Models for Controlling and Replenishing of Inventories in a Supply Chain (With Particular Reference to Robustness versus Forecasting Errors of Demand)

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Abstract: This article investigates robustness for supply chain. After reviewing the supply chain, and the basic concepts of supply chain robustness, we survey the uncertainty descriptions considered in the Model Predictive Control (MPC) literature, and the methods proposed for robust constraint handling, stability, and performance. The article concludes with some comments on future research directions as input to robustness and Model Predictive Control module.

[Mohammed Ali Yari, Sara Heidari, Hadi Ahmadi. Models for Controlling and Replenishing of Inventories in a Supply Chain (With Particular Reference to Robustness versus Forecasting Errors of Demand). Journal of American Science 2011;7(5):871-877]. (ISSN: 1545-1003). http://www.americanscience.org.

Keywords: supply chain, Controlling, Inventories, Robustness and Forecasting.

1. Introduction

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes the manufacturer, suppliers, transporters, warehouses, retailers and customers. And supply chain includes each function involved in receiving and filling a customer request. A supply chain is dynamic and involves the constant flow of information, product, and funds between different stages.

In our example, Wal-Mart provides the product, as well as pricing and availability information, to the customer.

The customer transfers funds to Wal-Mart. Wal-Mart conveys point-of-sales data as well as replenishment order via trucks back to the store. Wal-Mart transfers funds to the distributor after the replenishment.

The distributor also provides pricing information and sends delivery schedules to Wal-Mart. Similar information, material, and fund flows take place across the entire supply chain.

In another example, when a customer purchases online from Dell Computer, the supply chain includes, among others, the customer, Dell's Web site that takes the customer's order, the Dell assembly plant, and all of Dell's suppliers and their suppliers.

The Web site provides the customer with information regarding pricing, product variety, and product availability.

Having made a product choice, the customer enters the site to check the status of the order. Stages further up the supply chain use customer order information to fill the order. That process involves an additional flow of information, product, and funds between various stages of the supply chain. (Chopra S, and Meindl, 2007) There are two interconnections between supply chain stages: information flows and material flows. Information flows include replenishing and order requesting. And material flows including physical interconnections of goods between supply chain stages.

Material flows are forward movement among supply chain whereas information flow is backward flow of information.

Information sharing like inventory levels, orders, production, and delivery status has important role in supply chain. Supply chain stages must participate to competing with another supply chains and attain maximum of value generated that is the main objective of supply chain. The purpose of this paper is to survey the uncertainty and the techniques proposed for robust constraint handling, stability, and performance.

2. Supply chain

The Council of Supply Chain Management Professionals (CSCMP) defines Supply Chain Management as follows: "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers.

External and internal changes lead to uncertainties in supply chain stages. Hence the design needs to consider the dynamics of the enterprise and the related market.

There are various external changes such as demand changes, environmental factor changes, bank rates fluctuation, changes in political situation changes and others.

Internal changes such as material do not arrive on time, production facilities failure, supply routes failure, workers absence and falling sick, changes in customer orders o cancels order, and others. Such problems will increase the uncertainty and instability of each stage of the supply chain, and these problems spread and pass from one stage to another; both upstream and downstream.

The impact will spread like a domino and entire chain will cease to perform. Supply Chain designer have to consider and prepare for these uncertainties within the organization and across the organization, which cause the design task extremely difficult and challenging.

In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology.

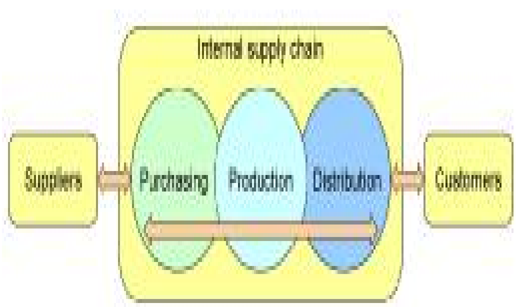

Fig1: An illustration of a company's supply chain; the arrows stand for supplier-relationship management, internal SCM and customer-relationship management (cf. Chen/ Paulraj, 2004)

3. Bullwhip effect

One of the most significant current discussions in supply chain is Bullwhip effect. Researchers try to identify and analyze main causes of this phenomenon and reduce it.

"The bullwhip effect occurs when the demand order variabilities in the supply chain are amplified as they moved up the supply chain.

Distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies. Companies can effectively counteract the bullwhip effect by thoroughly understanding its underlying causes. Industry leaders are implementing innovative strategies that pose new challenges:

1. Integrating new information systems,

2. Defining new organizational relationships, and

3. Implementing new incentive and measurement systems.

Not long ago, logistics executives at Procter & Gamble (P&G) examined the order patterns for one of their best-selling products, Pampers. Its sales at retail stores were fluctuating, but the variabilities were certainly not excessive.

However, as they examined the distributors' orders, the executives were surprised by the degree of variability.

When they looked at P&G's orders of materials to their suppliers, such as 3M, they discovered that the swings were even greater. At first glance, the variabilities did not make sense.

While the consumers, in this case, the babies, consumed diapers at a steady rate, the demand order variabilities in the supply chain were amplified as they moved up the supply chain. P&G called this phenomenon the "bullwhip" effect. (In some industries, it is known as the "whiplash" or the "whipsaw" effect.)

When Hewlett-Packard (HP) executives examined the sales of one of its printers at a major reseller, they found that there were, as expected, some fluctuations over time.

However, when they examined the orders from the reseller, they observed much bigger swings. Also, to their surprise, they discovered that the orders from the printer division to the company's integrated circuit division had even greater fluctuations.

What happens when a supply chain is plagued with a bullwhip effect that distorts its demand information as it is transmitted up the chain?

In the past, without being able to see the sales of its products at the distribution channel stage, HP had to rely on the sales orders from the resellers to make product forecasts, plan capacity, control inventory, and schedule production.

Big variations in demand were a major problem for HP's management. The common symptoms of such variations could be excessive inventory, poor product forecasts, insufficient or excessive capacities, poor customer service due to unavailable products or long backlogs, uncertain production planning (i.e., excessive revisions), and high costs for corrections, such as for expedited shipments and overtime. HP's product division was a victim of order swings that were exaggerated by the resellers relative to their sales; it, in turn, created additional exaggerations of order swings to suppliers.

In the past few years, the Efficient Consumer Response (ECR) initiative has tried to redefine how the grocery supply chain should work.

One motivation for the initiative was the excessive amount of inventory in the supply chain. Various industry studies found that the total supply chain, from when products leave the manufacturers' production lines to when they arrive on the retailers' shelves, has more than 100 days of inventory supply.

Distorted information has led every entity in the supply chain – the plant warehouse, a manufacturer's shuttle warehouse, a manufacturer's market warehouse, a distributor's central warehouse, the distributor's regional warehouses, and the retail store's storage space – to stockpile because of the high degree of demand uncertainties and variabilities.

Causes of the Bullwhip Effect

Perhaps the best illustration of the bullwhip effect is the well-known "beer game." In the game, participants (students, managers, analysts, and so on) play the roles of customers, retailers, wholesalers, and suppliers of a popular brand of beer.

The participants cannot communicate with each other and must make order decisions based only on orders from the next downstream player. The ordering patterns share a common, recurring theme: the variabilities of an upstream site are always greater than those of the downstream site, a simple, yet powerful illustration of the bullwhip effect.

This amplified order variability may be attributed to the players' irrational decision making.

Indeed, Sterman's experiments showed that human behavior, such as misconceptions about inventory and demand information, may cause the bullwhip effect.

In contrast, we show that the bullwhip effect is a consequence of the players' rational behavior within the supply chain's infrastructure.

This important distinction implies that companies wanting to control the bullwhip effect have to focus on modifying the chain's infrastructure and related processes rather than the decision makers' behavior.

We have identified four major causes of the bullwhip effect:

1. Demand forecast updating
2. Order batching
3. Price fluctuation
4. Rationing and shortage gaming

Each of the four forces in concert with the chain's infrastructure and the order managers' rational decision making create the bullwhip effect. Understanding the causes helps managers design and develop strategies to counter it.

Demand Forecast Updating

Every company in a supply chain usually does product forecasting for its production scheduling, capacity planning, inventory control, and material requirements planning. Forecasting is often based on the order history from the company's immediate customers.

The outcomes of the beer game are the consequence of many behavioral factors, such as the players' perceptions and mistrust. An important factor is each player's thought process in projecting the demand pattern based on what he or she observes. When a downstream operation places an order, the upstream manager processes that piece of information as a signal about future product demand. Based on this signal, the upstream manager readjusts his or her demand forecasts and, in turn, the orders placed with the suppliers of the upstream operation. We contend that demand signal processing is a major contributor to the bullwhip effect.

For example, if you are a manager who has to determine how much to order from a supplier, you use a simple method to do demand forecasting, such as exponential smoothing.

With exponential smoothing, future demands are continuously updated as the new daily demand data become available.

The order you send to the supplier reflects the amount you need to replenish the stocks to meet the requirements of future demands, as well as the necessary safety stocks.

The future demands and the associated safety stocks are updated using the smoothing technique. With long lead times, it is not uncommon to have weeks of safety stocks. The result is that the fluctuations in the order quantities over time can be much greater than those in the demand data." (Lee, H., Padmanabhan, P., & S., W., 1997b)

The first recognition of bullwhip effect in supply chain management has been done by Forrester (1958,1961). He presented some evidences of bullwhip effect phenomenon and discusses the causes of this phenomenon.

Lee et al.(1997 a,b) identified five main causes of bullwhip effect, including demand forecasting, lead time, batch ordering, shortages and price fluctuations. They considered AR(1) demand process in a simple two stage supply chain.

Chen et al.(2000a) quantified the bullwhip effect in a simple two stage supply chain with AR(1) demand process observed by the retailer. The retailer uses moving-average forecasting technique to predict future customer demands. They have derived a lower bound for the bullwhip effect.

Chen et al.(2000b) extend their results to a case where the downstream retailer use exponential smoothing method. They measured the bullwhip effect and found that it depends on both the nature of customer demand process and the forecasting technique used by retailer.

They concluded that if mean and variance of demand is known exactly, i.e. no forecasting method need to be used, there would no bullwhip effect. Furthermore bullwhip effect increases by increasing the lead time.

There are methods to reduce bullwhip effect. The main methods to desire this target are centralizing information to reducing uncertainty, reducing demand fluctuations, and lead time reduction.

4. Models for controlling and replenishing of inventories in a Supply Chain

Because of demand fluctuations over time, holding inventory during low demand is necessary in anticipation of future periods peak demand. This buildup inventory avoids or reduces overtime, lost sales and backorders during peak demand periods. Inventories carried because of anticipated changes of prices and uncertainties. Uncertainties occur because of demand request time, number of commodity requested, lead time length, revenue and cost factors.

To avoid uncertainty, an extra inventory named "safety stock" is hold to protect against actual demand exceeds the forecast. Inventories types exist at every stage of the supply chain are raw materials, semi-finished or finished goods.

Models for controlling and replenishing of inventories determine order quantities and replenishing times to minimize total inventory costs that are excess inventories and shortage costs.

Today use of IT systems improved inventory management and has contributed much of cost savings. The first service of IT is changing rules of thumb to historical demand.

It also makes the ability to analyze and change inventories in response to changing in demand. IT lead to manage product varieties, decrease in product life cycles, demand fluctuations, inventory level updates, coordinate and integrate with other IT systems via supply chain.

5. Forecasting methods in Supply Chain

Forecasting has an important role in the efficient operation of a supply chain, as it presents valuable information of future time.

Forecasting methods are classified as: Qualitative, Time series, and causal. Qualitative methods are subjective and are appropriate when a little historical data or experts may affect the results.

The sequence of demand is called time series. Time series use historical data and are appropriate when significant fluctuations don't occur. Causal methods assume demand forecast is correlated with environmental factors.

There is risk of forecasting error in forecasting methods. To avoid this risk we can reduce time responsiveness, for example reducing lead time of suppliers, and pooling of demand that try to smooth out lumpy demand by bringing together sources of demand. Various forecasting methods can compare by forecast error measures. Small forecasting errors are difficult to be detected.

Large errors detection is usually easy. By plot demand against time, we can detect long-term trends, cyclic variations or other reasonably patterns. There are some rules of forecasting: the forecasting is always wrong, the longer the forecast horizon, the worse is the forecast and aggregate forecasts are more accurate.

6. Supply chain uncertainties

External and internal changes lead to uncertainties in supply chain stages. Hence the design needs to consider the dynamics of the enterprise and the related market.

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Internal changes such as material do not arrive on time, production facilities failure, supply routes

failure, workers absence and falling sick, changes in customer orders o cancels order, and others. Such problems will increase the uncertainty and instability of each stage of the supply chain, and these problems spread and pass from one stage to another; both upstream and downstream.
The impact will spread like a domino and entire chain will cease to perform. Supply Chain designer have to consider and prepare for these uncertainties within the organization and across the organization, which cause the design task extremely difficult and challenging.

Furthermore, the lack visibility and understanding of the downstream process in the supply chain has increased the uncertainties, and weaken the design of the supply chain.

Finally, the supply chain design required validation before implementation. As the implementation required the involvement many resources horizontally and vertically in the chain, an invalidated design has high risk of de-proving the productivity and injecting more uncertainty into the chain.

7. Robustness analysis

Robustness analysis is used to support decisions under uncertainty about future. Application of robustness analysis is when uncertainty avoids confident decision; decisions must be or can be staged, or the first decision assumptions do not necessarily define completely the future state of the system. The main robustness criterion is that, other things being equal, an initial commitment should be preferred if the proportion of desirable future situations that can still be reached once that decision has been implemented is high.

Sterman (2006) states that "Supply chain instability is a pervasive and enduring characteristic of market economies.

Production, inventories, employment, revenue, profit and a host of other indicators fluctuate, irregularly but persistently, throughout the economy, in industries from A to Z—Aircraft to Zinc (e.g., W. Mitchell 1971, Zarnowitz 1985, Sterman 2000). Supply chain instability harms firms, consumers, and the economy through excessive inventories, poor customer service, and unnecessary capital investment.

Instability in employment erodes skill and worsens labor management relations. Volatility in revenue and profit increases risk and raises the cost of capital.

Instability diverts leadership attention from the design of successful new products and strategies to firefighting and crisis management.

Despite the undoubted benefits of the lean manufacturing and supply chain revolutions of the past decade, supply chain instability continues. Examples include record inventory write-offs,

excess capacity, price cuts, layoffs, and bankruptcies in computers, semiconductors, telecommunications, and other high-tech industries after 2000, and waves of zero-interest financing, employee discounts for all, and cash-back incentives accompanying surplus inventory in the automobile market."

Company indicators such as demand forecast, employment rate, led time, prices, and inventory level show an irregular and constant fluctuation. Instability in supply chain is costly because it creates "excessive inventories, poor customer service, and unnecessary capital investment" (Sterman 2006).

Disney et al. (2000) optimize the performance of an industrially design inventory control system. They use GA to quantify five characteristics of a production distribution system in classical control techniques.

They show their procedure can improve the performance of a production or distribution control system by trade-off between inventory levels and factory orders. Riddalls and Bennett (2002) study the stability of a continuous time version of the Beer Distribution Game.

They demonstrate the robust stability, i.e. stability for a range a production and distribution delays, and how inventory in lower stages can create vicious circle of unstable influences in the supply chain. Nagatani and Helbing (2004) analyzed several production strategies to robust supply chains, which is expressed by different specifications of the management function controlling the production speed independence of the stock levels.

They derive linear stability conditions and use simulations for different control strategies. Ortega and Lin (2004) use control theory for the production-inventory problem to address issues such as reduction of inventory variation, demand fluctuation, and replenishment rules optimization.

8. Model Predictive control (MPC)

Model Predictive Control (MPC), also referred to as Receding Horizon Control and Moving Horizon Optimal Control, and has been widely adopted in industry as an effective means to deal with multivariable constrained control problems (Lee and Cooley 1997, Qin and Badgewell 1997).

The first idea of model predictive control is from the 1960s (Garcia et al. 1989). The name MPC come from the idea of employing an obvious model of the plant to be controlled which is used to predict the future output behavior. This forecasting capability allows solving minimizing difference between the predicted output and the desired reference. It has constrains on the manipulated inputs and outputs.

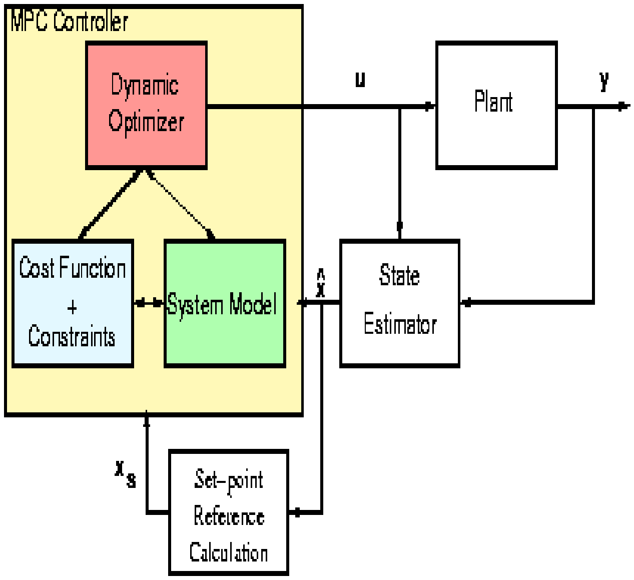

Fig: Basic MPC Loop

9. Conclusions

This review is not complete in the state of the art. There are various uncertainties in supply chain such as demand fluctuation, lead time fluctuations, price changes and other internal and external cause in supply chain.

Trying to desire stable supply chain and get robust model is difficult and also big improvement in scope of the supply chain. Every supply chain include and involve various stages, suppliers, manufacturers, etc, that cause different uncertainties.

In this paper we studied supply chain. Bullwhip effect and its causes are distinguished. Forecasting methods in supply chain, robustness and finally MPC method is considered in this paper.

The benefits of forecasting methods and robustness the supply chain can be important for future studies.

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