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A stochastic programming model for inventory management of blood products with age-specific demand

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Background

- The blood supply chain consists of the activities of collecting, processing, storing and distributing blood products
  - Red blood cells, platelets, plasma
- This work focuses on **platelet** inventory management in a **hospital blood bank**
- Platelets have special characteristics
  - Uncertain demand
  - Highly perishable
  - Age-specific demand for different treatments

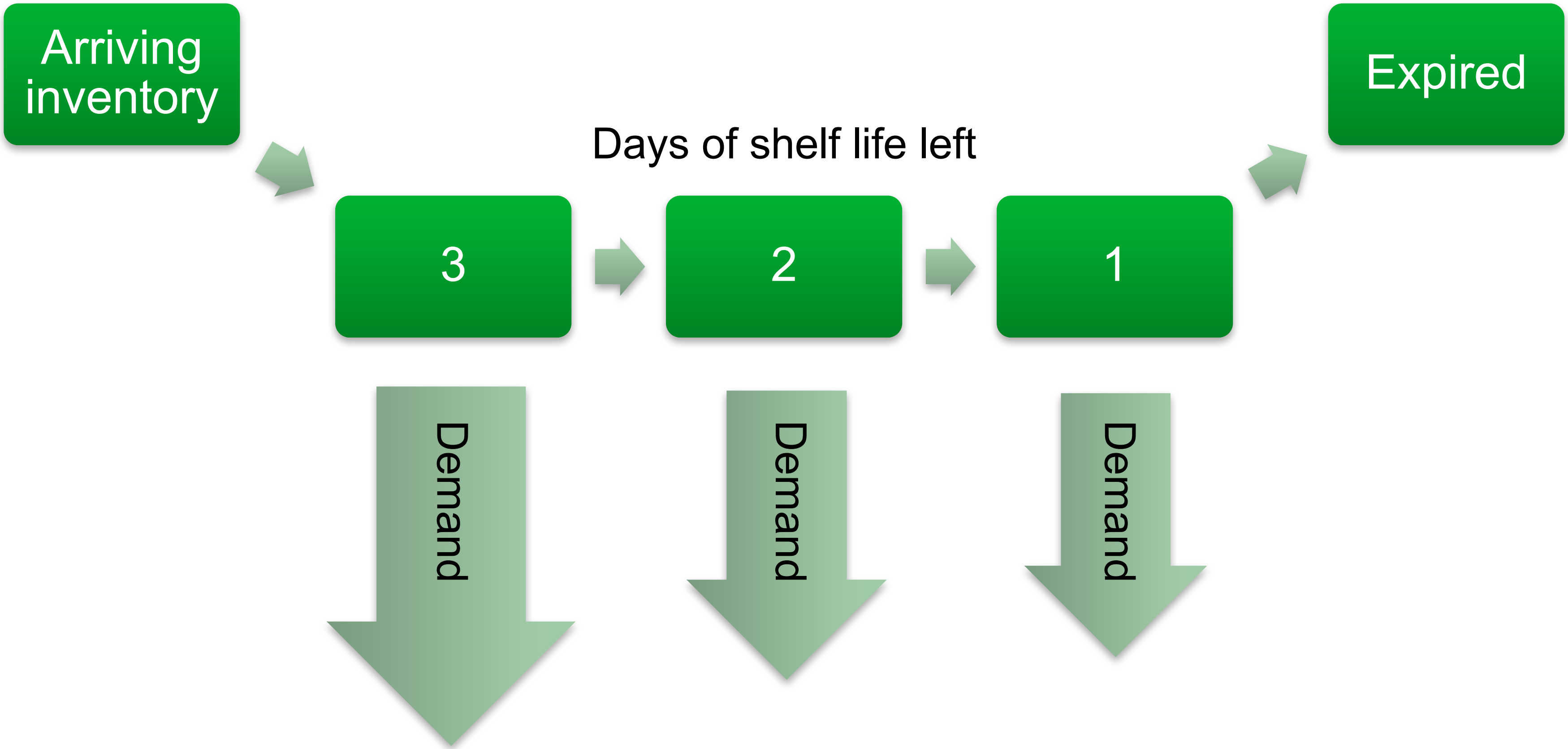
Objectives

- Formulate two-stage stochastic programming model to determine optimal order-up-to levels for platelets
  - Compare three different ordering policies
  - Based on Dillon et al., Dehghani et al.
- Implementation in Julia

Setting (1/2)

- Review periodicity is one day
- Orders arrive after a lead time of one day
- Arriving units are ‘fresh’ and have the maximum shelf life
- The demands for different aged items are distinct
- Substitution between age groups is allowed, but incurs a mismatch cost

Setting (2/2)


Arriving inventory
Expired
Days of shelf life left
3
2
1
Demand
Demand
Demand

Ordering policies

- Adapted from Haijema et al.
- NIS – New inventory to S
  - Every period, order S_{M} items.
- 1D – Total order-up-to policy
  - Order the difference between S_{TOT} and inventory level of items not expiring this period
- 2D – Double-level order-up-to policy
  - Order the difference between S_{TOT} and inventory level of items not expiring this period, but at least S_{M}

The Model

- Considers several scenarios simultaneously
  - Objective: minimize overall expected costs from ordering, holding, shortage, expiry and substitution
- Decision variables
  - Order-up-to levels
  - Ordering, expiry, and shortage quantities
  - Inventory levels
  - Use of units of certain age to fulfill demand for certain age
    - $a(\xi)_{t,k,m}$
  - Binary variables for linearization of ordering policies

The Model

- Constraints model the system and tie variables together
  - Inventory balance
  - Use of units
  - Inventory aging:
    - $ie(\xi)_{t,m+1} = is(\xi)_{t+1,m}$
  - Expiry
  - Order quantity
  - Unmet demand
  - etc.

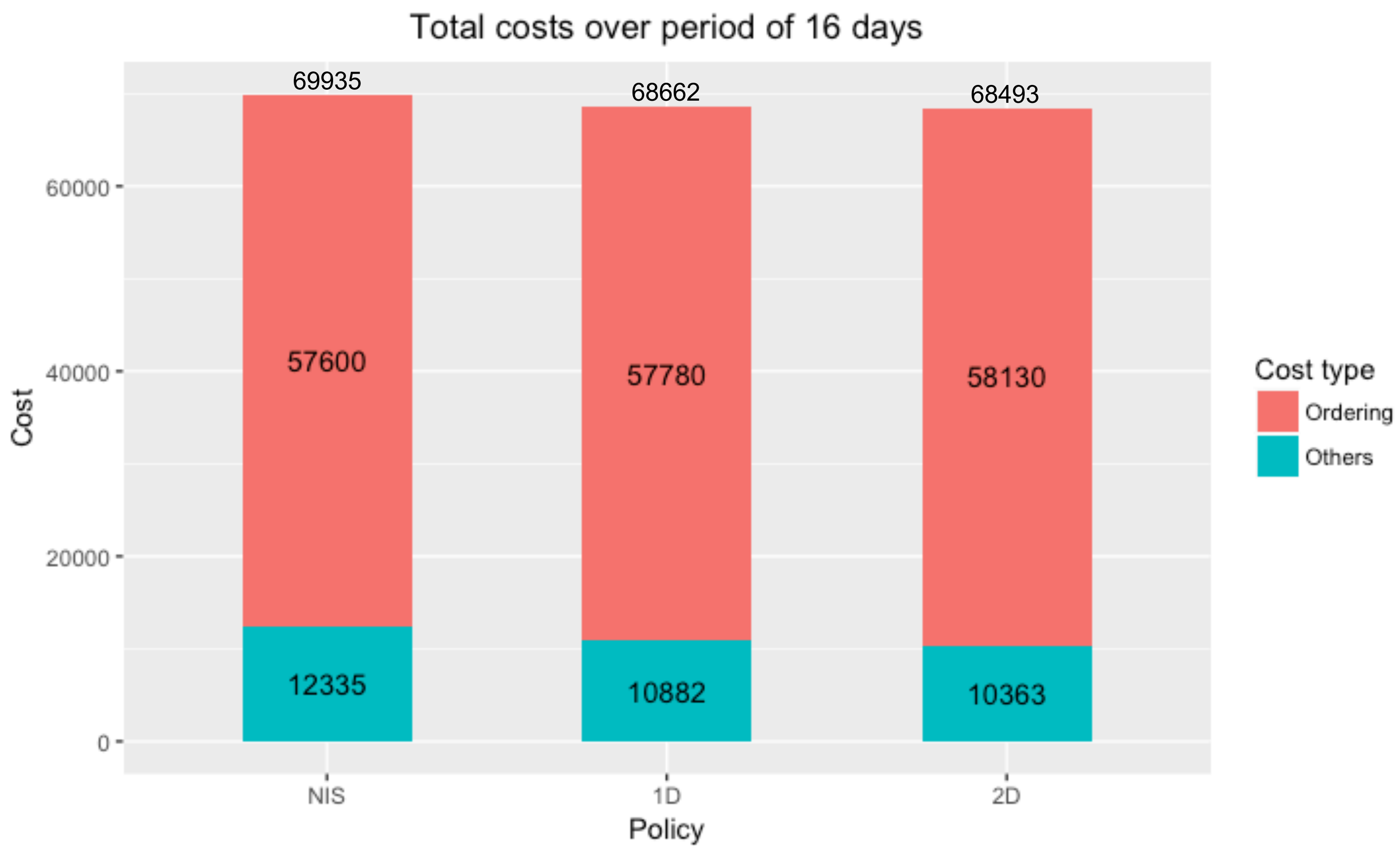
Results

- Computed with 40 scenarios and 16 time periods
- Demands from Poisson distribution with means 7, 2, 1
- Costs
  - Ordering 400
  - Shortage 300-1000
  - Expiry 200
  - Substitution 100-180
  - Holding 1

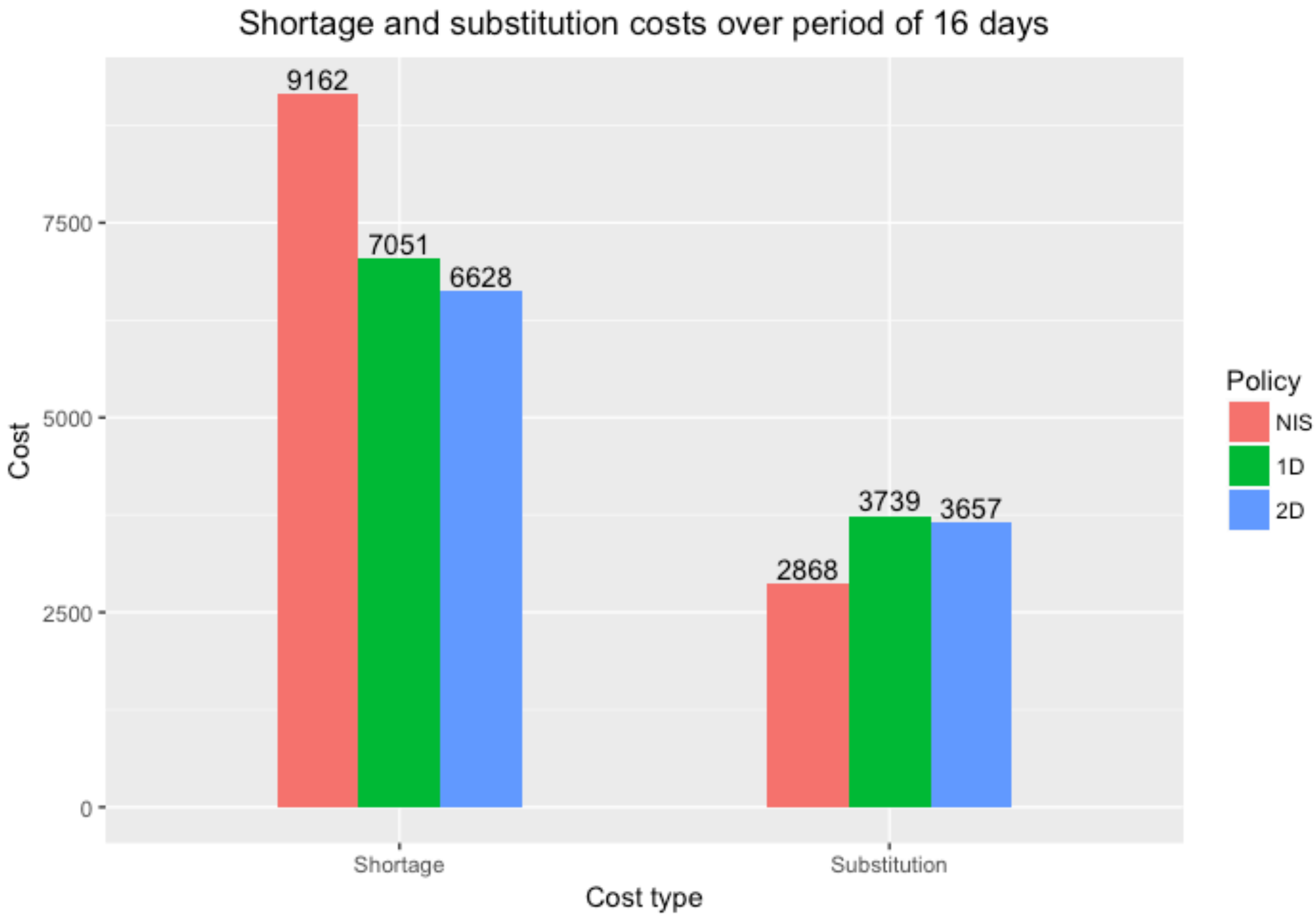
Results (1/3)

Policy	Order-up-to levels (units)	Service level (%)	Exact match (%)	Expiry level (%)
NIS	$S_M = 9$	89.6	83.8	0.9
1D	$S_{TOT} = 21$	90.1	78.7	0.09
2D	$S_M = 6$ $S_{TOT} = 21$	91.2	79.1	0.04

Results (2/3)


Total costs over period of 16 days
69935
68662
68493
57600
57780
58130
12335
10882
10363
60000
40000
20000
0
Cost
NIS
1D
2D
Policy
Cost type
Ordering
Others

Results (3/3)


Shortage and substitution costs over period of 16 days
9162
7051
6628
3739
3657
2868
7500
5000
2500
0
Cost
Shortage
Substitution
Cost type
Policy
NIS
1D
2D

Discussion

- Able to solve problem of limited size
- Can be solved with commercial software
- General and adaptable
  - Demand process
  - Different products
  - Additional constraints for service level / exact match requirements
- Limitations
  - Computational complexity
  - Does not take production or demand periodicity into account
  - Blood types not considered

Sources

- Ismail Civelek, Itir Karaesmen, and Alan Scheller-Wolf. Blood platelet inventory management with protection levels. European Journal of Operational Research, 243(3):826–838, 2015.
- Maryam Dehghani, Babak Abbasi, and Fabricio Oliveira. Proactive transshipment in the blood supply chain: a stochastic programming approach. (Preprint)
- Mary Dillon, Fabricio Oliveira, and Babak Abbasi. A two-stage stochastic programming model for inventory management in the blood supply chain. International Journal of Production Economics, 187:27–41, 2017
- René Haijema, Jan van der Wal, and Nico M van Dijk. Blood platelet production: Optimization by dynamic programming and simulation. Computers & Operations Research, 34(3):760–779, 2007.

Whole model

$$
\begin{aligned}
\min \quad & z = \sum_{\xi \in \Xi} P(\xi) \left[\sum_{t \in \mathcal{T}} \left(O\, q(\xi)_t + H\, v(\xi)_t + E\, e(\xi)_t + \right. \right. \\
& \left. \left. \sum_{m \in \mathcal{M}} \left(G_m\, f(\xi)_{t,m} + X \sum_{k \in \mathcal{M}} Q_{m,k}\, a(\xi)_{t,m,k} \right) \right) \right] && (1) \\
\text{s.t.} \quad & is(\xi)_{1,m} = B_m, \quad \forall\ \xi,\ m && (2) \\
& is(\xi)_{t,m} = \sum_{k \in \mathcal{M}} a(\xi)_{t,m,k} + ie(\xi)_{t,m}, \quad \forall\ \xi,\ t,\ m && (3) \\
& \sum_{k \in \mathcal{M}} a(\xi)_{t,k,m} + f(\xi)_{t,m} = D(\xi)_{t,m}, \quad \forall\ \xi,\ t,\ m && (4) \\
& v(\xi)_t = \sum_{m \in \mathcal{M} \setminus \{1\}} ie(\xi)_{t,m}, \quad \forall\ \xi,\ t && (5) \\
& e(\xi)_t = ie(\xi)_{t,1}, \quad \forall\ \xi,\ t && (6) \\
& ie(\xi)_{t,m+1} = is(\xi)_{t+1,m}, \quad \forall\ \xi,\ t \in \mathcal{T} \setminus \{T\},\ m \in \mathcal{M} \setminus \{M\} && (7) \\
& is(\xi)_{t+L,M} = q(\xi)_t \quad \forall\ \xi,\ t \leq T - L && (8) \\
& S_{tot}, S_M \in Z_{\geq 0} && (9)
\end{aligned}
$$

Ordering policies

NIS

$$q(\xi)_t = S_M, \quad \forall\ \xi,\ t \tag{10}$$

1D

$$q(\xi)_t = \max\{0, S_{tot} - \sum_{m>L} is(\xi)_{t,m}\} \quad \forall\ \xi,\ t \tag{11}$$

Linearization:

$$q(\xi)_t \geq S_{tot} - \sum_{m>L} is(\xi)_{t,m} \tag{12}$$

$$q(\xi)_t \leq S_{tot} - \sum_{m>L} is(\xi)_{t,m} + \overline{S}(1 - b(\xi)_t) \tag{13}$$

$$q(\xi)_t \leq \overline{S} b(\xi)_t \tag{14}$$

2D

$$q(\xi)_t = \max\{S_M, S_{tot} - \sum_{m>L} is(\xi)_{t,m}\} \quad \forall\ \xi,\ t \tag{15}$$

Linearization:

$$q(\xi)_t \geq S_{tot} - \sum_{m>L} is(\xi)_{t,m} \tag{16}$$

$$q(\xi)_t \geq S_M \tag{17}$$

$$q(\xi)_t \leq S_{tot} - \sum_{m>L} is(\xi)_{t,m} + \overline{S}(1 - b(\xi)_t) \tag{18}$$

$$q(\xi)_t \leq S_M + \overline{S} b(\xi)_t \tag{19}$$