Reducing the Bullwhip Effect in Supply Chain Management by Applying a Model Predictive Control Ordering Policy

Dongfei Fu, Clara Mihaela Ionescu, Robin De Keyser
EeSA - Department of Electrical energy, Systems & Automation, Ghent University,
Technologiepark 913, 9052 Gent, Belgium
E-mail: Dongfei.Fu@UGent.be

1 Introduction

The tendency of demand variability to increase as one moves upward a supply chain, is commonly known as bullwhip effect [1]. In this research we model and control a four nodes supply chain network consisting of a factory F_a, a distributor D_i, a wholesaler W_h and a retailer R_e as shown in Figure 1. Our own model based predictive control, namely the Extended Prediction Self-Adaptive Control strategy (EPSAC) is applied to generate optimal ordering decision that can reduce the bullwhip effect. In order to evaluate the efficiency of the control performance, we use quantifying measures of the bullwhip effect to compare various strategies.

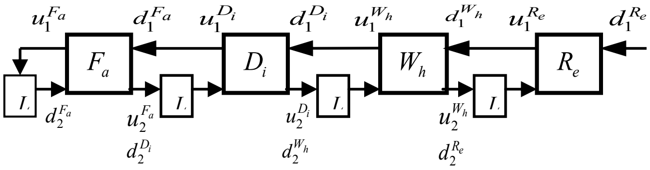

Figure 1. Block diagram of a four nodes supply chain

2 Process model

Consider a node $i \in \{F_a, D_i, W_h, R_e\}$ and the information and material exchange with its supplier and customer. A material balance around any network node involves the inventory level as well as the total incoming products from upstream node and total outgoing products to downstream node. The inventory position balance can be derived as:

$$y_1^i(t) = \frac{1}{1-z^{-1}}(d_2^i(t) - u_2^i(t)) \qquad (1)$$

where z^{-1} is the discrete time shift operator and corresponds to unit sample period delay. If we make a linearization assumption that there is always enough stock at node i to meet customer demand, then (1) can be simplified to

$$y_1^i(t) = \frac{z^{-1}}{1-z^{-1}}(u_1^i(t) - d_1^i(t)) \qquad (2)$$

which will be used as the prediction model in MPC control.

3 Control strategy

In order to calculate bullwhip, we need the ordering policy transfer function. Therefore, it's in principle necessary to formulate a closed loop expression for the MPC. We apply distributed EPSAC controllers to the system and each of them makes control decision for each node respectively. There is no information sharing in this control strategy and it is based on the SISO model (2) of supply chain. The closed loop transfer function of ordering policy can then be derived from the block diagram in Figure 2.

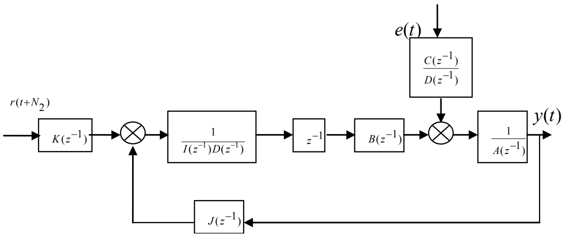

Figure 2. MPC closed form structure

4 Results

A measure of the bullwhip is defined as the ratio of the variance of the orders and the variance of the demand. The analytical expression for bullwhip metric can be in the following form. We assume an ARMA demand pattern (4), which is a weakly stationary stochastic process.

$$\text{Bullwhip} = \sum_{m=0}^{M} Z^{-1}\{T_{u/n}(z)\}^2 = \sum_{m=0}^{M} T_{u/n}[m]^2 \qquad (3)$$

We then calculate the bullwhip for classical *order-up-to* and fractional ordering policy, using (3).

$$n(t) = \frac{\Theta(z^{-1})}{\Phi(z^{-1})}e(t) = \frac{1-0.6z^{-1}}{1-0.8z^{-1}}e(t) \qquad (4)$$

The result given in Table 1 shows that MPC-EPSAC can produce a significantly lower demand variability compared to conventional *order-up-to* ordering policies.

Table 1. Bullwhip results

Ordering Policy	*Order-up-to*	Fractional	MPC
Bullwhip	10.7396	2.4429	1.3578

References

[1] Disney, S.M., Towill, D.R., "On the bullwhip and inventory variance produced by an ordering policy." *The International Journal of Management Science*, volume (31),157-167, 2003.

[2] De Keyser, R., "A Gent'le approach to predictive control." *UNESCO Encyclopedia of Life Support Systems*.Eolss Publishers Co.Ltd, Oxford, 2003.