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The Impact of Demand Information Sharing on the Supply Chain Stability

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1. Introduction

Supply chain management (SCM) is defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, distributors and retailers to make sure that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying customer requirements. As a long-term cooperation strategy among enterprises, supply chain requires stable operations as necessary conditions for optimization and long-term competitive advantage of the whole supply chain. Stability, therefore, becomes an important indicator in supply chain management.

Research on supply chain stability began in early 1960s. Based on system dynamics method, Forrester (1961) proves the presence and the cause of the bullwhip effect. He indicates that bullwhip effect could be weakened by improving decision-making behavior. From then on, the bullwhip effect and supply chain stability have been studied by many researchers. Most of these studies employed an ordering policy known as the APIOBPCS model (John *et al.*, 1994; Disney and Towill, 2003). APIOBPCS policy is optimal in that, the policy minimizes the variance of the inventory levels with a sequence of forecast errors of demand over the lead time given (Vassian, 1954). In discrete time domain, pure time delays are readily handled by the z-transform and many results are known about its stability (Disney and Towill, 2002), variance amplification properties (Disney and Towill, 2003; Disney *et al.*, 2004), and dynamic performance (Dejonckheere *et al.*, 2003). Disney *et al.* (2006) investigate the stability of a generalized OUT (Order Up To) policy for the step response in both discrete and continuous time. Disney *et al.* (2007) prove that discrete and continuous Bullwhip Effect expressions have similar structures and show that the two domains are managerially equivalent and each domain can be used to study a supply chain in practice.

The pure time delay causes complications in the time domain differential/difference equations. In the frequency domain, such equations generate an infinite number of zeros in the transfer function. Certain progress has been made on the stability of such systems by recasting the policy as a Smith Predictor (Warburton *et al.*, 2004; Riddalls and Bennett, 2002). However, little is known about variance amplification issues or other aspects of the model's dynamic performance. The use of Lambert ω function to solve such problems has recently gained some popularity. Several authors have studied the production and inventory control problem using continuous mathematics; and in the solution process the Lambert ω function is used (Warburton, 2004a, b; Warburton *et al.*, 2004).

Nagatani and Helbing (2004) study several conceivable production strategies to stabilize supply chains. They derive linear stability conditions using simulations for different control strategies. The results indicate that the linear stability analysis is a helpful tool for the judgment of the stabilization effect, although unexpected deviations can occur in the non-linear regime. Lalwani and Disney (2006) outline a framework for developing state space representations of production and inventory control policies from their transfer functions. They focus on the discrete time case and derived state space representations that are both controllable and observable. The state space approach is then used to determine the stability boundary of the production ordering system based on the eigenvalues of the state matrices. Saad *et al.* (2006) reveal the effectiveness of the various decision policies to improve stability under different types of disturbances. Their findings demonstrate the ability of the approach to provide a wealth of potential solutions, and confirm the qualitative behavior of a supply chain in response to the different policies. Strozzi *et al.* (2007) study the relationships among bullwhip effect, stability of the supply chain and costs-applied divergence-based control strategy to stabilize the supply chain dynamic with a consequent reduction of the total costs and bullwhip effect. Saeed (2008) points out that trend forecasting is often observed to increase instability creating the so-called bullwhip effect when used to assess demand. On the other hand, with reliability to increase stability in controller design, a trend of a tracking variable is used to drive correction. Ouyang (2008) analyzes the bullwhip effect in multi-stage supply chains operated with linear and time-invariant inventory management policies and shared supply chain information. Robust analytical conditions are derived based only on inventory management policies, to predict the presence of the bullwhip effect and bound its magnitude.

The concept of BIBO (bounded input, bounded output) stability is adopted in this study which means if a bounded input is given (e.g., step and impulse), the system produces a bounded output. A stable system will respond to any finite input and return to its initial conditions. An unstable system, however, will respond to a finite input with oscillations of ever increasing magnitude (or explode exponentially without bounds). A critically stable system will result in oscillations about the initial conditions of a constant magnitude (Disney, 2005). In contrast, an unstable system will produce infinite fluctuations in response to the input signal. In this paper, supply chain stability is defined as follows: suppose the supply chain system model has a stable initial state, then the system is stable if order, inventory and work-in-process response could recover equilibrium in a finite time after an appropriate demand disturbance. An unstable system will typically oscillate with ever increasing amplitude between positive and negative infinity. Of course, in a practical situation, the amplitude of the oscillations will be limited by the capacity of the plant (the production facility). A system can also be “critically stable” in that, by setting parameters on the boundary of stability, the system is in a perpetual limit cycle. Both critically stable and unstable systems are clearly inefficient and undesirable from a production/inventory control viewpoint, and thus should be avoided.

2. Review of the IOBPCS family

The IOBPCS (Inventory and Order Based Production Control System) family of Decision Support Systems is summarized in Table 1 (Sarimveis, 2007). As can be discovered, different members within the IOBPCS family have either some or all of these generic components. IOBPCS is the basic periodic review algorithm for issuing orders into a supply pipeline, in

Model	Full Name	Target Inventory	Demand policy	Inventory policy	Pipeline policy
IBPCS	Inventory based production control system	Constant	$G_i(z) = 0$	$G_i(z) = \frac{1}{T_i}$	$G_w(z) = 0$
IOBPCS	Inventory and order based production control system	Constant	$G_i(z) = \frac{\alpha}{1 - (1 - \alpha)z^{-1}}$	$G_i(z) = \frac{1}{T_i}$	$G_w(z) = 0$
VIOBPCS	Variable inventory and order based production control system	Multiple of average market demand	$G_i(z) = \frac{\alpha}{1 - (1 - \alpha)z^{-1}}$	$G_i(z) = \frac{1}{T_i}$	$G_w(z) = 0$
APIOBPCS	Automatic pipeline, inventory and order based production control system	Constant	$G_i(z) = \frac{\alpha}{1 - (1 - \alpha)z^{-1}}$	$G_i(z) = \frac{1}{T_i}$	$G_w(z) = \frac{1}{T_w}$ $G_w(z) = T_p$
APVIOBPCS	Automatic pipeline, variable inventory and order based production control system	Multiple of average market demand	$G_i(z) = \frac{\alpha}{1 - (1 - \alpha)z^{-1}}$	$G_i(z) = \frac{1}{T_i}$	$G_w(z) = \frac{1}{T_w}$ $G_w(z) = T_p$

Table 1. The IOBPCS family

this case based on the current inventory deficit and incoming demand from customers. At regular intervals of time the available system “states” are monitored and used to compute the next set of orders. This system is frequently observed in action in many market sectors. Towill (1982) recasts the problem into a control engineering format with emphasis on predicting dynamic recovery, inventory drift, and noise bandwidth (leading importantly to variance estimations). Edghill and Towill (1989) extended the model, and hence the theoretical analysis, by allowing the target inventory to be a function of observed demand. This Variable Inventory OBPCS is representative of that particular industrial practice where it is necessary to update the “inventory cover” over time. Usually the moving target inventory position is estimated from the forecast demand multiplied by a “cover factor”. The latter is a function of pipeline lead-time often with an additional safety factor built in. A later paper by John *et al.* (1994) demonstrates that the addition of a further feedback loop based on orders in the pipeline provided the “missing” third control variable. This Automatic Pipeline IOBPCS model was subsequently optimized in terms of dynamic performance via the use of genetic algorithms, Disney *et al.* (2000).

The lead-time simply represents the time between placing an order and receiving the goods into inventory. It also incorporates a nominal “sequence of events” delay needed to ensure the correct order of events.

The forecasting mechanism is a feed-forward loop within the replenishment policy that should be designed to yield two pieces of information; a forecast of the demand over the lead-time and a forecast of the demand in the period after the lead-time. The more accurate

this forecast, the less inventory will be required in the supply chain (Hosoda and Disney, 2005).

The inventory feed-back loop is an error correcting mechanism based on the inventory or net stock levels. As is common practice in the design of mechanical, electronic and aeronautical systems, a proportional controller is incorporated into the inventory feedback loop to shape its dynamic response. It is also possible to use a proportional controller within a (WIP) error correcting feedback loop. This has the advantage of further increasing the levers at the disposal of the systems designer for shaping the dynamic response. In particular the WIP feedback loop allows us to decouple the natural frequency and damping ratio of the system.

3. DIS-APIOBPCS model

Based on Towill (1996), Dejonckheere *et al.* (2004) and Ouyang (2008), this paper establishes a Demand Information Sharing (DIS) supply chain dynamic model where customer demand data (e.g., EPOS data) is shared throughout the chain. A two-echelon supply chain consisting of a distributor and a manufacturer is considered here for simplicity.

3.1 Assumptions

1. The system is linear, thus all lost sales can be backlogged and excess inventory is returned without cost.
2. No ordering delay. Only production and transportation delay are considered in distributor and manufacturer's lead-time.
3. Events take place in such a sequence in each period: distributor's last-period order is realized, customer demand is observed and satisfied; distributor observes the new inventory level and places an order to manufacturer; manufacturer receives the order.
4. Distributor and manufacturer will operate under the same system parameters for the deduction of mathematical complexity.
5. APIOBPCS is chosen to be adapted as the ordering policy here.

3.2 DIS-APIOBPCS description

This paper compares a traditional supply chain, where only the first stage observes consumer demand and upstream stages have to make their forecasts with downstream order information, with a DIS supply chain where customer demand data is shared throughout the chain. Their block diagrams are shown in Figs. 1 and 2. The two scenarios are almost identical except that every stage in the DIS supply chain receives not only an order from the downstream member of the chain, but also the consumer demand information.

This paper uses the APIOBPCS structure as analyzed in depth by John *et al.* (1994), which can be expressed as, "Let the production targets be equal to the sum of an exponentially smoothed (over T_a time units) representation of the perceived demand (that is actually a sum of the stock adjustments at the distributor and the actual sales), plus a fraction ($1/T_i$) of the inventory error in stock, plus a fraction ($1/T_w$) of the WIP error." By suitably adjusting parameters, APIOBPCS can be made to mimic a wide range of industrial ordering scenarios including make-to-stock and make-to-order.

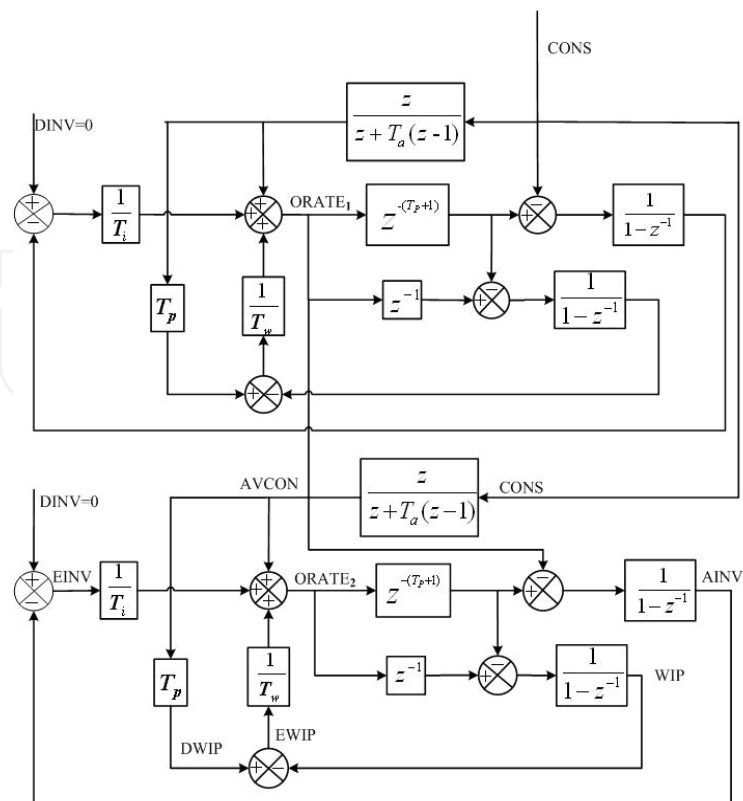


Fig. 1. DIS-APIOBPCS supply chain

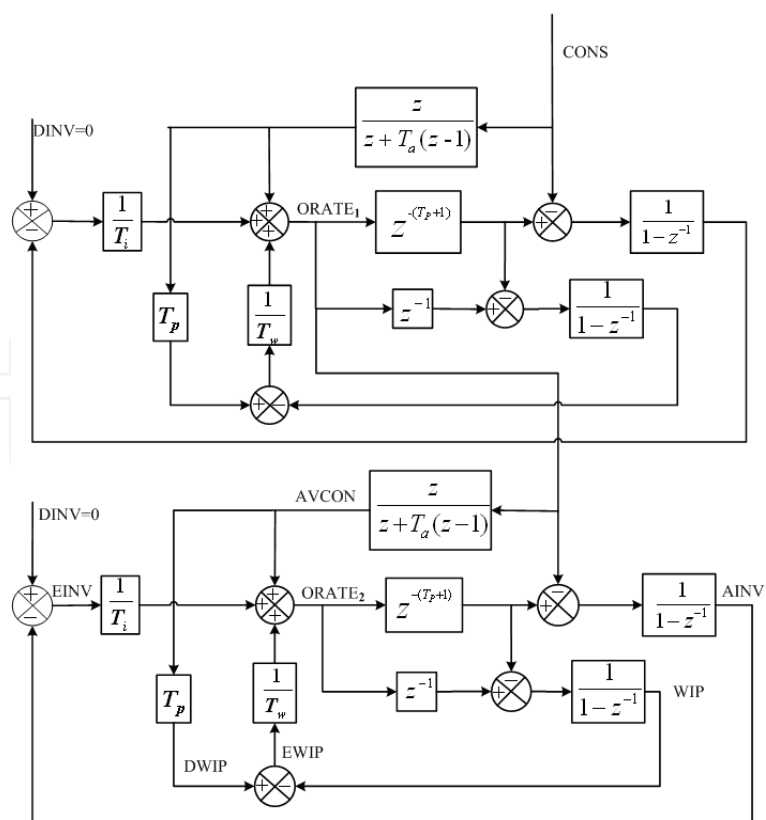


Fig. 2. Traditional supply chain

The following notations are used in this study:

AINV: Actual Inventory;

AVCON: Average Consumption;

WIP: Work in Process;

COMRATE: Completion Rate;

CONS: Consumption;

DINV: Desired Inventory;

DWIP: Desired WIP;

EINV: Error in Inventory;

EWIP: Error in WIP;

ORATE: Order Rate.

A demand policy is needed to ensure the production control algorithm to recover inventory levels following changes in demand. In APIOBPCS, this function is realized by smoothing the demand signal with a smoothing constant, T_a . The smoothing constant a in the z -transform can be linked to T_a in the difference equation $\alpha = \frac{1}{1 + T_a}$; T_p represents the

production delay expressed as a multiple of the sampling interval; T_w is the inverse of *WIP* based production control law gain. The smaller T_w value, the more frequent production rate is adjusted by *WIP* error. T_i is the inverse of inventory based production control law gain. The smaller T_i value, the more frequent production rate is adjusted by *AINV* error. It should be noted that the measurement of parameters should be chosen as the same as the sampling interval. For example, if data are sampled daily, then the production delay should be expressed in days.

3.3 Transfer function

In control engineering, the transfer function of a system represents the relationship describing the dynamics of the system under consideration. It algebraically relates a system's output to its input. In this paper, it is defined as the ratio of the z -transform of the output variable to the z -transform of the input variable. Since supply chains can be seen as sequential systems with complex interactions among different parts, the transfer function approach can be used to model these interactions. A transfer function can be developed to completely represent the dynamics of any replenishment rule. Input to the system represents the demand pattern and output the corresponding inventory replenishment or production orders.

The transfer functions of DIS-APIOBPCS system for *ORATE/CONS*, *WIP/CONS* and *AINV/CONS* are shown in Eqs.(1) –(3).

$$\frac{ORATE}{CONS} = \frac{z^{1+T_p} \left[T_i(T_p + T_w)(-1 + z) + (z + T_a(z - 1))T_w X_1 \right]}{\left[T_a(-1 + z) + z \right] \left\{ T_w + T_i \left[-1 + (1 + T_w(-1 + z))z^{T_p} \right] \right\}} \quad (1)$$

$$X_1 = \frac{z^{1+T_p} \left[-T_a T_w + T_i(T_p + T_w)(-1 + z) + (1 + T_a)T_w z \right]}{\left[T_a(-1 + z) + z \right] \left\{ T_w + T_i \left[-1 + (1 + T_w(-1 + z))z^{T_p} \right] \right\}}$$

Here, X_1 is the *ORATE/CONS* transfer function of the distributor.

$$\text{Let } \Omega(z) = \frac{ORATE}{CONS},$$

Then,

$$\frac{WIP}{CONS} = \left(\frac{1 - z^{-T_p}}{z - 1} \right) \cdot \Omega(z) \quad (2)$$

$$\frac{AINV}{CONS} = \frac{\Omega(z) \cdot z^{-T_p} - X_1 z}{z - 1} \quad (3)$$

4. Stability analysis of DIS-APIOBPCS supply chain

It is particularly important to understand system instability, because in such cases the system response to *any* change in input will result in uncontrollable oscillations with increasing amplitude and apparent chaos in the supply chain. This section establishes a method to determine the limiting condition for stability in terms of the design parameters.

The stability condition for discrete systems is: the root of the system characteristic equation (denominator of closed-loop system transfer function) must be in the unit circle on the z plane. The problem is that the algebraic solutions of these high degree polynomials involve a very complex mathematical expression that typically contains lots of trigonometric functions that need inspection. In such cases, the necessary and sufficient conditions to show whether the roots lie outside the unit circle are not easy to determine. Therefore, the Tustin Transformation is taken to map the z -plane problem into the w -plane. Then the well-established Routh-Hurwitz stability criterion could be used. The Tustin transform is shown in Eq.(4). This method changes the problem from determining whether the roots lie inside the unit circle to whether they lie on the left-hand side of the w -plane.

$$z = \frac{1 + \omega}{1 - \omega} \quad (4)$$

Take $T_a=2$, $T_p=2$ for example, the characteristic equation is showed in Eq.(5) and the ω -plane transfer function now becomes Eq.(6).

$$D(z) = [2(z - 1) + z] \left\{ T_w + T_i \left[-1 + (1 + T_w(-1 + z))z^2 \right] \right\}^2 = 0 \quad (5)$$

$$\begin{aligned} &T_w \omega^4 + (2T_w + 4T_i + 2T_i T_w) \omega^3 + (16T_i + 14T_i T_w - 12T_w) \omega^2 \\ &+ (-20T_i + 14T_w + 22T_i T_w) \omega + (10T_i T_w - 5T_w) = 0 \end{aligned} \quad (6)$$

This equation is still not easy to investigate algebraically, but the Routh-Hurwitz stability criterion can now be utilized which does enable a solution in Eq.(7).

$$\text{When } 0.5 < T_i < 1.618, \quad \frac{T_i(-3 - T_i - \sqrt{9T_i^2 - 2T_i + 1})}{2(T_i^2 - T_i - 1)} < T_w < \frac{T_i(-3 - T_i + \sqrt{9T_i^2 - 2T_i + 1})}{2(T_i^2 - T_i - 1)}$$

$$\text{When } T_i > 1.618, \quad T_w > \frac{T_i(-3 - T_i + \sqrt{9T_i^2 - 2T_i + 1})}{2(T_i^2 - T_i - 1)} \quad (7)$$

There is no limit to the value of T_p and T_a for this approach, but these parameters must be given to some certain values for clarity. Thus, the stability conditions of the system under different circumstances are obtained, as shown in Table 2.

$T_a=1,2$	$T_p=1$	$\frac{2T_i}{2T_i+1} < T_w < \frac{-T_i}{T_i-1}, \quad 0 < T_i < 1$ $T_w > \frac{2T_i}{2T_i+1}, \quad T_i > 1$
	$T_p=2$	$\frac{T_i(-3-T_i-\sqrt{9T_i^2-2T_i+1})}{2(T_i^2-T_i-1)} < T_w < \frac{T_i(-3-T_i+\sqrt{9T_i^2-2T_i+1})}{2(T_i^2-T_i-1)}$ $0.5 < T_i < 1.618$ $T_w > \frac{T_i(-3-T_i-\sqrt{9T_i^2-2T_i+1})}{2(T_i^2-T_i-1)} \quad T_i > 1.618$
	$T_p=3$	$\frac{2T_i}{2T_i+1} < T_w < \frac{T_i(-4T_i-2T_i^2+3-\sqrt{8T_i^2-4T_i-16T_i^3+1+16T_i^4})}{2(T_i^3-2T_i^2-T_i+1)}$ $0 < T_i < 2.155$ $T_w > \frac{2T_i}{2T_i+1} \quad T_i > 2.155$

Table 2. Stability conditions of the APIOBPCS system

According to control engineering, a system’s stability condition only depends on the parameters affecting feedback loop, as Table 2 shows. The stability boundary of DIS-APIOBPCS is determined by T_p , T_i , and T_w , whereas T_a will not change the boundary. It is interesting to note that the D-E line where $T_i = T_w$ (Deziel and Eilon, 1967) always results in a stable system and has other important desirable properties, as also reported in Disney and Towill (2002).

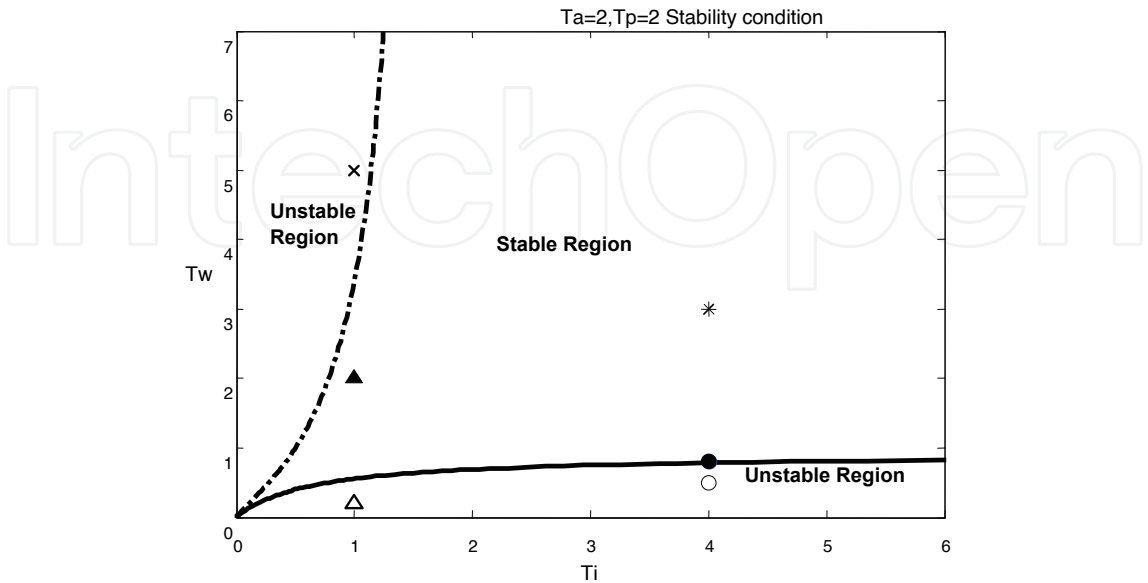


Fig. 3. The stability boundary when $T_a = 2$ and $T_p = 2$

Thus it is important that system designers consider carefully about parameter settings and avoid unstable regions. Given $T_p=2$, the stable region of DIS-APIOBPCS is shown in Figure 3, which also highlights six possible designs to be used as test cases of the stable criteria to a unit step input. For sampled values of T_w and T_i , the exact step responses of the DIS-APIOBPCS supply chain are simulated (Fig. 4) for stable; critically stable; and unstable designs.

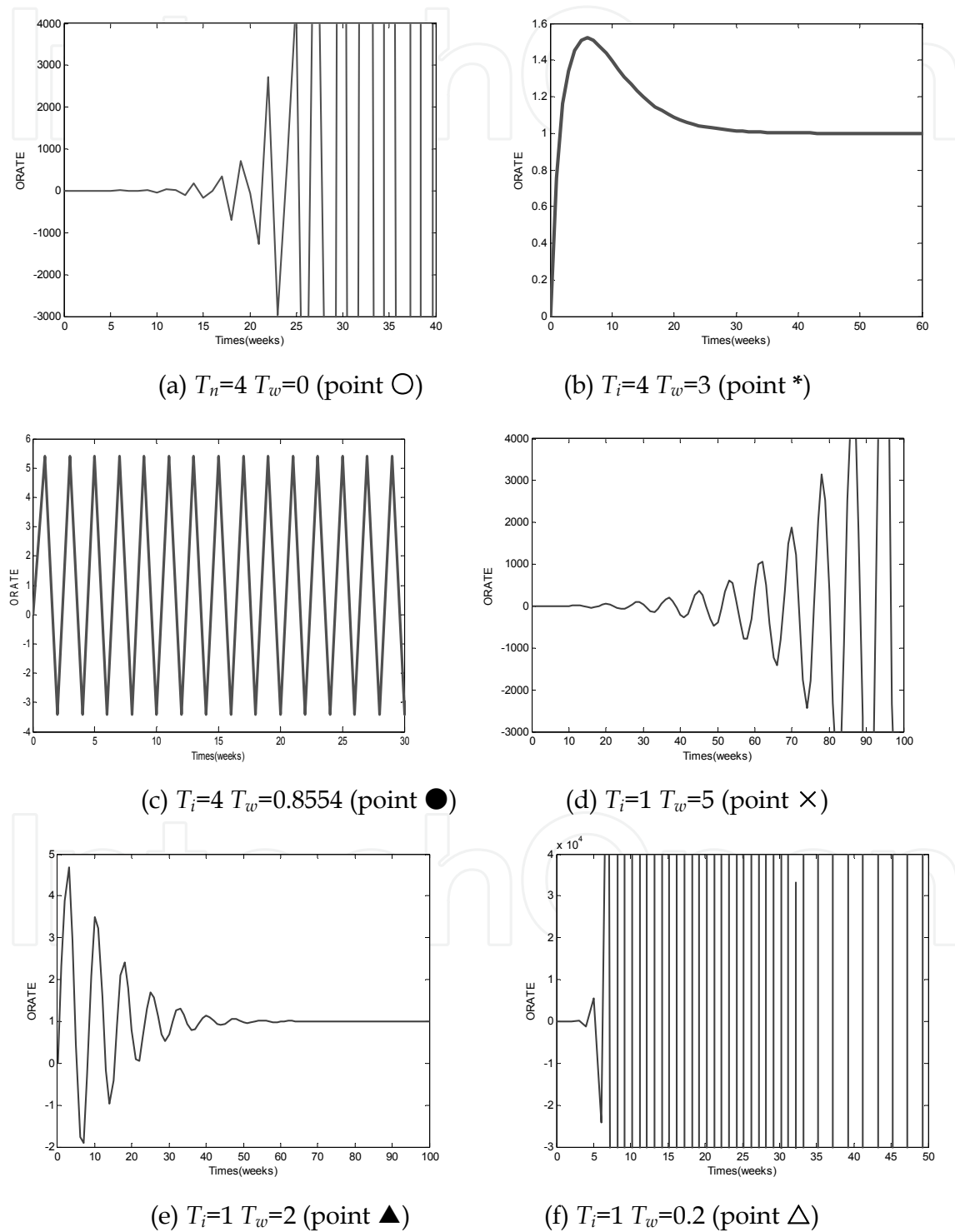


Fig. 4. Sampled dynamic responses of DIS-APIOBPCS

These above plots conform the theory by clearly identifying the stable region for DIS-APIOBPCS. The stable region provides supply chain operation a selected range for parameter tuning. In other words, the size of the region reflects the anti-disturbance capability of a supply chain system. As long as T_i and T_w are located in the stability region, the supply chain could ultimately achieve stability regardless the form of the demand information. While the parameters are located outside the stability region however, rather than returning to equilibrium eventually, the system will appear oscillation. In real supply chain systems, this kind of oscillation over production and inventory capacity will inevitably lead system to collapse.

5. Dynamic response of DIS-APIOBPCS

Note that having selected stable design parameters, T_a , T_i , T_w and T_p significantly affect the DIS supply chain response to any particular demand pattern. This section concentrates on the fluctuations of *ORATE*, *AINV* and *WIP* dynamic response. There are various performance measures under different forms of demand information. For demand signals in forms of step and impulse, it is appropriate to use peak value, adjusted time and steady-state error as measures of supply chain dynamic performance. For Gaussian process demand, noise bandwidth will be a better choice. For other forms of demand information, such as cyclical, dramatic and the combinations of the above, which measures should be used still needs further investigation.

5.1 Dynamic response of DIS-APIOBPCS under step input

Within supply chain context, the step input to a production/inventory system may be thought of as a genuine change in the mean demand rates (for example, as a result of promotion or price reductions). A system's step response usually provides rich insights when seeking a qualitative understanding of the tradeoffs involved in the "tuning" of an ordering policy (Bonney et al., 1994; John et al., 1994; Disney et al., 1997). Such responses provide rich pictures of system behavior. A unit step input is a particularly powerful test signal that control engineers to determine many properties of the system under study. For example, the step is simply the integral of the impulse function, thus understanding the step response automatically allows insight to be gained on the impulse response. This is very useful as all discrete time signals may be decomposed into a series of weighted and delayed impulses.

By simulation, a thorough understanding of the fundamental dynamic properties can be clarified, which characterize the geometry of the step response with the following descriptors.

Peak value: The maximum response to the unit step demand which reflects response smoothness;

Adjusted time: transient time from the introduction of the step input to final value (± 5 percent error) which reflect the rapidness of the supply chain response;

Steady-state error: I/O difference after system returns to the equilibrium state, which reflects the accuracy of the supply chain response.

5.1.1 The impact of T_p on DIS-APIOBPCS step response

As in real supply chain management environment, T_p is a parameter which is hardly to change frequently and artificially. No matter how T_p is set, the steady-state error of *ORATE*,

$AINV$ and WIP keeps zero. As shown in Figure 5, the smaller T_p value, the smaller peak value and shorter adjusted time. That is to say, when facing an expanding market demand, supply chain members could try to shorten the production lead-time in order to lower required capacity and accelerate response to market changes.

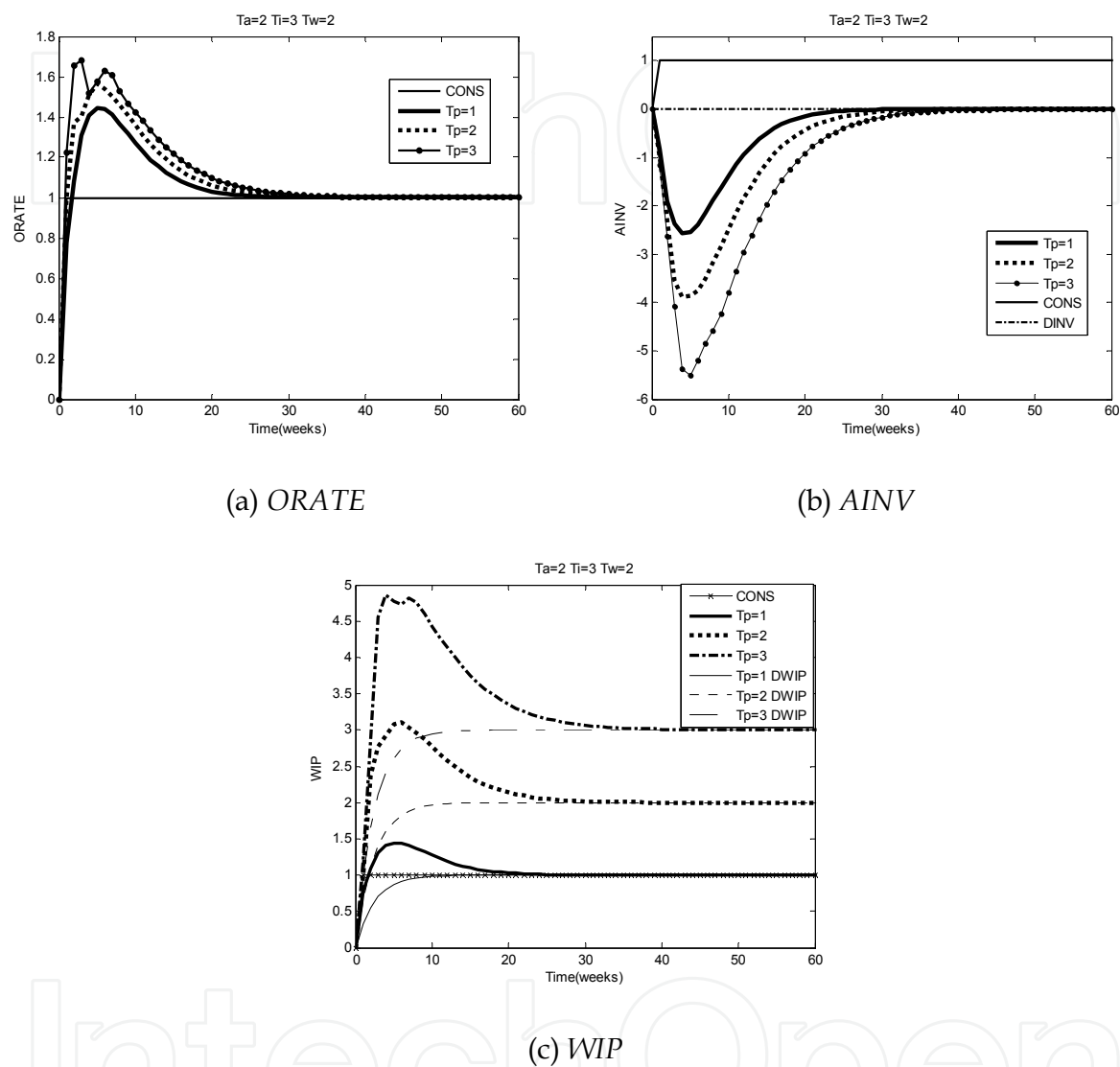


Fig. 5. The impact of T_p on DIS-APIOBPCS step response

5.1.2 The impact of T_w on DIS-APIOBPCS step response

Fig.6 depicts the responses of DIS-APIOBPCS under different T_w settings. It is shown that given other parameters as constant, with T_w increasing, the adjusted time of $ORATE$, $AINV$ and WIP responses and the peak value of $ORATE$ response will first decline and then rise, and the peak value of $AINV$ and WIP responses will rise, while all the steady-state error will remain zero. This means if the supply chain has a low production or stock capacity, when the market demand is expanded, less proportion of WIP should be considered in order quantity determination, to promote the performance and dynamic response of the supply chain.

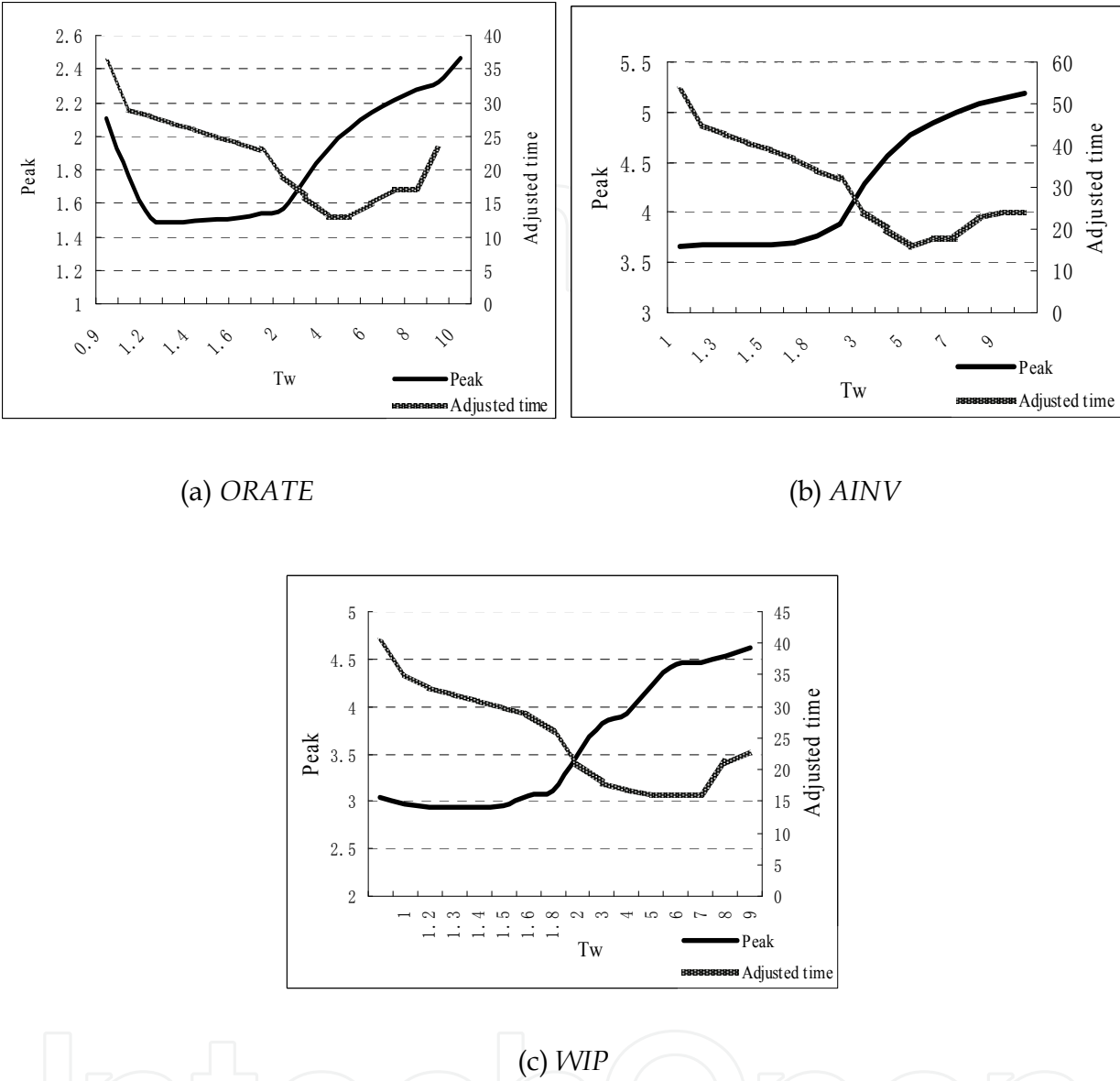


Fig. 6. The impact of T_w on DIS-APIOBPCS step response

5.1.3 The impact of T_i on DIS-APIOBPCS step response

Responses of DIS-APIOBPCS under different T_i settings are shown in Fig.7. With other parameters given, it can be found that the peak value of *ORATE*, *AINV* and *WIP* responses will decline when T_i increase, but the adjusted time follows a U-shaped process, and the steady-state error keeps zero. This phenomenon indicates that when the market demand expands, supply chain members must strike a balance between production, inventory capacity and replenishment capabilities, and make a reasonable decision on inventory adjustment parameter so as to maximize supply chain performance and to maintain long-term and stable capability.

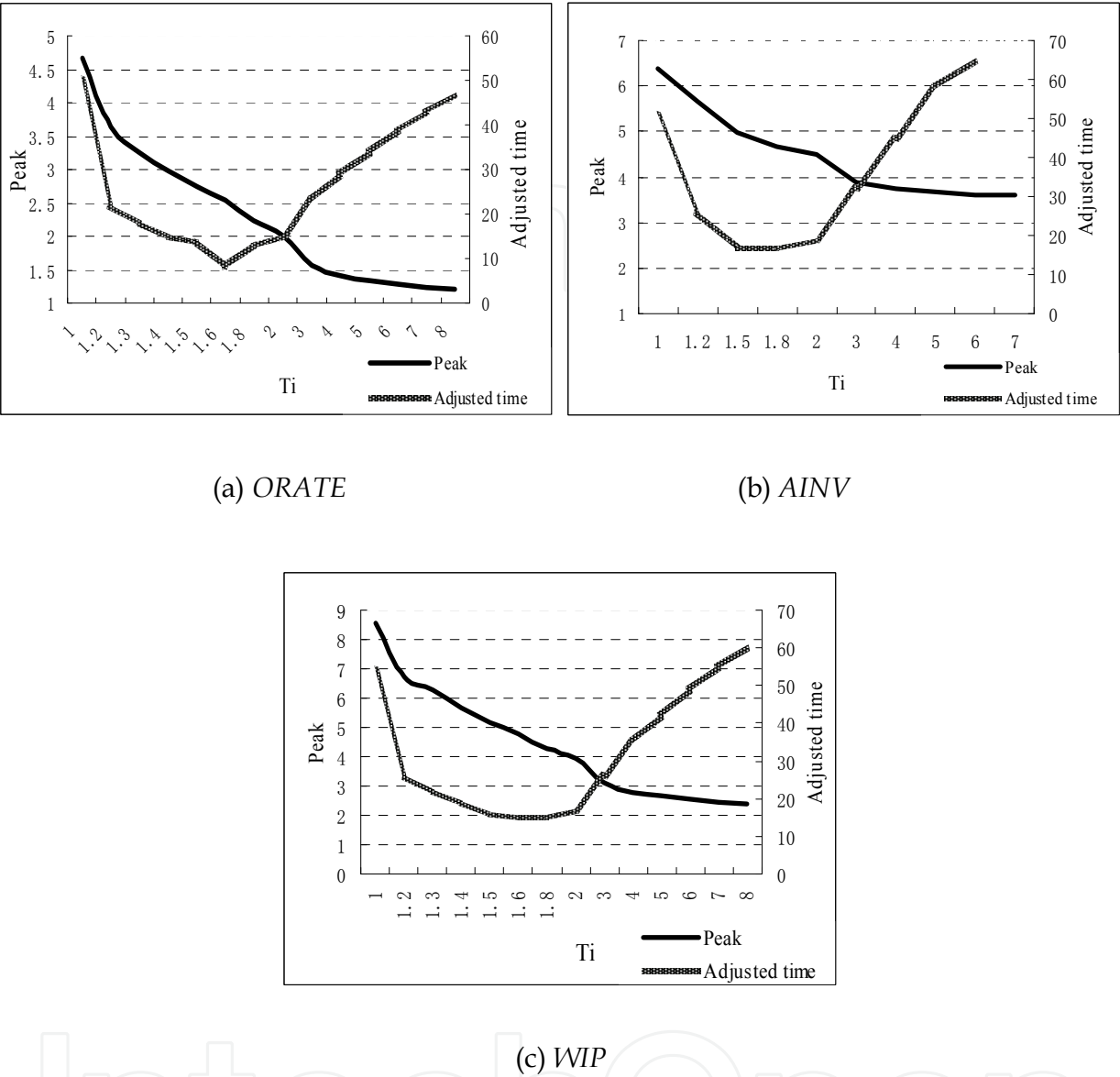


Fig. 7. The impact of T_i on DIS-APIOBPCS step response

5.1.4 The impact of T_a on DIS-APIOBPCS step response

As shown in Fig.8, increasing T_a is followed by declining peak value of *ORATE* and *WIP* response and rising adjusted time, but the *AINV* peak value will first decline then rise. From the analysis above, it is clear that T_a should be reduced for the purpose of enhancing the rapidness of the supply chain. But if the manager aims at production and inventory smoothness, T_a settings around 3.5 will be a reasonable choice.

From Section 5.1, it can be concluded that as long as the system parameters are located in the stable region, the steady-state error of dynamic response will keep zero, which means the requirement of response accuracy can always be met, whereas the smoothness and

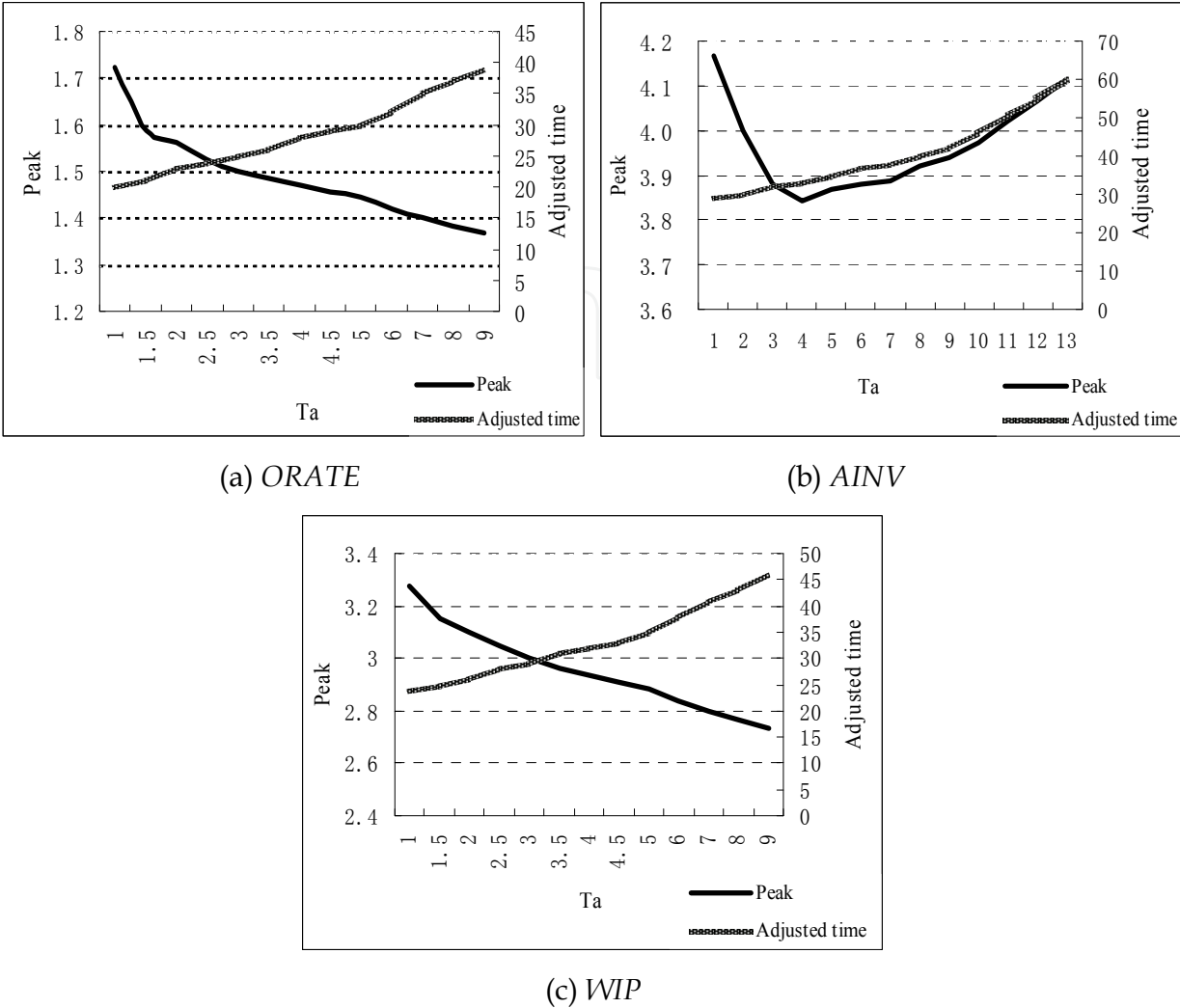


Fig. 8. The impact of T_a on DIS-APIOBPCS step response

rapidness of dynamic response sometimes have the contradictory requirements on system parameter settings. For instance, the dynamic response of *ORATE*, *AINV* and *WIP* will be all smoother and more rapid by decreasing T_p , however, smoothness needs T_i to stay low while rapidness prefers a higher T_i value. The supply chain members should adjust the system parameters integratively for all the objectives of dynamic response so as to improve the overall supply chain performance.

5.2 Dynamic response of DIS-APIOBPCS under impulse input

Demand in form of impulse can be seen as a sudden demand in the market. The sudden demand appears frequently because there are a large number of uncertain factors in the market competition environment. Sudden demand will have a serious impact on supply chains, thus enterprises need to restore stability from this sudden change as soon as possible, thereby reducing the volatility of the various negative effects.

5.2.1 The impact of T_p on DIS-APIOBPCS impulse response

From Fig. 9, it can be seen that no matter how T_p is set, the steady-state error of *ORATE*, *AINV* and *WIP* keep zero. The smaller T_p value, the smaller peak value and shorter adjusted

time. That is to say, when facing a sudden market demand, supply chain members could try to shorten the production lead-time in order to restore supply chain stability.

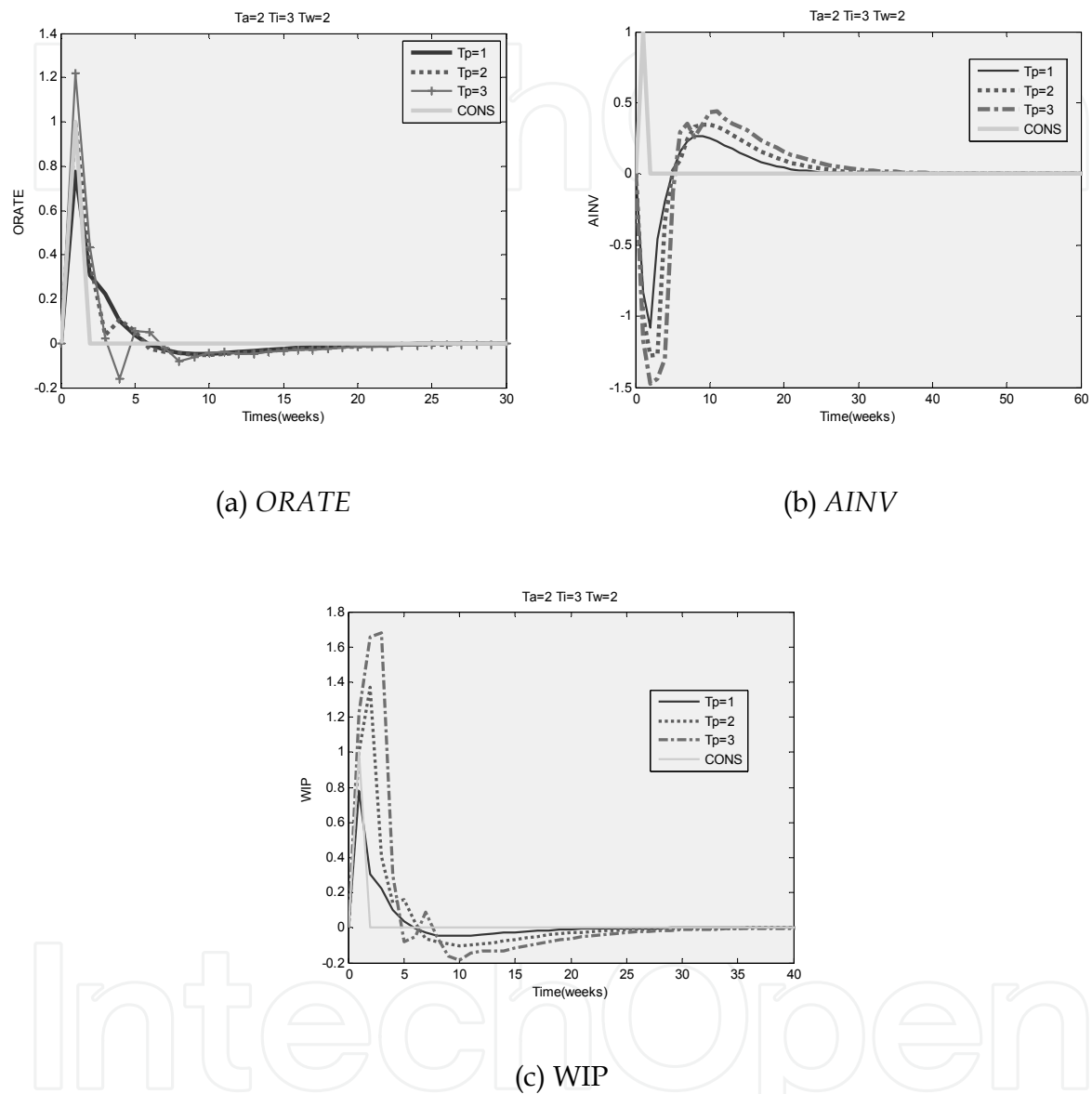
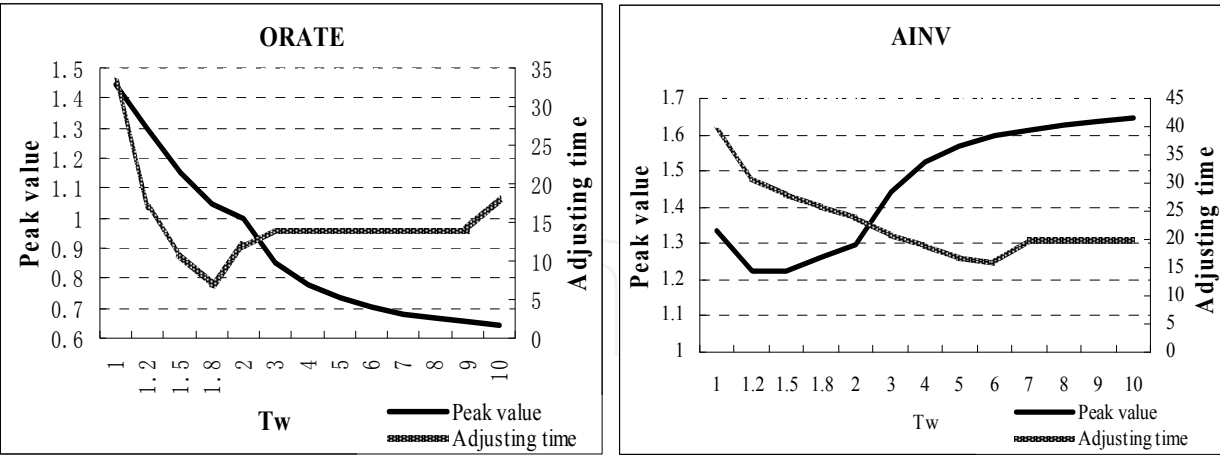


Fig. 9. The impact of T_p on DIS-APIOBPCS impulse response

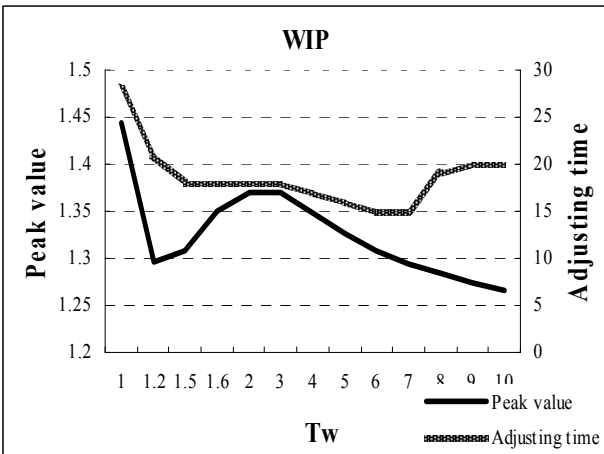
5.2.2 The impact of T_w on DIS-APIOBPCS impulse response

Fig.10 depicts that with other parameters given and the increase of T_w , the adjusted time of *ORATE* and *WIP* response will first decline and then rise, the adjusted time of *AINV* response will decline when $T_w < 6$ and then rise. The peak value of *ORATE* declines; the peak value of *WIP* will first decline then rise and eventually declines. But with the increase of T_w , the peak value of *AINV* response will rise.



(a) *ORATE*

(b) *AINV*

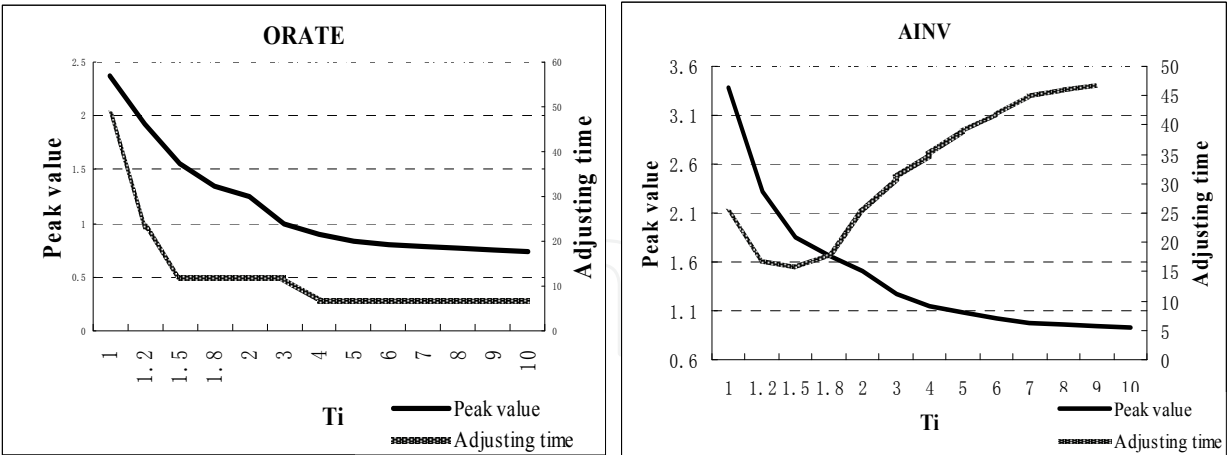


(c) *WIP*

Fig. 10. The impact of T_w on DIS-APIOBPCS impulse response

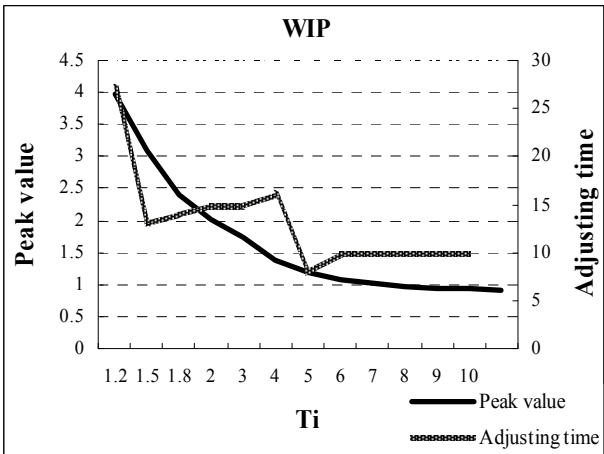
5.2.3 The impact of T_i on DIS-APIOBPCS impulse response

Impulse responses of DIS-APIOBPCS under different T_i are shown in Fig.11. With other parameters given, it can be found that the peak value of *ORATE*, *AINV* and *WIP* response will decline when T_i increases. The adjusted time of *AINV* response follows a process that first decline and then rise; the adjusted time of *ORATE* and *WIP* response will decline. The steady-state error keeps zero. This phenomenon indicates that when the market demand bursts, supply chain members must strike a balance between production, inventory capacity and recovery capabilities, and make a reasonable decision on inventory adjustment parameter so as to maximize supply chain performance and maintain long-term and stable operation.



(a) ORATE

(b) AINV



(c) WIP

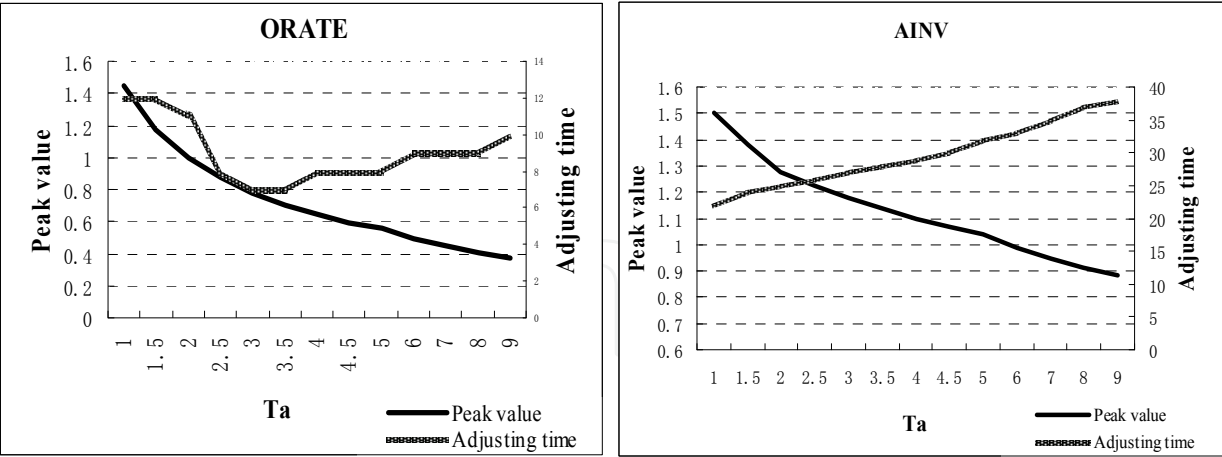
Fig. 11. The impact of T_i on DIS-APIOBPCS impulse response

5.2.4 The impact of T_a on DIS-APIOBPCS impulse response

As shown in Fig.12, increasing T_a is followed by declining peak value of ORATE, AINV and WIP response and rising adjusted time. From the analysis above, it is clear that T_a should be reduced for the purpose of enhancing the rapidness of supply chain. But if the manager aims at production and inventory smoothness, T_a settings should be higher.

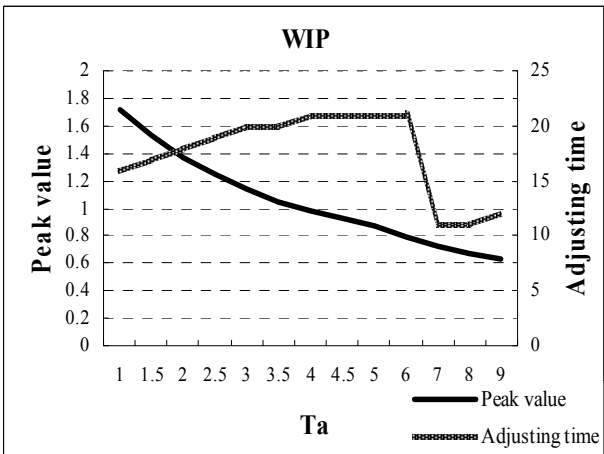
5.3 Dynamic response of the DIS-APIOBPCS under stochastic demand input

Noise bandwidth (W_n) is commonly used in communication engineering system to measure the inherent attributes of the system. It is defined as the area under the squared frequency response of the system, expressed as Eq.(8).



(a) ORATE

(b) AINV



(c)WIP

Fig. 12. The impact of T_a on DIS-APIOBPCS impulse response

$$W_n = \int_0^\pi \left| ORATE_f \right|^2 dw \tag{8}$$

Noise bandwidth is a performance measure that is proportional to the variance of the ORATE response when the demand information consists of pure white noise (constant power density at all frequencies), (Garnell and East, 1977 and Towill, 1999). Pure white noise maybe interpreted as an independently and identically distributed (i.i.d.) normal distribution. Thus, the noise bandwidth may be reasonably considered a surrogate metric for production adaptation costs. These costs may include such factors as hiring/firing, production on-costs, over-time, increased raw material stock holdings, obsolescence, lost capacity etc. So when demand is i.i.d. form, the noise bandwidth can directly measure fluctuations in production.

The relationship between W_n and system parameters T_a , T_i and T_w are shown in Fig.13.

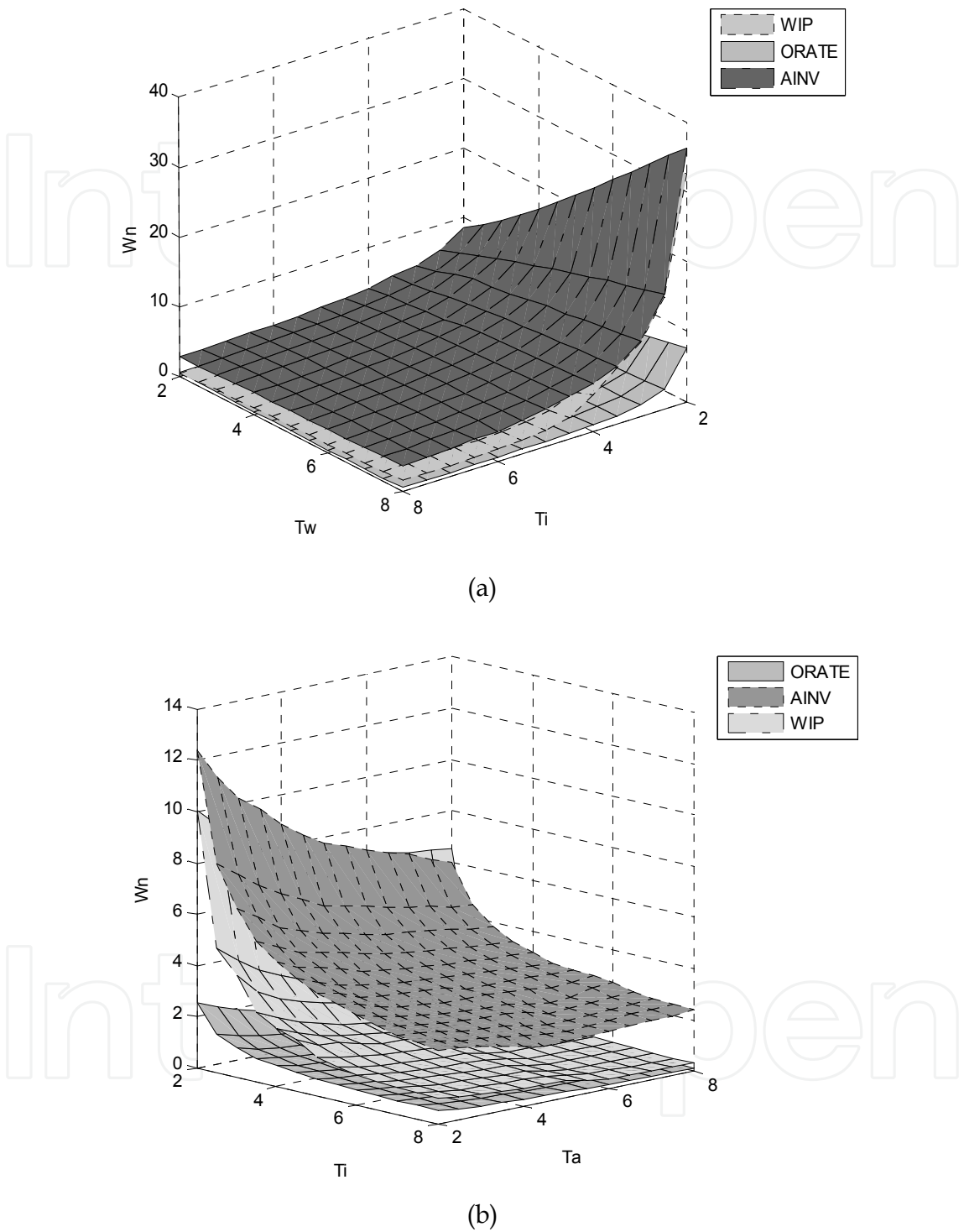


Fig. 13. The impact of system parameters on dynamic response under stochastic input

The fluctuations of *ORATE*, *AINV*, and *WIP* response caused by demand fluctuations could be reduced by tuning system parameters. From Fig.13, it can be concluded that the *ORATE* and *WIP* fluctuation can be weakened by increasing T_a and decreasing T_w . The inventory fluctuation can be weakened by increasing T_i and reducing T_w . Moreover, T_a should be

increased when T_i is small, otherwise T_a should be reduced. This shows that for members of the supply chains, system fluctuation can be reduced by adjusting the system parameters in feed-forward and feedback loops. However, when the inventory adjustment parameter T_i is a larger value, reducing inventory fluctuations has the opposite requirements on T_a .

5.4 Dynamic response of the DIS-APIOBPCS under different order intervals

In Sections 5.1-5.3, this paper analyzes how the system parameters impact the system dynamic responses to customer demand in forms of step, impulse, Gaussian Process in DIS-APIOBPCS system. In this part, dynamic response to variant order intervals is studied. In order to filter out the disturbance of random factors in simulation, demand information in form of impulse will be appropriate. According to the step response of peak value and adjusted time in DIS-APIOBPCS system, if T_w takes 2, 3 or 4, the unit impulse response will be more desirable, given $T_a=2$, $T_p=2$, $T_i=3$ as shown in Fig.14. When $T_w=2$, the unit impulse response has a peak value of 1, but in other situations, the response will either has a higher or lower peak value.

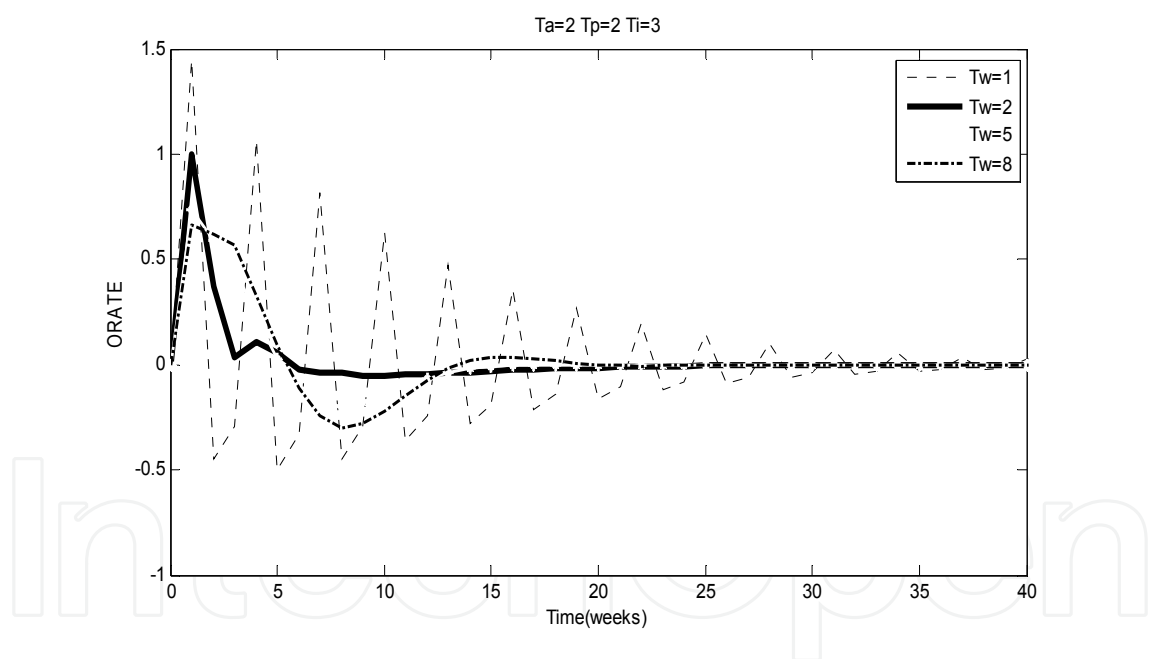


Fig. 14. The impact of T_w on DIS-APIOBPCS impulse response

From the simulation experiments under different order intervals from 1 to 10 week, the maximum and minimum value of the response can be seen in Fig.15. When the order interval is 1 week, the *ORATE* response has a minimum oscillation amplitude and the one of *WIP* response is 0. The oscillation amplitude of *AINV* response will be minimal when the order interval is 2 week as shown in Fig.16.

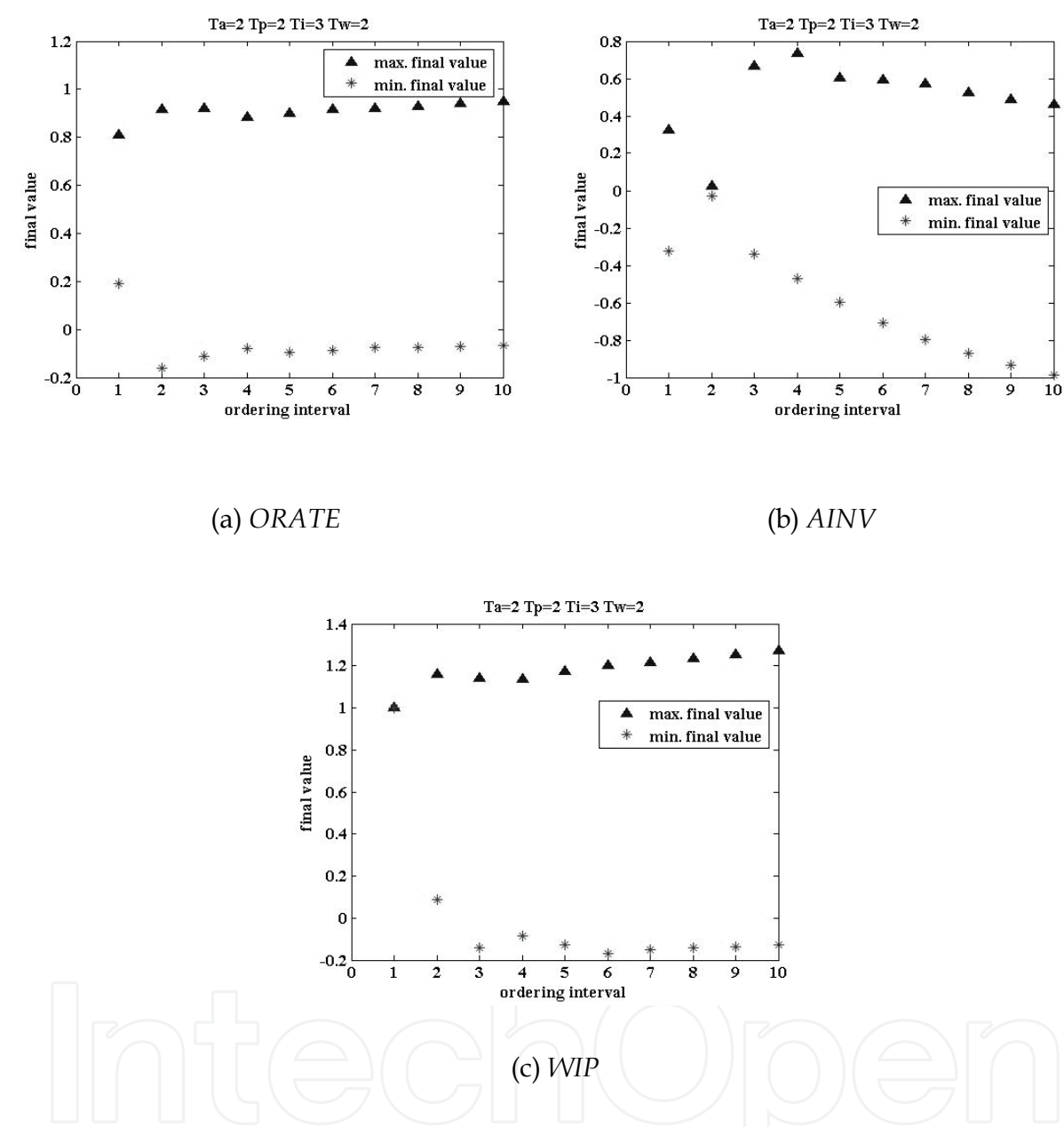
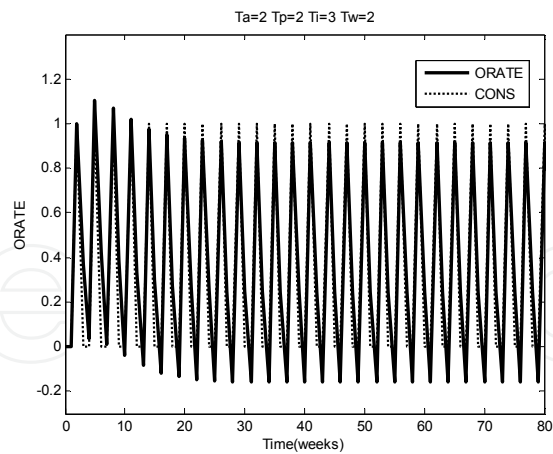
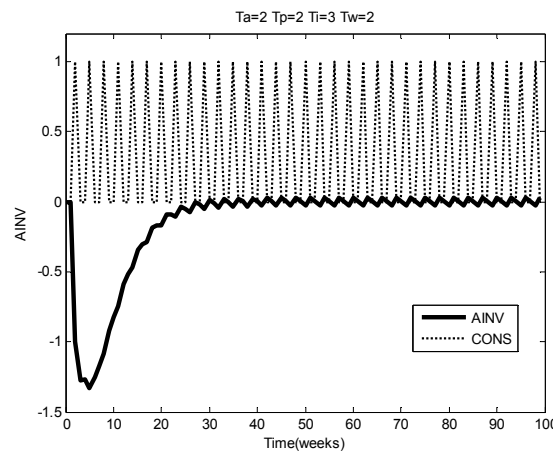


Fig. 15. The maximum and minimum value of response under different order intervals

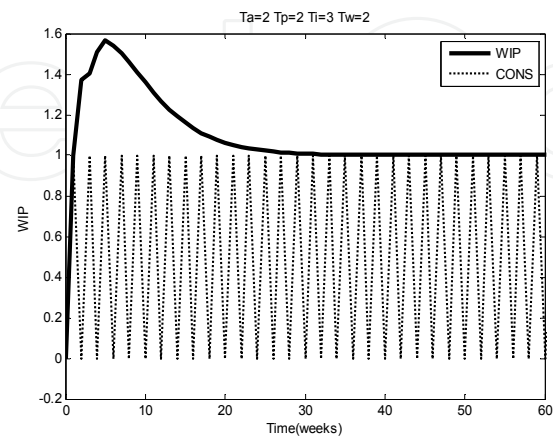
When the order interval of the supply chain is fixed, the system parameter setting will also influence the dynamic response. With other parameters given, the optimal order interval of *ORATE* response is still 1 week whether T_p is increasing. However, the optimal order interval of *AINV* and *WIP* response will increase with T_p , and the increase of T_i , T_w and T_a have no influence on the optimal order intervals. So it can be concluded that the optimal order intervals will only be decided by the production lead-time no matter how much other parameters are set. Because the page limits, this paper only gives the situation when $T_p=2$ and $T_p=4$, as shown in Figs.17 and 18.



(a) *ORATE*



(b) *AINV*



(c) *WIP*

Fig. 16. The dynamic response under optimal order interval

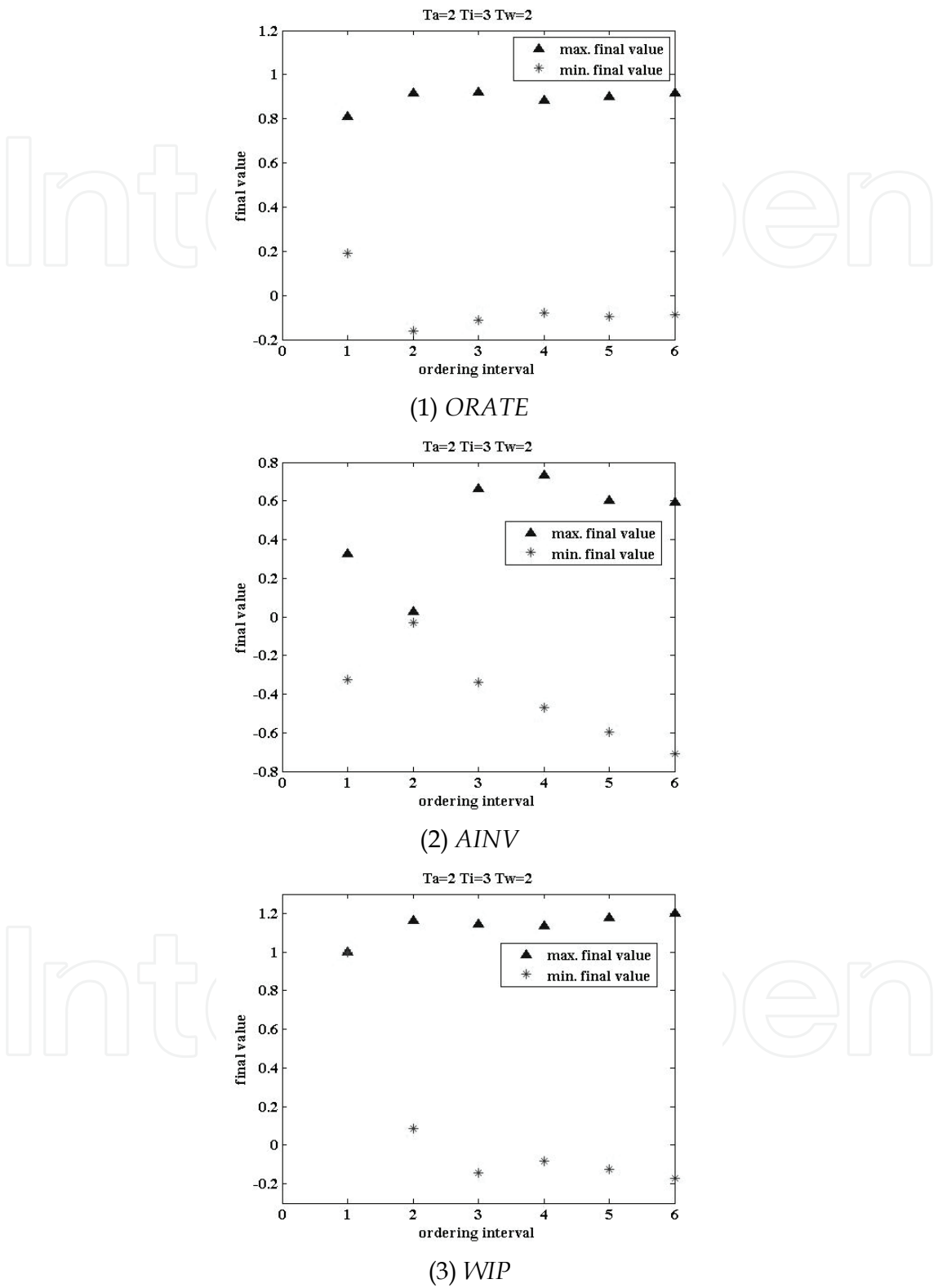


Fig. 17. The impact of order intervals on dynamic response when $T_p=2$

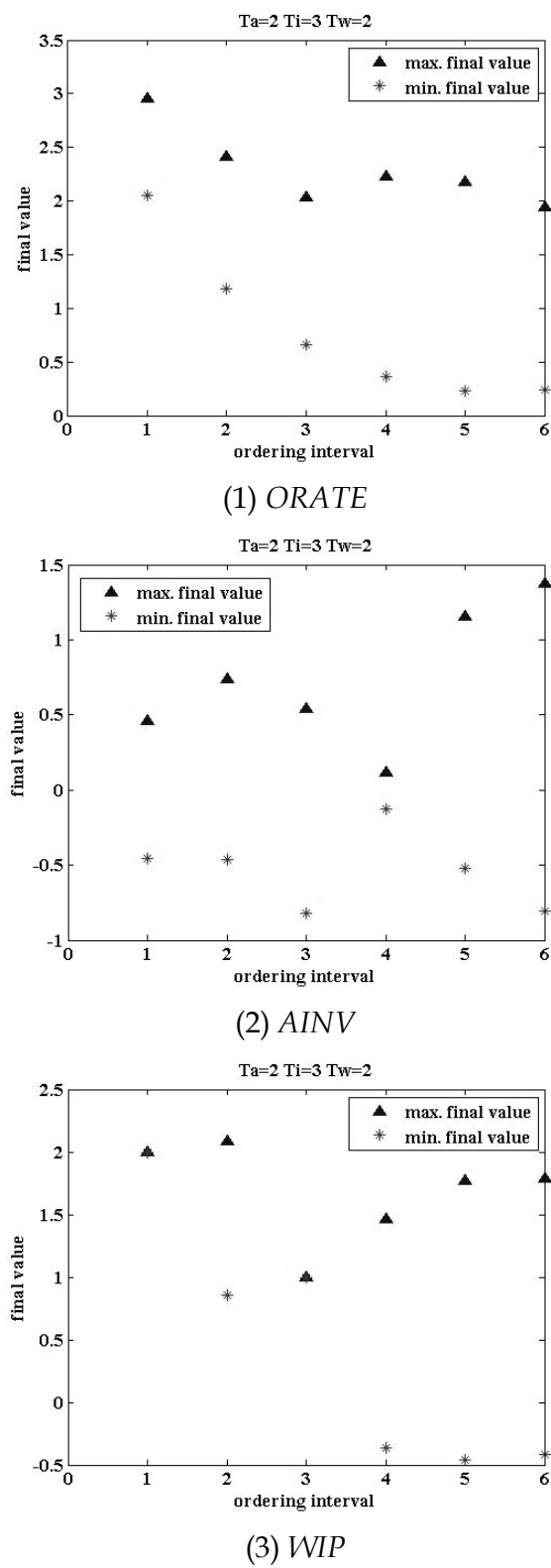


Fig. 18. The impact of order intervals on dynamic response when $T_p=4$

6. Conclusions

Based on APIOBPCS model, this paper analyzes a demand information-sharing two-echelon supply chain system model (DIS-APIOBPCS). The management significance of four key parameters is analyzed and the stability condition under different lead-times is figured out. The stability boundary is verified by simulation. Any parameters' value beyond the stability region will lead to instability of supply chain, thus it could be avoided via tuning parameters of the feedback loops within the supply chain for a specific production lead-time.

Then the system dynamic responses to customer demand in forms of stepwise, impulsive, stochastic distribution and variant order intervals are analyzed. Regarding the step and impulsive demand information input, the smaller the production lead-time, the lower the peak value and the shorter the adjusted time. This means companies can reduce capacity requirements when the market demand expands (and *vice versa*) by decreasing production lead-times. T_i and T_w not only provide a means of ensuring stability, but also drive capacity requirements to satisfy a step increase in demand. Supply chain members must strike a balance between production, inventory capacity and recovery capabilities, and make a reasonable decision on inventory adjustment parameters so as to maximize supply chain performance and maintain long-term and stable operation. Under normally distributed input, the noise bandwidth can directly measure fluctuations in production. The fluctuations of *ORATE*, *AINV*, and *WIP* response caused by demand fluctuations could be reduced by tuning system parameters. The optimal order intervals will only be affected by the production lead-time.

The DIS-APIOBPCS system model could be expanded to any two enterprises in multi-echelon supply chain systems and those using other information sharing strategies. Furthermore, research on stability condition and dynamic response under other demand information forms is an important problem in supply chain management.

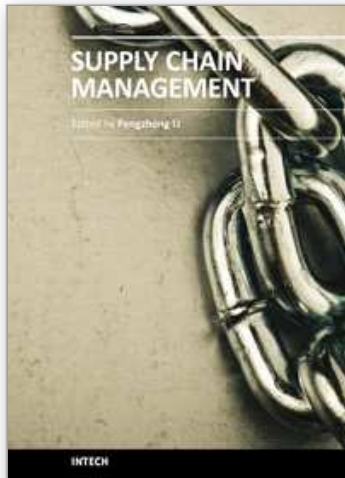
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8. References

- Dejonckheere J., Disney S.M., Lambrecht M.R., Towill D.R. Measuring and avoiding the Bullwhip Effect: a control theoretic approach. *European Journal of Operations Research*, 2003, 147 (3), 567–590.
- Dejonckheere J., et al. The impact of information enrichment on the bullwhip effect in supply chains: a control engineering perspective, *Euro. J. Operational Res.* 2004, 153(3): 727–750.
- Disney S.M., Naim M.M., Towill D.R. Genetic algorithm optimization of a class of inventory control systems. *International Journal of Production Economics* 2000, 68:259–78.
- Disney S.M., Towill D.R. A discrete transfer function model to determine the dynamic stability of a vendor managed inventory supply chain. *International Journal of Production Research*, 2002, 40 (1), 179–204.

- Disney S.M., Towill D.R. On the Bullwhip and inventory variance produced by an ordering policy. *The International Journal of Management Science*, 2003, 31(3): 157–167.
- Disney S.M., Towill D.R., Van de Velde, W. Variance amplification and the golden ratio in production inventory control systems. *International Journal of Production Research*, 2004, 90 (3), 295–309.
- Disney S.M., Towill D.R. Eliminating drift in inventory and order based production control systems. *International Journal of Production Economics*, 2005, 93–94: 331–344.
- Disney S.M., Towill D.R., Warburton, R.D.H. On the equivalence of control theoretic, differential, and difference equation approaches to modeling supply chains. *International Journal of Production Economics*, 2006, 101 (1), 194–208.
- Warburton R.D.H., Disney S.M. Order and inventory variance amplification: The equivalence of discrete and continuous time analyses. *International Journal of Production Economics*, 2007, 110(1-2): 128–137.
- Fernanda Strozzi, Carlo Noè, José-Manuel Zaldívar. The Control of Local Stability and the Bullwhip Effect in a Supply Chain. *International Journal of Production Economics*, 2007, 12:1–11.
- Forrester J.W. *Industrial Dynamics*. MIT Press, Cambridge, MA. 1961
- Sarimveis H., et al. Dynamic modeling and control of supply chain systems: A review. *Computers and operations research*, 2008, 35(11): 3530–3561.
- Khalid Saeed. Trend forecasting for stability in supply chains. *Journal of Business Research*, Available online 16 January 2008.
- Lalwani C.S., Disney S.M., Towill D.R. Controllable, observable and stable state space representations of Order-up-to policy. *International Journal of Production Economics*, 2006, 101:172–184
- Nordin Saad, Visakan Kadirkamanathan. A DES Approach for the Contextual load modeling of Supply Chain System for Instability Analysis. *Simulation Modeling Practice and Theory*, 2006, 14:541–563
- Riddalls C.E., Bennett S. The stability of supply chains. *International Journal of Production Research*, 2002, 40 (2), 459–475.
- Takashi Nagatani, Dirk Helbing. Stability Analysis and Stabilization Strategies for Linear Supply Chains. *Physica A*, 2004:633–660.
- Towill D.R. Dynamic analysis of an inventory and order based production control system. *International Journal of Production Research* .1982;20:671–87.
- Towill D.R. Industrial dynamics modeling of supply chains. *International Journal of Physical Distribution & Logistics Management*, 1996, 26(2):23–42.
- Vassian H.J. Application of discrete variable servo theory to inventory control. *Operations Research*, 1954. 3, 272–282.
- Warburton R.D.H. An analytical investigation of the Bullwhip Effect. *Production and Operations Management* , 2004a, 13 (1), 150–160.
- Warburton R.D.H. An exact solution to the production inventory control system. *International Journal of Production Economics*, 2004b, 92 (1), 81–96.
- Warburton R.D.H., Disney S.M., Towill D.R., Hodgson J.P.E. Further insights into the stability of supply chains. *International Journal of Production Research*, 2004, 42 (3), 639–648.
- Yanfeng Ouyang. The effect of information sharing on supply chain stability and the bullwhip effect. *European Journal of Operational Research*. 2007, 182(3), 1107–1121.



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The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.

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