Simulation of a serial supply chain under P-system inventory control

Aim: To analyse the performance of a 4-stage serial supply chain under P-system inventory control at all stages of the supply chain using Excel spreadsheet.

Description of the supply chain:

Customer demand is normally distributed and the retailer faces the customer demand. The four stages are Retailer, Wholesaler, Distributor and Factory. Retailer places orders to wholesaler; wholesaler places orders to distributor and so on. Every stage in a supply chain has a lead time of two weeks. This lead time is the sum of the order transmission time and shipment time. The order transmission time to the immediate upstream stage is one week and the delivery time to downstream stage is also one week. Factory issues order to shop floor based on the inventory position. Factory takes one week to prepare and transmit the order to shop floor and it takes one week to produce and deliver the item to finished goods store. The inventory position is reviewed in every week. There will be an initial inventory in every stage of the supply chain. Simulate the supply chain inventory behaviour when P-system inventory control is used at all stages of the supply. Two-period moving average may be used for forecasting the demand. There is no safety stock in any stage of the supply chain. Demand not met in any stage is considered as lost sales. Calculate the total cost of the supply chain for the given cost structure and fill rate of each stage. Also, comment on the bullwhip effect.

System requirements and cost structures

Customer demand – $N(20,5)$

Lead time between stages – 2 weeks

\[
\text{Lead time} = \text{Order transmission time} + \text{Delivery time}
\]

\[
\text{Order transmission time} - \text{One week}
\]

\[
\text{Delivery time} - \text{One week}
\]

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Retailer</th>
<th>Wholesaler</th>
<th>Distributor</th>
<th>Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding cost per unit per week (₹)</td>
<td>20</td>
<td>18</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Shortage cost per unit per week (₹)</td>
<td>60</td>
<td>50</td>
<td>45</td>
<td>40</td>
</tr>
</tbody>
</table>
Data considered for performance measure – from 12th week to 50th week

**Inventory Policy at every stage of the supply chain**

**Order up to level policy:**
- An order up to level is fixed and is equal to the expected demand during review period and lead time.
- Order quantity is equal to the difference between the order up to level and inventory position.
- Inventory position is equal to sum of the on hand inventory and orders placed but not yet received.

**The simulation model is developed based on the following assumptions:**
1. Purchase order is placed at the beginning of the period
2. Each stage receives replenishment order quantity at the beginning of the period
3. The initial inventory at the start of simulation at each stage is 60 units
4. Customer order arises at retailer only
5. No back orders are allowed
6. There are no capacity constrains and storage space constraints at each stage in the supply chain
7. The factory has infinite production capacity and enough raw materials for production

![Fig. 1. Order and shipment flow in supply chain](image)

**Demand estimation**

Two-period moving average method

**At retailer**

Initial forecast at the beginning of simulation = 20 units
Second period forecast is taken as the first period demand
Third period onwards demand is forecasted based two-period moving average method
**Data updating procedure**

R OW₁ → W RO₂

The above piece of information means ‘Order placed to Wholesaler on week 1 (OW₁) by Retailer (R) reaches (→) the wholesaler (W) on week 2 which is represented in wholesaler page as Retailer Order (RO₂)’.

**Representation above logic in Excel Worksheets**

Note the week 2 ‘Order placed to Wholesaler’ by retailer in Fig 2. This quantity is shown in Fig 3 as ‘Retailer Order’ in week 3. The transfer of ‘Order placed to wholesaler’ to wholesaler page as ‘Retailer Order’ is done with a statement in Excel as =Retailer!L₄ (Note this in the Formula bar of Fig 3.) This is applicable as the order transmission time is one week.

![Fig 2. Excel worksheet of Retailer (Excel worksheet name: Retailer)](image)

![Fig 3. A part of Excel worksheet of Wholesaler (Excel worksheet Name: Wholesaler)](image)

Before interpreting the piece of information given below, see notations provided below.

W AQ₂ → R RQ₃

W OD₁ → D WO₂  
D AQ₂ → W RQ₃
Order placed: If (OUL = 0, 0, if (IP>OUL, 0, OUL-IP))

Forecast\(t\) = Roundup((Demand_{t-1} + Demand_{t-2})/2)

Allocated Quantity\(t\) = If (BI>OQ, OQ,BI)

OUL = 3* Forecast

Lost sales = OQ – AQ

\(EI = BI – AQ\)

\(BI\)\(_t\) = \(EI\)\(_{t-1}\)+RQ\(_t\)

\(IP\)\(_t\) = \(BI\)\(_t\) +OP in previous periods (Because backorder quantity is zero.)

**Notations**

R – Retailer, W – Wholesaler, D – Distributor, F – factory

OW – Order placed to Wholesaler, RO – Retailer Order,

AQ – Allocated Quantity, RQ – Replenishment Quantity,

OD - Order placed to Distributor, WO – Wholesaler Order,

OF - Order placed to Factory, DO – Distributor Order

OUL – Order Upto Level, IP – Inventory Position

BI – Beginning Inventory, EI – Ending Inventory

Create a workbook with 5 worksheet. Name the worksheet appropriately, may be as ‘Retailer’, ‘Wholesaler’, ‘Distributor’, ‘Factory’ and ‘Performance’. The pdf version of 5 Excel worksheets is attached herewith. Use the format available in this pdf files to create appropriate excel worksheets. Program in Excel worksheet using the ‘data updating procedure’ given above.

The normal random demand generation procedure is given below.

**Procedure for developing Normal Random variate in EXCEL**
Normal random variate generation using MATLAB

R = round(random('norm',m,sd,[x,y]));

R = RANDOM(NAME,A,B,[X,Y]) returns a X × Y array of random numbers chosen from a two-parameter probability distribution

ROUND - Round towards nearest integer
FLOOR - Round towards minus infinity
CEIL - Round towards plus infinity
FIX - Round towards zero

Normal random variate generation using EXCEL

R = Rand()
NORMINV(R, m, sd)

Generation of stream of random numbers

Type =rand() in cell and copy down to more cells based on the required number of random numbers. Now, freeze the random numbers. To freeze, select these cells and Copy. Then paste these numbers in these cells where the =rand() formula in them, using Values from the Paste Special.

Generation of stream normal random numbers

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>Random numbers</td>
<td>=NORMINV(A2,20,5)</td>
</tr>
<tr>
<td>2</td>
<td>0.511864</td>
<td>20.14871943</td>
</tr>
<tr>
<td>3</td>
<td>0.347355</td>
<td>18.03764319</td>
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<tr>
<td>4</td>
<td>0.186055</td>
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<td>0.426613</td>
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<td>8</td>
<td>0.985466</td>
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<td>9</td>
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<td>10</td>
<td>0.834576</td>
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<tr>
<td>11</td>
<td>0.874683</td>
<td>25.74404463</td>
</tr>
</tbody>
</table>

Fig: use of NORMINV function – See formula bar

To get integer values use the function ‘Round()’. It is demonstrated below

=ROUND(NORMINV(A2,20,5),0)