Supply Chain Management: Forcasting techniques and value of information

Donglei Du
(ddu@unb.edu)

Faculty of Business Administration, University of New Brunswick, NB Canada Fredericton
E3B 9Y2

Table of contents I

1 Value of Information

Information is always better than no information. Why? I

- Helps reduce variability
- Helps improve forecasts
- Enables coordination of systems and strategies
- Improves customer service
- Facilitates lead time reductions
- Enables firms to react more quickly to changing market conditions.

Forecast Techniques I

- A **forecast** is a statement about the uncertain future (such as weather forecast). In business, forecasts are mainly used to predict demands, so we focus on this aspect.
- There are two types of forecasting methods, one is qualitative forecasting, and another is quantitative forecasting.
  1. Qualitative forecasting (a.k.a. judgmental forecasts): uses subjective inputs, such as
     1. Executive opinions,
     2. Sales force composite,
     3. Consumer surveys,
     4. Outside opinion,
     5. Opinions of managers and staff
     6. Delphi method: Experts completes a series of questionnaires, each developed from the previous one, to achieve a consensus forecast. It is often used to predict when a certain event will occur.

Forecast Techniques II

2. Market research methods: Use market testing and surveys to predict particularly newly introduced products.
3. Quantitative forecasting:
    - Time series model: uses historical data assuming the future will be like the past.
    - Associative model: uses explanatory variables to predict the future.

- We will discuss the time series model which will be used in the discussion of the bullwhip effect.

Time series models I

- A **time series** is a time-ordered sequence of observations taken at regular intervals over a period of time.
- Forecasting techniques based on time-series assume the future values of the series can be estimated from the past values.
- Analysis of time series data should try to identify the behavior of the series, such as, long-term or short-term behavior, random or nonrandom behavior, which will require us to adopt different techniques correspondingly.
- Here we introduce several simple but useful ones.

Techniques for Averaging I

- Averaging techniques generate forecasts that reflect changes in average of a time series, when there is no long-term trend or seasonality. They can handle stable series as well as step changes and gradual changes in the series.

Moving Average I

- One, very simple, method for time series forecasting is to take a moving average (also known as weighted moving average).
- The moving average m_t over the last L periods ending in period t is calculated by taking the average of the values for the periods $t-L+1, t-L+2, t-L+3, ..., t-1, t$ so that

$$m_t = \frac{Y_{t-L+1} + Y_{t-L+2} + Y_{t-L+3} + ... + Y_{t-1} + Y_t}{L}$$

- To forecast using the moving average we say that the forecast for all periods beyond t is just m_t (although we usually only forecast for one period ahead, updating the moving average as the actual observation for that period becomes available).

An example I

- Consider the following example: the demand for a product for 6 months is shown below - calculate the three month moving average for each month and forecast the demand for month 7.

Month	1	2	3	4	5	6
Demand (100's)	42	41	43	38	35	37

- Now we cannot calculate a three month moving average until we have at least 3 observations - i.e. it is only possible to calculate such an average from month 3 onward.

$$
\begin{aligned}
m_3 &= (42 + 41 + 43)/3 = 42 \\
m_4 &= (41 + 43 + 38)/3 = 40.7 \\
m_5 &= (43 + 38 + 35)/3 = 38.7 \\
m_6 &= (38 + 35 + 37)/3 = 36.7
\end{aligned}
$$

An example II

- We use m_6 as the forecast for month 7. Hence the demand forecast for month 7 is 3670 units.
- One advantage with this forecast is simple, but how good is it? For example we could also produce a demand forecast for month 7 using a two month moving average. This would give the following:

$$\begin{aligned}
m_2 &= (42+41)/2 = 41.5\\
m_3 &= (41+43)/2 = 42\\
m_4 &= (43+38)/2 = 40.5\\
m_5 &= (38+35)/2 = 36.5\\
m_6 &= (35+37)/2 = 36
\end{aligned}$$

An example III

- Would this forecast ($m_6 = 3600$ units) be better than our current demand forecast of 3670 units?
- Rather than attempt to guess which forecast is better we can approach the problem logically. In fact, as will become apparent below, we already have sufficient information to make a logical choice between forecasts if we look at that information appropriately.
- In an attempt to decide how good a forecast is we have the following logic. Hence we can construct the table below:

Month	1	2	3	4	5	6	7
Demand (100's)	42	41	43	38	35	37	?
Forecast	-	-	-	m_3	m_4	m_5	m_6
	-	-	-	42	40.7	38.7	36.7
Error	-	-	-	4	5.7	1.7	?

An example IV

- Based on the above table ,we can calculate the average squared error for three month moving average:

$$\text{average squared error} = \frac{4^2 + 5.7^2 + 1.7^2}{3} = 17.13$$

- Constructing the same table for the two month moving average we have:

Month	1	2	3	4	5	6	7
Demand (100's)	42	41	43	38	35	37	?
Forecast	-	-	m_2	m_3	m_4	m_5	m_6
	-	-	41.5	42	40.5	36.5	36
Error	-	-	-1.5	4	5.5	-0.5	?

An example V

- Similarly we can calculate the average squared error for the two month moving average:

$$\text{average squared error} = \frac{(-1.5)^2 + 4^2 + 5.5^2 + (-0.5)^2}{4} = 12.19$$

- Average squared error is known technically as the mean squared deviation (MSD) or mean squared error (MSE).

Notes I

- Note here that we have actually done more than distinguish between two different forecasts (i.e. between two month and three month moving average). We now have a criteria for distinguishing between forecasts, however they are generated - namely we prefer the forecast generated by the technique with the lowest MSD (historically the most accurate forecasting technique on the data had we applied it consistently across time).

Single exponential smoothing I

- One disadvantage of using moving averages for forecasting is that in calculating the average all the observations are given equal weight (namely $1/L$), whereas we would expect the more recent observations to be a better indicator of the future (and accordingly ought to be given greater weight). Also in moving averages we only use recent observations, perhaps we should take into account all previous observations.
- One technique known as exponential smoothing (or, more accurately, single exponential smoothing) gives greater weight to more recent observations and takes into account all previous observations.

Single exponential smoothing II

- Define a constant μ where $\leq \mu \leq 1$ then the (single) exponentially smoothed moving average for period t (M_t say) is given by

$$\begin{aligned}
M_t &= \mu Y_t + \mu(1-\mu)Y_{t-1} + \mu(1-\mu)^2 Y_{t-2} + \mu(1-\mu)^3 Y_{t-3} + \cdot \\
&= \mu Y_t + (1-\mu)[\mu Y_{t-1} + \mu(1-\mu)Y_{t-2} + \mu(1-\mu)^2 Y_{t-3} + \cdot \\
&= \mu Y_t + (1-\mu)M_{t-1} \\
&= M_{t-1} - \mu(M_{t-1} - Y_t)
\end{aligned}$$

- So you can see here that the exponentially smoothed moving average takes into account all of the previous observations, compare the moving average above where only a few of the previous observations were taken into account. Moreover, the exponentially smoothed moving average for period t is a linear

Single exponential smoothing III

combination of the current value (Y_t) and the previous exponentially smoothed moving average (M_{t-1}).

- The constant μ is called the smoothing constant and the value of μ reflects the weight given to the current observation (Y_t) in calculating the exponentially smoothed moving average M_t for period t (which is the forecast for period $t+1$). For example if $\mu = 0.2$ then this indicates that 20% of the weight in generating forecasts is assigned to the most recent observation and the remaining 80% to previous observations.
- Note that the last equation implies

$$\text{current forecast} = \text{previous forecast} - \mu(\text{error in previous forecast})$$

- So exponential smoothing can also be viewed as a forecast continually updated by the forecast error just made.

An example I

- Consider the following example: for the demand data given in the previous section calculate the exponentially smoothed moving average for values of the smoothing constant $\mu = 0.2$ and 0.9. We have the following for $\mu = 0.2$.

$$\begin{aligned}
M_1 &= Y_1 = 42(\text{we always start with } M_1 = Y_1) \\
M_2 &= 0.2Y_2 + 0.8M_1 = 0.2(41) + 0.8(42) = 41.80 \\
M_3 &= 0.2Y_3 + 0.8M_2 = 0.2(43) + 0.8(41.80) = 42.04 \\
M_4 &= 0.2Y_4 + 0.8M_3 = 0.2(38) + 0.8(42.04) = 41.23 \\
M_5 &= 0.2Y_5 + 0.8M_4 = 0.2(35) + 0.8(41.23) = 39.98 \\
M_6 &= 0.2Y_6 + 0.8M_5 = 0.2(37) + 0.8(39.98) = 39.38
\end{aligned}$$

An example II

- Note here that it is usually sufficient to just work to two or three decimal places when doing exponential smoothing. We use M_6 as the forecast for month 7, i.e. the forecast for month 7 is 3938 units.
- We have the following for $\mu = 0.9$.

$$
\begin{aligned}
M_1 &= Y_1 = 42 \\
M_2 &= 0.9Y_2 + 0.1M_1 = 0.9(41) + 0.1(42) = 41.10 \\
M_3 &= 0.9Y_3 + 0.1M_2 = 0.9(43) + 0.1(41.10) = 42.81 \\
M_4 &= 0.9Y_4 + 0.1M_3 = 0.9(38) + 0.1(42.81) = 38.48 \\
M_5 &= 0.9Y_5 + 0.1M_4 = 0.9(35) + 0.1(38.48) = 35.35 \\
M_6 &= 0.9Y_6 + 0.1M_5 = 0.9(37) + 0.1(35.35) = 36.84
\end{aligned}
$$

- As before M_6 is the forecast for month 7, i.e. 3684 units.

An example III

- In order to decide the best value of μ (from the two values of 0.2 and 0.9 considered) we choose the value associated with the lowest MSD (as above for moving averages).
- For $\mu = 0.2$ we have that

$$
\begin{aligned}
MSD &= \frac{(42-41)^2 + (41.80-43)^2 + (42.04-38)^2 + (41.23 -}{5} \\
&= 13.29
\end{aligned}
$$

- For $\mu = 0.9$ we have that

$$
\begin{aligned}
MSD &= \frac{(42-41)^2 + (41.10-43)^2 + (42.81-38)^2 + (38.48 -}{5} \\
&= 8.52
\end{aligned}
$$

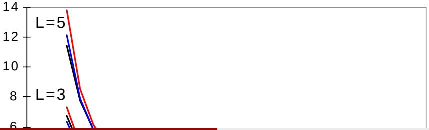
- Hence, in this case, $\mu = 0.9$ appears to give better forecasts than $\mu = 0.2$ as it has a smaller value of MSD

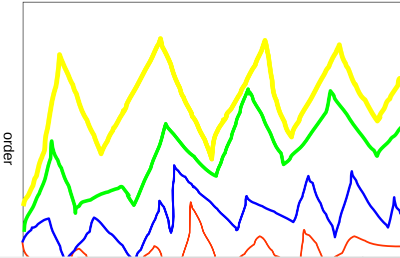
A brief summary I

- We have given just an overview of the types of forecasting methods available. The key in forecasting nowadays is to understand the different forecasting methods and their relative merits and so be able to choose which method to apply in a particular situation (for example consider how many time series forecasting methods the package has available).
- All forecasting methods involve tedious repetitive calculations and so are ideally suited to be done by a computer. Forecasting packages, many of an interactive kind (for use on pc's) are available to the forecaster.

The Bullwhip Effect and its Impact on the Supply Chain I

- The increase in variability as we travel up in the the supply chain is referred to as the *Bullwhip* effect. Said differently, order variability is amplified up the supply chain; upstream echelons face higher variability.
- Consider a simple four-stage supply chain with the orders placed by different facilities, as illustrated in the following graphs, clearly shows the increase in variability across the supply chain.:





The Bullwhip Effect and its Impact on the Supply Chain II

The Bullwhip Effect and its Impact on the Supply Chain I

- This effect leads to inefficiencies in supply chains, since it increases the cost for logistics and lowers its competitive ability. Particularly, the bullwhip effect negatively affects a supply chain in three respects:
  - Dimensioning of capacities: A variation in demand causes variation in the usage of capacities. Here companies face a dilemma: If they dimension their capacities according to the average demand, they will regularly have delivery difficulties in case of demand peaks. Adjusting their capacities to the maximum demand leads to poorly used resources.

The Bullwhip Effect and its Impact on the Supply Chain II

- Variation in inventory level: The varying demand leads to variation in inventory levels at each tier of the supply chain. If a company delivers more than the next tier passes on, the inventory level increases. Vice versa, the inventory is reduced in case a company delivers less than the next tier passes on. A high level of inventory causes costs for capital employed while a low level of inventory puts the delivery reliability at risk.
- High level of safety stock: The safety stock that is required to assure a sufficient service level increases with the variation of demand. Thus the stronger the bullwhip effect is in a supply chain, the higher is the safety stock required.

Reasons that lead to the Bullwhip Effect I

- An important issue for supply chains is to cope with the bullwhip effect. For that purpose, the reasons for the amplification of the demand variation need to be identified.
  1. Lead time of information and material as the primary reason for the bullwhip effect: The lead time of information and material is the primary reason for the bullwhip effect. A supply chain?s reaction on a change in end customer demand is delayed firstly because it takes time to pass on information about the change to suppliers and secondly because these suppliers need time to adjust their capacities and deliveries. The longer a supply chain is unable to react on a changed demand, the heavier it needs to react as soon as this is possible. Thus the bullwhip effect increases with longer lead times.
  2. Secondary reasons for the bullwhip effect—Planning and behavioural aspects:

Reasons that lead to the Bullwhip Effect II

1. Demand forecast based on orders of the succeeding tier:If the demand forecast of a company is based on orders of the succeeding tier instead of the effective demand of the end customer, the variation of demand is amplified up the supply chain. This fact is analytically proven under the assumption of constant planning lead times.
2. Historically oriented-techniques for demand forecast.
3. Batch ordering: Companies subsume demand in batches in order to reduce set-up costs and order-fixed costs. This leads to suppliers facing distorted and delayed information on end customer demand. The constant demand of the end customer is on the one hand transformed in points of time with demand at the level of the order batch size and on the other hand in periods without demand

Reasons that lead to the Bullwhip Effect III

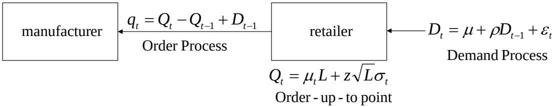
4. Price fluctuation: Companies vary the prices of their products and offer temporary price reduction to end customers or retailers for marketing reasons. As a consequence customers start speculating with the products. They buy more in times of low prices and postpone demand in times of high prices. This behavior of the customers increases the variation of end customer demand, which is then amplified up the supply chain by the bullwhip effect
5. Exaggerated order quantity in case of delivery bottlenecks: If the demand for a product exceeds the supply, suppliers often ration their products, for example by delivering only a certain percentage of the quantity ordered by customers. This can induce customers to order more than their actual demand. As soon as bottlenecks are overcome, orders exceeding actual demand are canceled. This phenomenon again results in an increased variation of end customer demand.

Quantifying The Bullwhip Effect I

- we consider first a simple two-stage model and then we extend it to multistage models in both centrailized and decentralized controls.

A simple two-stage chain I

- To understand the factors that are contributing to the bullwhip effects, we use a simple quantitative model to illustrate.
- Consider a two-stage supply chain with a single retailer and single manufacturer.



A simple two-stage chain II

- Assume the underlying demand process seen by the retailer is AR(1), that is,

$$D_t = \mu + \rho D_{t-1} + \epsilon_t, t = 1, 2, \ldots$$

  where $\mu \geq 0$ and $|\rho| < 1$, and ϵ_t are i.i.d random variables with $E[\epsilon_t] = 0$ and $V[\epsilon_t] = \sigma^2$. Obviously, when $\rho = 0$, the demands D_t are also i.i.d.
- Retailer observes customer demand at period t and orders q_t from the manufacturer using the periodic review policy to bring the inventory level to the order-up-to point $Q(t)$ and order placed at time t is received at period $t + L$.

A simple two-stage chain III

- To implement this inventory policy, the retailer must estimate the average and standard deviation of demand based on its observed customer demand. Therefore, the order-up-to point $Q(t)$ is varying with respect to time t:

$$Q_t = \mu_t L + z \times \sqrt{L}\sigma_t, \tag{1}$$

where μ_t and σ_t are the estimated average and standard deviation of daily demand at the time t by the retailer. The constant z is chosen such that the stock-out probability is equal to a specified service level.

A simple two-stage chain IV

- Suppose we use the moving average forecast technique, i.e., in each period the retailer estimates the mean demand as the average of the previous p observations of demand, and the standard deviation is estimated in a similar manner:

$$\mu_t = \frac{\sum_{i=t-p}^{t-1} D_i}{p} \tag{2}$$

$$\sigma_t^2 = \frac{\sum_{i=t-p}^{t-1} (D_i - \mu_t)^2}{p-1} \tag{3}$$

A simple two-stage chain V

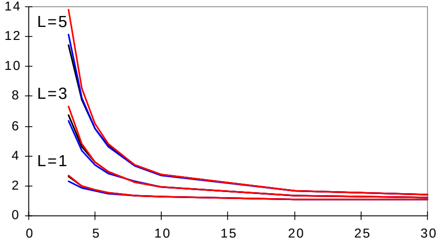
- Now the order quantity placed by the retailer:

$$q_t = Q_t - Q_{t-1} + D_{t-1}$$

Which implies

$$\frac{Var(q_t)}{Var(D_t)} \geq 1 + \left(\frac{2L}{p} + \frac{2L^2}{p^2}\right)(1 - \rho^p).$$

Managerial insights from the formula I



- Exists, in part, due to the retailer's need to estimate the mean and variance of demand.
- The increase in variability is an increasing function of the lead time.
- The more complicated the demand models and the forecasting techniques, the greater the increase.

Managerial insights from the formula II

- Centralized demand information can significantly reduce the bullwhip effect, but will not eliminate it.

A General Multi-stage Chain I

- First, assume we have centralized demand information. In this case, we have a centralized (1) demand, (2) forecasting technique, and (3) inventory policy.
- The variance of the order placed by the k-th stage of the supply chain relative to the variance of the customer demand is just

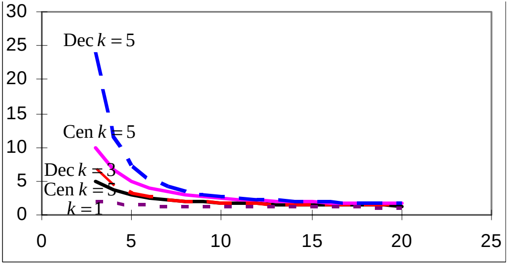
$$\frac{Var(q^k)}{Var(D_t)} \geq 1 + \frac{2\sum_{i=1}^{k} L_i}{p} + \frac{2\left(\sum_{i=1}^{k} L_i\right)}{p^2}$$

  Where L_i is the lead time between stage i and stage $i+1$.
- Next, assume we have decentralized demand information. In this case,

$$\frac{Var(q^k)}{Var(D_t)} \geq \Pi_{i=1}^{k}\left[1 + \frac{2L_i}{p} + \frac{2L_i^2}{p^2}\right]$$

A General Multi-stage Chain II

- For both centralized and decentralized systems, the bullwhip effects exists, the difference is in terms of how much the variability grows as we move from stage to stage.
- The variability grows additively and multiplicatively respectively for the centralized and decentralized systems. Therefore *centralized demand information can significantly reduce the bullwhip effect, but may not completely eliminate it (because of other factors, such as lead time being uncertain)*.



A General Multi-stage Chain III

Methods for Coping with Bullwhip effect I

- Our ability to quantify the Bullwhip effect leads to a number of suggestions for reducing the Bullwhip effect.
  - Reduce uncertainty on demand and lead time: Point-of-Sale (POS), Sharing information, Sharing forecasts and policies
  - Reduce variability of demand: Eliminate promotions, instead use Every-Day Low Pricing (EDLP) strategy
  - Reduce lead times: EDI (Effective Data Interchange)—recuding information lead time, Cross docking—reducing order lead time
  - Strategic partnerships: Vendor managed inventory (VMI), Data sharing

Section 1

Value of Information

Information for Effective Forecasts I

- Pricing, promotion, new products
  - Different parties (such as retailer and supplier) have this information.
  - Retailers may set pricing or promotion without telling distributor
  - Distributor/Manufacturer might have new product or availability information
- Collaborative Forecasting addresses these issues

Information for Coordination of Systems I

- Information is required to move from local to global optimization
- Questions:
  - Who will optimize?
  - How will savings be split?
    - Supply chain contract
    - Strategic partnership
- Information is needed:
  - Production status and costs
  - Transportation availability and costs
  - Inventory information
  - Capacity information
  - Demand information

Information for Locating Desired Products

- How can demand be met if products are not in inventory?
  - Locating products at other stores
  - What about at other dealers?
- What level of customer service will be perceived?

Information for Lead-Time Reduction

- Why?
  - Customer orders are filled quickly
  - Bullwhip effect is reduced
  - Forecasts are more accurate
  - Inventory levels are reduced
- How?
  - EDI (effective data interchange)
  - POS data leading to anticipating incoming orders.

Information to Address Conflicts

- Lot Size — Inventory:
  - Manufacturers like large lot size to utilize the production EOS, but it leads to high inventory
  - Advanced manufacturing systems: Kanban, Just-in-time, and CONWIP reduce inventory.
  - POS data for advance warnings
- Inventory — Transportation:
  - Transportation EOS and inventory level
  - Lead time reduction for batching
  - Information systems for combining shipments
  - Cross docking
  - Advanced DSS
- Lead Time— Transportation:
  - Lower transportation costs
  - Improved forecasting
  - Lower order lead times
- Product Variety—Inventory: Delayed differentiation