Ain Shams University
Faculty of Engineering
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Modelling and Simulation of Compound Bullwhip Effect

A thesis submitted in partial fulfillment for the requirements of the degree of Master of Science in Mechanical Engineering

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Statement

This thesis is submitted in the partial fulfillment of a Master of Science degree in Mechanical Engineering, to Ain Shams University. The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university.

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List of publications

[1] Mikhail, M. H., Abdin, M. F., Awad, M. A., 2012. Introducing order batching to compound bullwhip effect. Engineering Research Journal 135, M104-M116.

[2] Mikhail, M. H., Abdin, M. F., Awad, M. A., 2013. Impact of order batching on compound bullwhip effect. The Journal of American Science 9 (6), 509-514.

[3] Mikhail, M. H., Abdin, M. F., Awad, M. A., 2013. Modeling and simulation of compound bullwhip effect. LAP Lambert Academic Publishing, Germany.

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Abstract

Order batching in supply chains provides economic benefit, where it is beneficial economically for a company to produce large batches, since it can reduce the number of facility set-ups and improve manufacturing efficiency. However, rounding of orders to achieve a batch size is recognized as a source of the bullwhip effect problem within supply chains. Previous researches revealed that by choosing a batch size that is multiple of the average demand, order rates could be close to the actual demand, producing little demand amplification, thus bullwhip effect is reduced.

This thesis considers a supply chain consisting of a supplier feeding more than one retailer in batches to cover demand for a number of future time units. Stochastic demand and price are described by a first order autoregressive AR(1) time series process. Aggregate bullwhip effect resulting from the synergistic effect between retailers demand is considered depending on demand and price parameters of the retailers along with the number of forecasting time units. Optimum batch size is selected based on the minimum mean square error (MMSE) demand forecasting method, such that aggregate bullwhip effect is less than the sum of separate bullwhip effect for each retailer.

Keywords: Bullwhip effect BWE, order batching, demand forecasting, separate bullwhip effect, aggregate bullwhip effect.

Summary

Bullwhip effect is defined as the increase of order variability as one move up the supply chain from customers to retailers, wholesalers, distributors, and suppliers. It is considered one of the main problems in supply chains, resulting in huge and costly disturbances at the supplier end of the chain.

This thesis considers a two-stage serial supply chain consisting of a supplier feeding more than one retailer simultaneously with stochastic demand and price described by a first-order autoregressive AR(1) time series process. Compound or aggregate BWE is introduced resulting from the interaction between the demand streams (retailers); this should be less than the sum of separate BWE of each retailer for higher system performance.

Supplier delivers orders to retailers in batches to gain economic benefit by aggregating demand to save in production and transmission costs. However, order batching amplifies bullwhip effect depending on the batch size. Orders placed to supplier depend on past demand and demand change due to demand forecasting update. Batching is done by aggregating demand for (n) future time units to determine the batch size to be delivered based on the minimum mean square error (MMSE) forecasting method.

Formulas are reached that relates both, separate and aggregate bullwhip effect to demand and price parameters of each retailer, in addition to, the number of forecasting time units' (n). Demand parameters are defined including: demand autocorrelation, cross-correlation, and demand interaction; price parameters including: price autocorrelation, price cross-correlation with demand, and market responsiveness to price changes.

Before issuing an order, supplier should make sure that aggregate BWE is dampened over the sum of separate BWE for higher system performance and lower costs. This is done by substituting in separate and aggregate BWE formulas, knowing demand and price parameters of the retailers and the number of forecasting time units' (n) to determine the optimum batch size to be delivered.

Simulation is run for various demand and price variables. It is shown that for high demand interaction between retailers, aggregate BWE is amplified. The retailers follow each other in demand increasing or decreasing, resulting in the magnification of demand forecasting error. So, it is preferred that demand interaction between retailers is as low as possible.

For the supplier to gain economic benefit of batching, it is possible that orders are delivered to retailers in batches with large batch size depending on the number of forecasting time units' (n). It is shown that by increasing demand forecasting, aggregate BWE is increased due to the aggregation of demand forecasting error, resulting in higher costs.

Output plots show the effect of demand and price parameters of each retailer along with demand interaction between retailers on separate and aggregate BWE at different forecasting times. For each case, optimum batch size is selected, such that aggregate BWE is less than the sum of separate BWE of each retailer.

Notations

a_i	Average (mean) demand for retailer *i*
β_{ip}	Market responsiveness to price changes
$d_{i,t}$	Demand during time *t* for a single retailer
D_i	Aggregated demand forecast for retailer *i*
$\varepsilon_{i,t}$	Random error due to demand forecasting
λ	Price autocorrelation
M_i	Bullwhip effect of a single demand stream
$\overline{M}$	Aggregate (compound) BWE of the two streams
μ	Stationary demand over time
n	Number of future time units (days, weeks, months)
p_t	Product's dynamic price during time *t*
$q_{i,t}$	Order made during time *t* from a single retailer
ρ_{ii}	Autocorrelation due to demand inertia for retailer *i*
ρ_{ij}	Demand interaction between the two streams
σ_{ij}	Demand cross-correlation between the two streams
σ_{ip}	Cross-correlation between demand and price
$y_{i,t}$	Order up-to-level for time *t*
z_t	Variable demand during time *t*

List of figures

Fig.	**Title**	**Page**

Table of contents