (2), the moving average and moving standard deviations were calculated for the previous period. In this study, moving averages and moving standard deviations were calculated for the previous 10 days, unless otherwise noted. This study uses the periodic ordering method and considers demand uncertainty. To absorb the demand uncertainty, the moving standard deviation and safety stock factor are used in the first term. The second term is the inventory required to respond to a shutdown of a certain time and is expressed as the product of the moving average of the demand quantity and the rate of shutdowns. In this study, the percentage of shutdowns during operation was 0.2.

$$A\_SS_{m,t} = \sigma \times k + \mu \times c \tag{2}$$

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In the ADI, equations 3 through 7 show how to figure out the production plan and order amount. There is a difference between what was expected and what happened in this study because ADI and business order are taken into account. The plan will not match the reality unless this difference is taken into account when the plan is being made. To make up for the difference, the order amount needs to be changed as shown in Equation (3). The gap between the planned and real stock is used to figure out the amount of pay. Since the real amount is used, Section 2.2.2 goes into more depth about the amount of pay. As shown in Equation (4), the output requirement is both the amount that was told to be given and the amount that was supposed to be made the day before. Based on how much of the product inventory meets the safety stock level given by Equation (5), we can figure out whether there was an overflow or lack the day before. The amount that can be made is shown by Equation (6), since each provider has a different production ability and output is limited. The safety stock is filled with parts that are needed the next day since the ordered parts don't come until the next day. It was thought that a single part could make a single result for this study. So, Equation (7) can be used to show the order amount.

$$A\_MO_{m,t} = A\_NS_{m,t} + DIF_{m,t} \quad \text{(This compensation equation is applied to the first day of a weekly set of ADI.)} \tag{3}$$

$$A\_NP_{m,t} = A\_NS_{m,t} + A\_SHO_{m,t} \tag{4}$$

$$A\_SHO_{m,t} = -1 \times (A\_PRS_{m,t} - A\_SS_{m,t}) \tag{5}$$

$$A\_CP_{m,t} = \min\{A\_NP_{m,t}, C_m\} \tag{6}$$

$$A\_ORD_{m,t} = A\_CP_{m,t+1} + A\_SS_{m,t} - A\_PAE_{m,t} \tag{7}$$

Equations (8) through (11) show the determination of the inventory plan for the ADI. Since the product is shipped at the end of operations, the product stock at the start of operations is unchanged from the end of operations on the previous day, and thus, can be expressed as Eq. (8). The product stock quantity at the end of the operation is expressed as Eq. (9) based on the assumption that the quantity ordered for delivery is shipped. Parts are received at the start of the operation, and the parts inventory at the start of the operation is expressed by Eq. (10) based on the assumption that the quantity ordered upstream on the previous day is received. At the end of the operation, the parts are consumed from the inventory at the start of the operation by the production quantity, and the parts inventory at the end of the operation is represented by Eq. (11).

$$A\_PRS_{m,t} = A\_PRE_{m,t-1} \tag{8}$$

$$A\_PRE_{m,t} = A\_PRS_{m,t} + A\_CP_{m,t} - A\_NS_{m,t} \tag{9}$$

$$A\_PAS_{m,t} = A\_PAE_{m,t-1} + A\_ORD_{m,t-1} \tag{10}$$

$$A\_PAE_{m,t} = A\_PAS_{m,t} - A\_CP_{m,t} \tag{11}$$

In this study, it was assumed that a product is shipped at the end of an operation and arrives at the start of the next operation. Therefore, a firm order for the next day, including the date and quantity of delivery, is sent daily. As described above, the firm order is represented by Eqs. (1) through (11), with the initial letter changed to C, as in ADI.

2.2.2 Flow of the products

The symbols used in this section are defined as follows.

$F\_AD_{m,t}$:	Actual delivery quantity	$F\_AP_{m,t}$:	Actual production quantity
$F\_PRS_{m,t}$:	Actual quantity of production stock at the start of operation	$F\_PRE_{m,t}$:	Actual quantity of production stock at the end of operation
$F\_PAS_{m,t}$:	Actual quantity of parts inventory at the start of operation	$F\_PAE_{m,t}$:	Actual quantity of parts inventory at the end of operation
$F\_SHO_{m,t}$:	Actual quantity of surplus or shortage of the shipment on the previous day (treat a shortage as positive)	$F\_CS_{m,t}$:	Actual quantity that can be shipped (Actual stock quantity before shipment)
$F\_AS_{m,t}$:	Actual shipment quantity		

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For the actual quantity, the equations are different because information treatment depends on the type of supplier, as described above. Equation (12) shows the actual quantity of delivery upstream.

$$F\_AD_{m,t} = F\_AS_{m+1,t-1} \quad (12)$$

Equations (13) and (14) show the actual production quantities for each type. The actual production quantity is determined using Eq. (13) and (14) since the supplier cannot produce a product without sufficient parts inventory. In the case of Type A, the firm order is used for production, and in the case of Types B and C, the ADI is used for production.

(Type A) $$F\_AP_{m,t} = \min\{C\_CP_{m,t}, F\_PAS_{m,t}\} \quad (13)$$

(Type B, C) $$F\_AP_{m,t} = \min\{A\_CP_{m,t}, F\_PAS_{m,t}\} \quad (14)$$

Equation (15) shows the actual quantity that can be shipped. Just before shipment, the product stock at the start of the operation and the production quantity are available for shipment. This is the stock quantity before shipment.

$$F\_CS_{m,t} = F\_PRS_{m,t} + F\_AP_{m,t} \quad (15)$$

Equations (16) and (17) show the actual quantity of shipments of each type. The shipping quantity is determined from the temporary inventory quantity before shipment and the required shipping quantity, including the stock remaining up to the previous day. In Types A and B, the firm order is used for shipment, and in Type C, ADI is used for shipment.

(Type A, B) $$F\_AS_{m,t} = \min\{F\_CS_{m,t}, C\_NS_{m,t} + F\_SHO_{m,t}\} \quad (16)$$

(Type C) $$F\_AS_{m,t} = \min\{F\_CS_{m,t}, A\_NS_{m,t} + F\_SHO_{m,t}\} \quad (17)$$

Equations (18) and (19) show the actual quantity of surplus or shortage of shipments on the previous day for each type.

(Type A, B) $$F\_SHO_{m,t} = \max\{C\_NS_{m,t-1} + F\_SHO_{m,t-1} - F\_AS_{m,t-1}, 0\} \quad (18)$$

(Type C) $$F\_SHO_{m,t} = \max\{A\_NS_{m,t-1} + F\_SHO_{m,t-1} - F\_AS_{m,t-1}, 0\} \quad (19)$$

Equations (20) through (23) show the actual quantity of production stock and parts inventory. The actual inventories of the products and parts were the same as those in Eq. (8) through (11) during the planning phase.

$$F\_PRS_{m,t} = F\_PRE_{m,t-1} \quad (20)$$

$$F\_PRE_{m,t} = F\_CS_{m,t} - F\_AS_{m,t} \quad (21)$$

$$F\_PAS_{m,t} = F\_PAE_{m,t-1} + F\_AD_{m,t} \quad (22)$$

$$F\_PAE_{m,t} = F\_PAS_{m,t} - F\_AP_{m,t} \quad (23)$$

Equations (24) and (25) show the compensation quantity between planned and actual used to modify the order quantity. The compensation quantity is calculated by the difference between the actual and planned product stock at the end of the operation. This compensation is based on the information used for production.

(Type A) $$DIF_{m,t} = -1 \times (F\_PRE_{m,t} - C\_PRE_{m,t}) \quad (24)$$

(Type B, C) $$DIF_{m,t} = -1 \times (F\_PRE_{m,t} - A\_PRE_{m,t}) \quad (25)$$

2.3 Supply-chain structure

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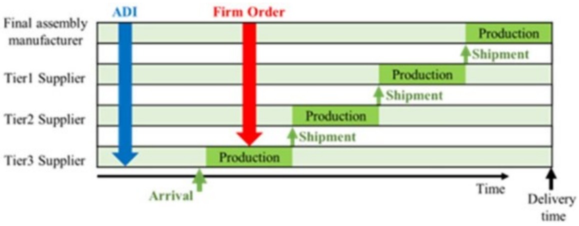
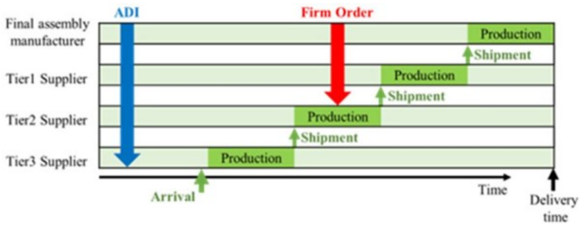
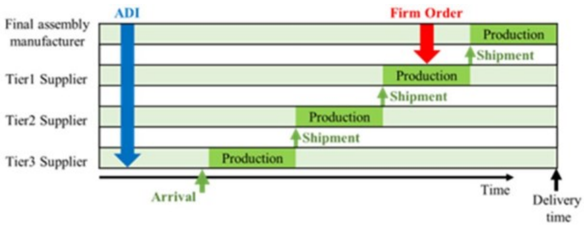
The three types of providers that were talked about in Section 2 are all part of the supply chain.1. Figure 4 shows the times of the ADI, the firm order, and the output in the supply chain. Note that knowledge comes after a certain amount of time. transfer between sources, even though it's very small compared to the horizontal line. This means that the data is likely to be sent almost at the same time. When the firm order is sent depends on when each seller can send the goods and how long it takes to make them. Table 1 shows that there are three different outcomes based on when the firm order is sent. As shown in Fig. 4a, it changes to Combination I when a clear order from the final assembly maker is received in time for the delivery date. As the delivery date gets closer, it changes to Combination II and then to Combination III, as shown in Fig. 4b and 4c. This study did not look at combinations of only Type A, which is make-to-stock, and only Type C, which is make-to-order.



(a) Supply chain of Combination I



(b) Supply chain of Combination II



(c) Supply chain of Combination III

Fig. 4 Timing of the ADI, firm order, production, parts arrival, and product shipment for each combination.

Table 1 Supplier combinations.

Combination Name	Tier-1 Supplier	Tier-2 Supplier	Tier-3 Supplier
Combination I	Type A	Type A	Type B
Combination II	Type A	Type B	Type C
Combination III	Type B	Type C	Type C

3. Simulation

The supply chain model described above was implemented on a computer, and a simulator was constructed. Several case studies have been conducted to analyze the characteristics of a production system using ADI.

3.1 Validity of the simulator

First, the bullwhip effect was checked to see if the model was correct. As we've already talked about, the bullwhip effect is when changes in demand in the supply chain get worse as they move up the chain. So, to test the bullwhip effect, the changes in order amount between providers are compared. The standard deviation ratio or variance ratio is used to figure out how big the bullwhip effect is (Chen et al., 2000; Hasama and Song, 2007). This study used the standard deviation ratio of each supplier's order number to show the size of the bullwhip effect, which is shown in Equation (26). The size of the bullwhip effect is shown by B. A bullwhip impact happens when **B** > 1, and it gets stronger as B gets bigger. The bullwhip effect doesn't happen if **B** is less than 1.

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$$B(m,n) = \frac{SD[AD_{n,t}]}{SD[AD_{m,t}]} \quad (m < n) \tag{26}$$

The standard deviation ratios, B(Tier 1, Tier 2) and B(Tier 1, Tier 3), of the order quantity of the Tier-1 supplier against those of Tier 2 and Tier 3 were calculated using the average of the moving standard deviation of the 20-day reference period. Because the flows of the ADI and firm order follow the same process, the result is the same for any supplier combination when there is no gap between the ADI and firm order. Therefore, it is sufficient to use only Combination II, which contains all the three types.

In this simulation, the conditions are defined as follows:

・The supplier combination is Combination II and the production capacity of each supplier is sufficiently large.

・The ADI was generated using a random number that followed a normal distribution with an average $\mu_f = 500$ and standard deviation $\sigma_f = 20$.

・The firm order has no gap with the ADI.

・The period for calculating the moving average μ and moving standard deviation σ for the safety stock in Eq. (2) is 10 days.

Under these conditions, ten simulations were performed, and each simulation was conducted for 500 days. Figure 5 shows the fluctuation of the order quantity from the 140th to the 190th day. The solid blue line represents a Tier-1 supplier, the solid red line represents a Tier-2 supplier, and the black line represents a Tier-3 supplier. As Fig. 5 shows, for Combination II, Tier 1 is a Type A supplier, Tier 2 is a Type B supplier, and Tier 3 is a Type C supplier.

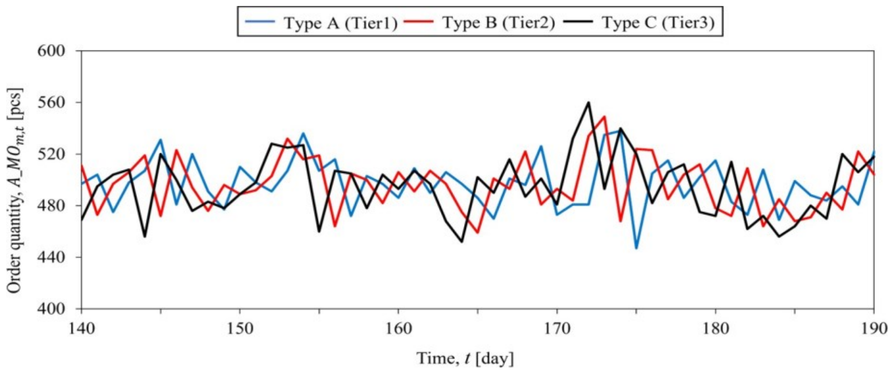

Fig. 5 Fluctuation of the order quantity from the 140th to the 190th day when the ADI is generated using a random number that follows a normal distribution with average $\mu_f = 500$ and standard deviation $\sigma_f = 20$ in Combination II. (The period on the horizontal axis is a partial excerpt of the same period as in the later results.)

In Fig. 5, the upstream supplier fluctuates earlier than the downstream supplier. This is because due dates are determined, and to ensure timely production on the final assembly manufacturer, it is necessary for the upstream to respond to fluctuations earlier than the downstream. In addition, the fluctuation of the order quantity was largest in Type C, followed by Type B and Type A. After calculating the average of the ten simulations, the standard-deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) were 1.08 and 1.28, respectively. Both the fluctuation and comparison of the standard deviation ratios show that the bullwhip effect occurs and is noticeably greater in upstream suppliers. These results are similar to those of an analysis using actual data (Ueno, 2018) and a study of the factors that affect the bullwhip effect (Hasama and Song, 2007). From these results, it can be concluded that the simulator is valid.

3.2 Effect of the average and standard deviation of the ADI

Depending on the product, the mean and standard deviation of the demand distribution differ. The standard deviation ratios in Section 3.1 analyze whether they are caused by the ADI generating conditions (mean and standard deviation). In this section, the effect of the differences in the average and standard deviation of the ADI is analyzed using the standard deviation ratios of the order quantities. Table 2 lists the simulation results for changing the average μ_f and standard

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deviation σ_f of the ADI under the conditions described in Section 3.1. The values in Table 2 are the averages of the ten simulations.

Table 2 Standard-deviation ratios of the order quantities for changing the average μ_f and the standard deviation σ_f of the ADI.

μ_f	σ_f	B(Tier 1, Tier 2)	B(Tier 1, Tier 3)
500	20	1.08	1.28
500	40	1.08	1.26
500	60	1.08	1.27
600	20	1.08	1.27
600	40	1.08	1.27
600	60	1.08	1.27
700	20	1.07	1.26
700	40	1.08	1.27
700	60	1.07	1.26

From Table 2, it can be seen that the standard deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) are approximately 1.08 and 1.27, respectively, in each condition, and the standard deviation ratios of the order quantity are almost constant, even though the average and standard deviation of the ADI are changed. Therefore, the bullwhip effect is not affected by changes in the average or standard deviation of the order quantity in the ADI.

3.3 Effect of rapid changes in the market

In Sections 3.1 and 3.2, the effect on the supply chain when demand changes continuously was examined. In this section, the effects of a simple increase or decrease rather than a continuous change in demand are analyzed. This case study deals with the case of a sudden increase and decrease in demand, assuming an expansion due to rapid market growth or contraction due to rapid market decline. In this simulation, the effects of increasing or decreasing the ADI in a stepwise pattern were analyzed. The condition for the ADI was changed as follows: the order quantity increased or decreased by 10%, 20%, and 30% stepwise from 500 when $t = 150$.

Under these conditions, the simulations were executed for 500 days. The fluctuations in orders, production, and product stocks from the 140th to the 190th day are shown in Fig. 6 for the stepwise increase and in Fig. 7 for the stepwise decrease.

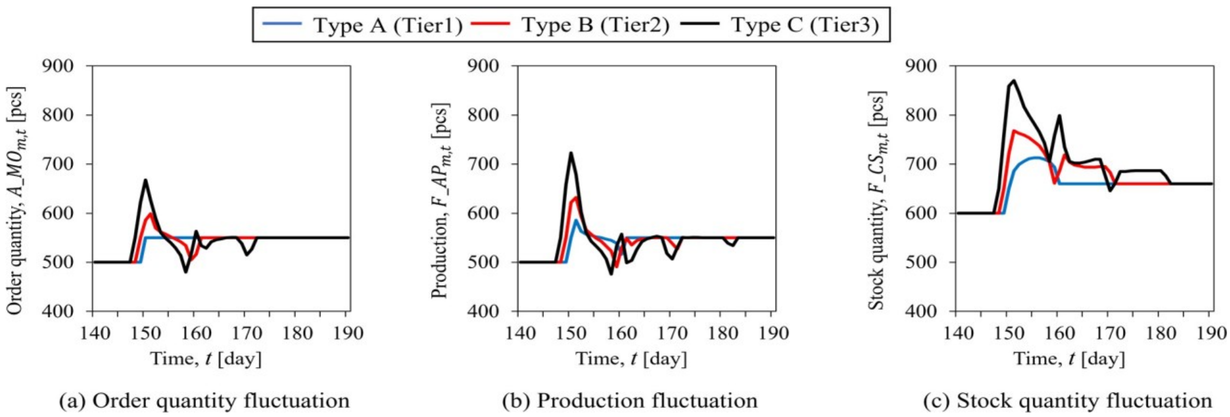

Fig. 6 Order, production, and stock-quantity fluctuation from the 140th to the 190th day in Combination II with a stepwise 10% increase in ADI.

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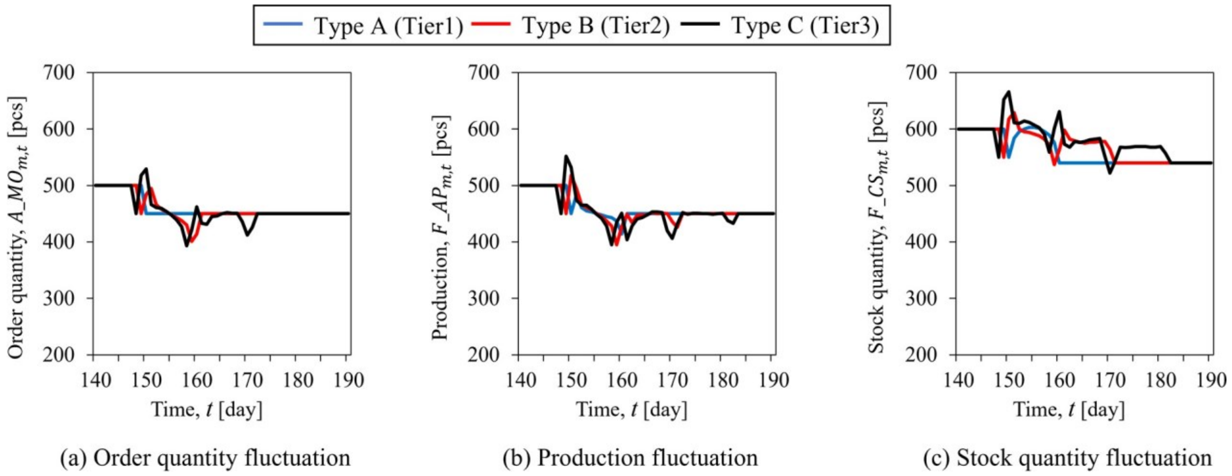

Fig. 7 Order, production, and stock-quantity fluctuation from the 140th to the 190th day in Combination II with a stepwise 10% decrease in ADI.

In Figs. 6 and 7, as in Fig. 5, the upstream supplier receives orders earlier than the downstream supplier, and the fluctuation of the order quantity is the largest in Type C, followed by Type B and Type A. In addition, all suppliers first show a stepwise change, and their fluctuations are wavy and damping; however, the amplitude of the stepwise decrease is smaller than that of the stepwise increase.

The standard deviation ratios of the order quantities for each condition are presented in Table 3.

Table 3 Standard-deviation ratios of order quantities when changing the width of the stepwise changes.

Case	B(Tier 1, Tier 2)	B(Tier 1, Tier 3)
Increase by 10% from 500	1.81	3.21
Increase by 20% from 500	1.81	3.20
Increase by 30% from 500	1.81	3.20
Decrease by 10% from 500	1.52	2.11
Decrease by 20% from 500	1.52	2.11
Decrease by 30% from 500	1.52	2.11

Table 3 indicates that the standard deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) are smaller when demand decreases than when it increases. Furthermore, the standard deviation ratios for both stepwise increases and decreases were constant regardless of the width of the stepwise changes.

3.4 Effect of safety-stock calculation period

In the case studies up to this section, the moving average and moving standard deviation for the safety stock were calculated from the order quantity of the previous 10 days. Suppliers need to maintain safety stock to provide a stable supply, although excess inventory is undesirable from a financial perspective. Therefore, the effect on the supply chain is analyzed when inventory levels are reduced by increasing the safety stock calculation period. Under the same conditions as in the case of a stepwise 10% increase in demand, as described in Section 3.3, the calculation period of the safety stock was changed to 10, 20, and 30 days. The fluctuations in order quantities for each case are shown in Fig. 8.

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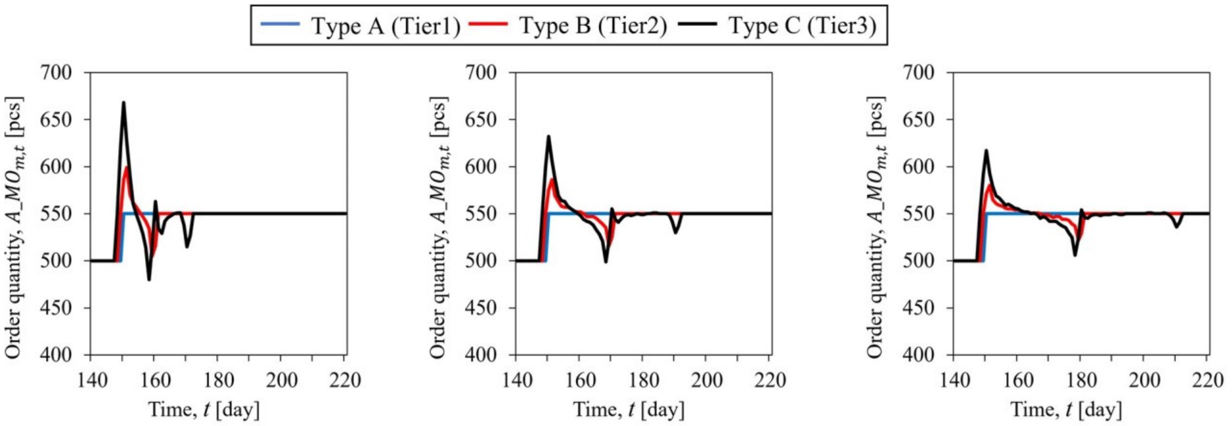

(a) The calculation period 10 days (b) The calculation period 20 days (c) The calculation period 30 days

Fig. 8 Fluctuation of the order quantity for changing the calculation period of the safety stock.

As shown in Fig. 8, the longer the calculation period of the safety stock, the longer the period for the convergence of the stepwise changes. However, the fluctuation width of the order quantity decreased. The standard deviation ratios of the order quantities for each reference period are presented in Table 4. The first increase occurs simultaneously, and the subsequent increases and decreases occur periodically.

Table 4 Standard-deviation ratios of the order quantity when changing the calculation period of the safety stock.

Case	*B*(Tier 1, Tier 2)	*B*(Tier 1, Tier 3)
Reference period: 10 days	1.81	3.21
Reference period: 20 days	1.83	2.93
Reference period: 30 days	1.77	2.73
Reference period: 40 days	1.70	2.54

Table 4 indicates that the longer the calculation period of the safety stock, the smaller the standard deviation ratios *B* (Tier 1, Tier 2) and *B* (Tier 1, Tier 3), although the difference is slight.

3.5 Effect of the gap between the ADI and firm order

Because the ADI is simply a production forecast, there is usually a gap between the ADI and firm order. This gap indicates that the production forecast in the ADI is inaccurate. In this section, we analyze the effect of supplier combinations when there is a gap between the ADI and firm order. In this study, a firm order containing a gap from the ADI is generated using a random number that follows a normal distribution with an average ADI and standard deviation $\sigma_k = 20$. Using this condition for the firm order, the same simulation as in Section 3.1 was executed for the three combinations. The fluctuations in orders, production, and product stocks from the 140th to the 190th day are shown in Fig. 9 for Combination I, Fig. 10 for Combination II, and Fig. 11 for Combination III.

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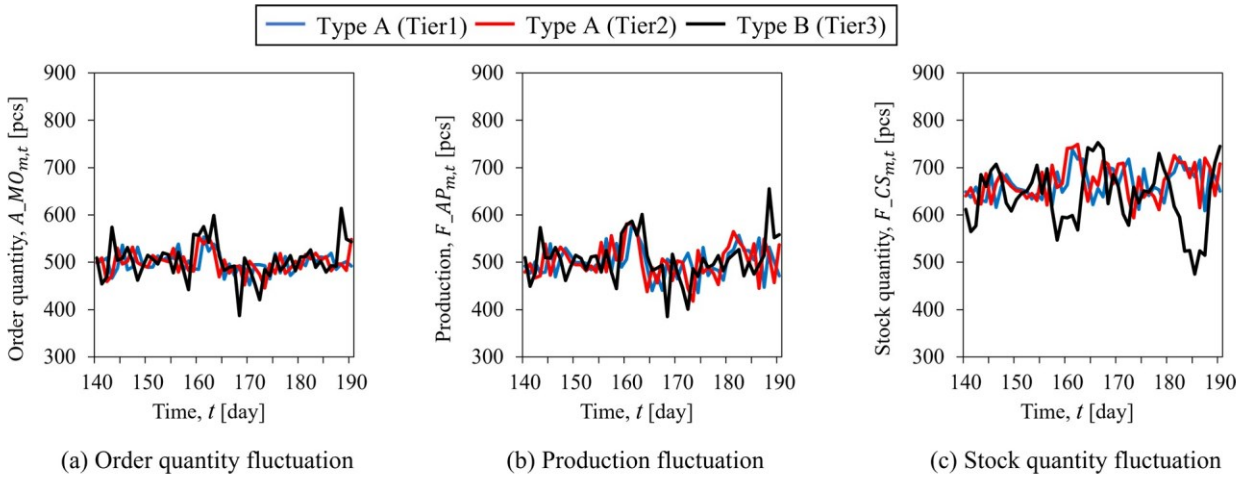

Fig. 9 Order, production, and stock-quantity fluctuation from the 140th to the 190th day in Combination I.

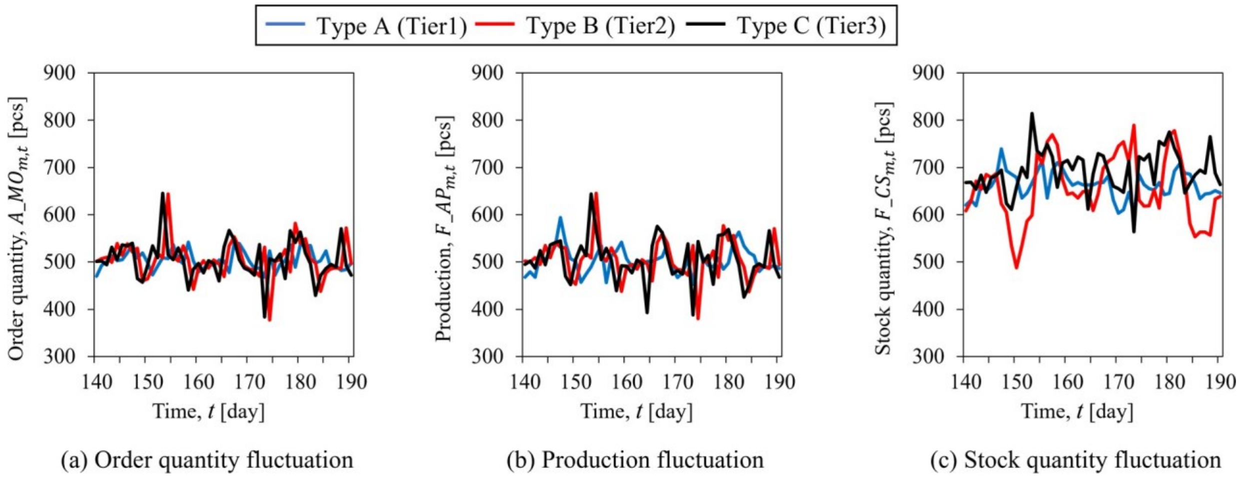

Fig. 10 Order, production, and stock-quantity fluctuation from the 140th to the 190th day in Combination II.

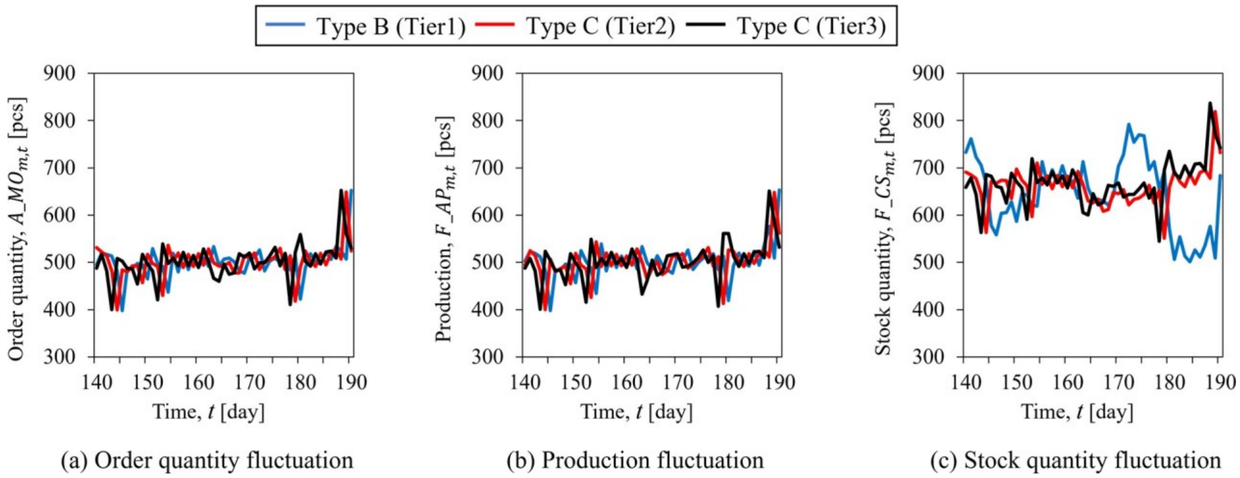

Fig. 11 Order, production, and stock-quantity fluctuation from the 140th to the 190th day in Combination III.

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Fig. 9 shows that for Combination I, the Tier-3 seller of Type B (shown in black) has bigger changes in both the order quantity shown in Fig. 9a and the production quantity shown in Fig. 9b. The changes for the other two suppliers are about the same. In Tier 3, which is Type B, the stock amount shown in Fig. 9c changes in a way that is different from the others. Figure 10 shows that for Combination II, the changes in the order quantity (Fig. 10a) and the production quantity (Fig. 10b) are bigger for the Tier-2 seller (Type B) and the same for the Tier-3 supplier (Type C). Also, the direction of the changing stock amount shown in Fig. 10c is different for Tier 2, whose type is B.

In Combination III, as shown in Fig. 11, all providers have the same width and variation trend in both the order quantity (Fig. 11a) and the production quantity (Fig. 11b). The changes in stock amount shown in Fig. 11c have a different pattern for the Tier-1 provider, whose type is B, than for the other two combos. Next, the standard deviation used to make a fixed order is changed, and the impact of a bigger gap from the ADI is studied. The standard deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) of the order number are shown in Table 5. These ratios change when the standard deviation k for firm order creation is set to 20, 40, or 60.

Table 5 Standard-deviation ratios of the order quantity for changing the standard deviation σ_k of the firm order.

Combination	σ_k	B(Tier 1, Tier 2)	B(Tier 1, Tier 3)
I(A, A, B)	20	1.08	2.07
I(A, A, B)	40	1.07	2.99
I(A, A, B)	60	1.08	3.59
II(A, B, C)	20	1.61	1.76
II(A, B, C)	40	2.36	2.46
II(A, B, C)	60	3.09	3.17
III(B, C, C)	20	1.01	1.11
III(B, C, C)	40	1.01	1.14
III(B, C, C)	60	1.01	1.14

Table 5 indicates that in Combination I, the larger the standard deviation σ_k of the firm order, the larger the standard deviation ratio B(Tier 1, Tier 3) of the order quantity. However, it is clear that the standard deviation ratio B(Tier 1, Tier 2) of the order quantity is almost constant, regardless of the standard deviation σ_k of the firm order. In Combination II, the larger the standard deviation σ_k of the firm order, the larger the standard deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) of the order quantity. In Combination III, the standard deviation ratios B(Tier 1, Tier 2) and B(Tier 1, Tier 3) of the order quantity are almost constant even though the standard deviation σ_k of the firm order increases.

4. Discussion

The layout of the production line from Section 2.3 and the effects from Section 3 are talked about here. Section 2.3 says that there are three types of sellers in the production line. It is talked about how the model in this work can be used for a more complex multi-stage supply chain.

Let us say there is a $\boldsymbol{T}$-stage supply chain with $S1$, $S2$,... $\boldsymbol{SS}$ as the names of the suppliers. The supply chain is shown in Figure 12 if a sure order is sent to the nth ($1 \leq m \leq \boldsymbol{S}$) seller during production and suppliers of the same type are put next to each other. It is shown in Figure 12a that when $m = n$, Type B is the most upstream provider. As shown in Figure 12b, when $1 < m < \boldsymbol{T}$, the intermediate producers in the supply chain are Type B. This is Combination II. The provider further down the chain, Type B, is Combination III when $m = 1$. This is shown in Figure 12c. You can handle any multistage supply chain as if it were a single chain by using these three sets. The three types of providers are different, though, so the two-stage plan can't handle them. So, the suggested supply chain model can be used as the main part of the research model for a single-chained multistage supply chain.

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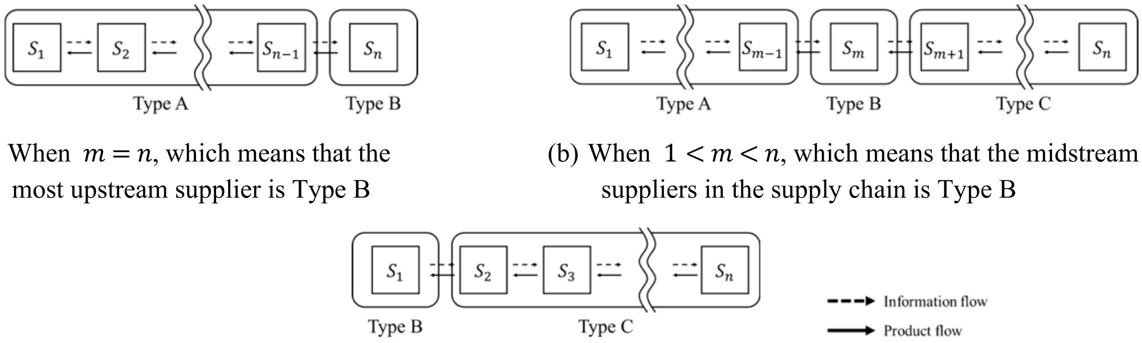

(a) When $m = n$, which means that the most upstream supplier is Type B

(b) When $1 < m < n$, which means that the midstream suppliers in the supply chain is Type B

(c) When $m = 1$, which means that the most downstream supplier is Type B

Fig. 12 n-stage supply chain classification.

It seems strange, but Section 3.2 shows that the average and standard deviation in the ADI don't change the standard deviation ratio. The standard deviation of the order number for each seller goes up as the average and standard deviation go up. The rate of change is almost constant, though. This means that the standard deviation ratio stays pretty much the same. When demand changes quickly, Section 3.3 shows that sellers first show a stepwise change, and then their changes are wavy and smooth. The safety-stock equation, shown in Equation (2), has something to do with this change. First, the amount of safety stock goes up as the changing standard deviation of the order number goes up. In answer to this rise, the order amount goes up. But because more safety stock makes a gap in the stock, the production quantity goes down and the order quantity goes down with it. As these steps are repeated, the order amount goes up or down with dampening. When demand goes down, the standard deviation ratio is smaller than when demand goes up. So, we can say that the bullwhip effect is less strong when demand goes down. This is because the drop in demand leads to less safety stock being needed, which partly cancels out the rise in safety stock caused by changes in demand.

It is made clear in Section 3.4 that the longer the calculation time of the safety stock, the longer it takes for the stepwise change to become more stable and the smaller the order amount fluctuation width. We expect that a longer assessment time will lower the amount of stock and make things easier for sellers further up the chain. It is hard to react to changes in the market, though, when the calculation period is longer, so it is hard to make the calculation period longer.

In Section 3.5, it is shown that when there is a break in the fixed order, the order quantity and production quantity change more for Type B suppliers and their main suppliers. However, the stock quantity changes more only for Type B suppliers. This is because Type B handles material in different ways during production and shipment. A fixed order is used to decide when to ship in Type B, and output is based on the ADI. There is a gap between the planned and real acts because of this difference. In Type B, the order amount goes up to make up for the gap, and this affects all providers after that. Because Type B suppliers' inventory can change a lot, the supply chain needs to be able to handle big changes in inventory by having Type B suppliers build big warehouses ahead of time and be able to work with Type C suppliers who make and ship without firm orders.

5. Conclusion

It is harder for companies further up the supply chain to deal with a production system that uses information about future demand. The goal of this study is to make this task easier by creating an ADI-based supply chain analysis model. First, a supply chain with four companies was used to divide sellers into three groups based on when the firm order was placed and when the goods were produced. Second, a model was made of how the production activity model is structured for each type of provider. As research simulations, these models were made and put into action. Lastly, there were a number of case studies. The simulation showed that the bullwhip effect was stronger for sellers further upstream. This meant that the model that was made was true.

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As the simulator's research showed, changes in order, output, and stock levels were wavering and slowing down. However, the bullwhip effect was stronger when quick changes happened. Therefore, optimisation means avoiding sudden rises or falls in the value. Also, when there was a delay between the ADI and the final order, the change in demand was bigger for Type B providers first, then for the other Type C suppliers. Because of this, the bullwhip effect was smaller in Combination III because each provider almost handled the same amount of information. However, this wasn't the best way to handle changes in the stock amount. Based on these findings, the following things can help optimise the supply chain. The first is to keep demand steady when it changes quickly. The second goal is to close the gap between what Type B providers were supposed to do and what they actually did.

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