Inventory Management: How Hospitals Keep Blood in Stock

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What is inventory management?

- Tracking an organisation's stock levels and placing required orders
- Particularly important when stocking perishable products
- Use Markov decision process to model the problem as we make sequential decisions and have uncertainty in the model
- Aim: to find the best ordering strategy

Our Hospital Scenario

- Modelling one blood type
- Cost of one unit of blood is £180
- Cost of disposal is £0.30 per unit
- Cost of storage is £30 per day
- Penalty cost of unfulfilled demand is £1,000
- Average daily demand is 5 units

Decision Making Process

- Every morning we observe the current stock level
- We place an order
- We have the day's demands
- Ordered stock arrives and is added to the inventory ready for the next morning

The Newsvendor Model

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- Aim: find the optimal amount of stock to start each day with

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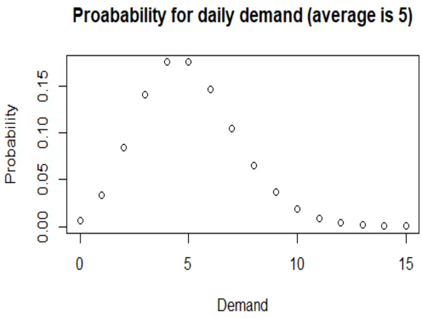


The Newsvendor Model

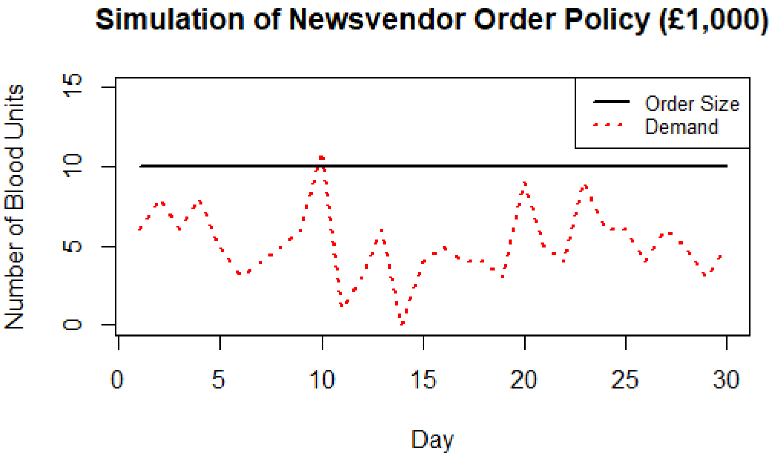
Probability of meeting our demand:

$$\frac{\text{cost of understocking}}{\text{cost of understocking} + \text{cost of overstocking}}$$

$$\frac{1000}{1000 + (30 + 0.3)} = 0.97$$

If we want a 97% chance of meeting our demand, we need to order 10 units of blood each day

The Newsvendor Model



The Newsvendor Model

- In the 100 day simulation, we are short by 4 units
- We satisfy demand on 96% of days (target was 97%)

Periodic Review Model

- Assumption: stock never expires
- Aim: find the optimal target amount of stock we want to start each day with and determine an ordering policy

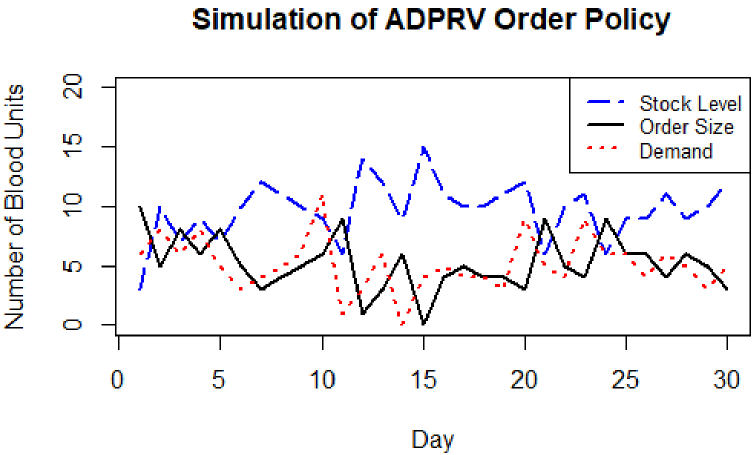
Periodic Review Model

- Assumption: stock never expires
- Aim: find the optimal target amount of stock we want to start each day with and determine an ordering policy
- There isn't an exact solution due to the random demand
- One possible method is calculate the expected next-day stock level

Age-Dependent Periodic Review Model

- Assumption: stock has a maximum shelf-life of 35 days, but each day has a probability of expiring

Age-Dependent Periodic Review Model



Age-Dependent Periodic Review Model

Penalty cost £1,000

- In the 100 day simulation, we are short by 9 units

Penalty cost £100,000

- In the 100 day simulation, we are short by 3 units

Cost Comparison

- Run 200 simulations for both models
- The optimal ordering would be to order exactly enough to satisfy each day's demand

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Newsvendor model cost **97.5%** more than the optimal solution on average

Age-dependent periodic review model cost **14.4%** more than the optimal solution on average

Conclusion

- Age-dependent periodic review model was considerably more cost effective than the newsvendor model, and could have a similar satisfaction rate
- Hospitals order for several days ahead to ensure they always have a base supply which was not accounted for here
- Blood can also be substituted between patients, so we would need to model multiple blood types together

Thank you for listening!
Any questions?

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Periodic Review

p the penalty cost, h the holding cost.

$\boldsymbol{x_t} = (x_{t,1}, ..., x_{t,m})$ is the numbers of units in stock at the start of period t, where $x_{t,i}$ denotes those of age i

D_t is the demand at time t

The optimal base-stock level at time $t+1$:

$$F^{-1}_{D_{t+1}}\left(\frac{p}{p+h}\right)$$

Heuristic policy for ordering quantity (optimal base level minus expected EoD stock):

$$q_t = \text{Nint}\left[\max\left(0, F^{-1}_{D_{t+1}}\left(\frac{p}{p+h}\right) - \mathbb{E}_{D_t}[\max(x_t - D_t, 0)]\right)\right]$$

Age-Dependent Periodic Review

θ is the disposal cost

$\boldsymbol{\psi} = (\psi_1, ..., \psi_m)$ the probability of expiring at age i

The number of unsold items of age i at time t:

$$Y_{t,i} = \max\left(0, x_{t,j} - \max\left(0, D_t - \sum_{j=i+1}^{m} x_{t,j}\right)\right)$$

Expected stock at time $t+1$ (after stock has expired):

$$I_{t+1} = \sum_{i=1}^{m-1} (1 - \psi_i)\mathbb{E}_{D_t}[Y_{t,i}]$$

Approximate a_t (the probability of an item not selling at time t):

$$\hat{a}_t = \frac{\sigma_{D_t}}{\sigma_{D_t} + \mu_{D_t}}$$

Age-Dependent Periodic Review

$$g_t = \left(\frac{\sum_{i=1}^{m} \left(\psi_i \prod_{v=1}^{i-1} \hat{a}_{t+v}(1-\psi_v) \right)}{\sum_{i=1}^{m} \left(\prod_{v=1}^{i-1} \hat{a}_{t+v}(1-\psi_v) \right)} \right)$$

Ordering quantity:

$$q_t = \text{Nint}\left[\max\left(0, F_{D_{t+1}}^{-1}\left(\frac{p}{p+h+g_t\theta} \right) - I_{t+1} \right) \right]$$