OR for Blood Donor Management

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Blood Management is of general human and societal interest. Dutch blood donations roughly involve 750,000 yearly voluntary donations. These encompass decision making and trade-offs as of general managerial interest as shown on the right.
It will be highlighted how the so-called field of Operations Research (OR) (a mathematical discipline for logistical problems) and techniques from this area can provide quantitative and formal support. The results are real-life based on Dutch Blood Supply.

- Personnel capacity and production planning (cost efficiency) versus customer (patients/donors) friendliness (waiting times for donors within blood collection sites).
- Demand fulfillment (lives can be at risk) for having sufficient stocks.
- Different levels of uncertainties (demands, donors, walk-ins, and intake durations).
- Quality (age of donated blood) and waste (outdating).
- Donor recruitment

1. Blood Inventory

1.1 Platelet logistics

- No production in weekends and holidays
- Uncertain demand (over 50%)
- Shelf life = 4, 5, 6, or 7 days

Goal

- Outdating: **15-20%** ⇓

1.2 Approach

Step 1. Stochastic Dynamic Programming

d: the day of the week ($d = 1,2,\dots,7$)
$\boldsymbol{x}$: $(x_1, x_2, \dots, x_5)$ = the inventory state with
x_r = # pools with residual shelf life of r days.
$\boldsymbol{V}_n(d,\boldsymbol{x})$: minimal expected costs over n days, with $\boldsymbol{V}_0(\cdot,\cdot) = 0$.

$$\boldsymbol{V}_n(d,\boldsymbol{x}) = \min_k \sum_b p_d(b) \left\{ \begin{array}{ll} (b - \sum_r x_r)^+ c^S & \text{(shortage)} \\ + & \\ (\sum_r x_r - b)^+ c^O & \text{(outdating)} \\ + & \\ \boldsymbol{V}_{n-1}(d+1, \text{"}x - b + k\text{"}) & \text{(future)} \end{array} \right\}$$

Step 2/3. Simulation and validation of SDP: simple rule

1.3 Results

- Optimal ⇒ Simple rule
- Shortage ⇓ 0.1%
- **Outdating ⇓ 1%**

Dijk, N.M. van, Haijema, R., Wal, J. van der, & Sibinga, C. S. (2009). Blood platelet production: a novel approach for practical optimization. *Transfusion*, *49*(3), 411-420.

2. Blood Donor Delays

2.1 Collection sites

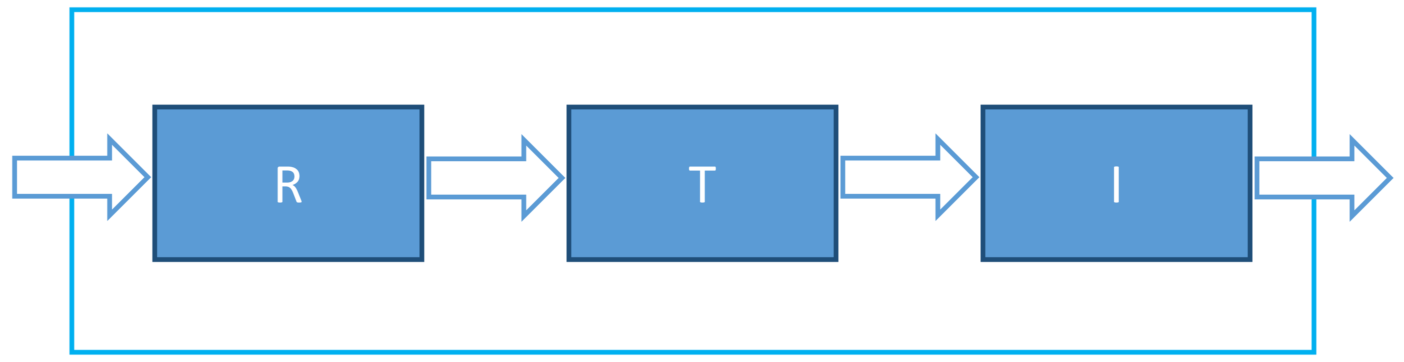
- Dutch (≈ 50) sites
- 750,000 donations
- Stochastic durations

Goal

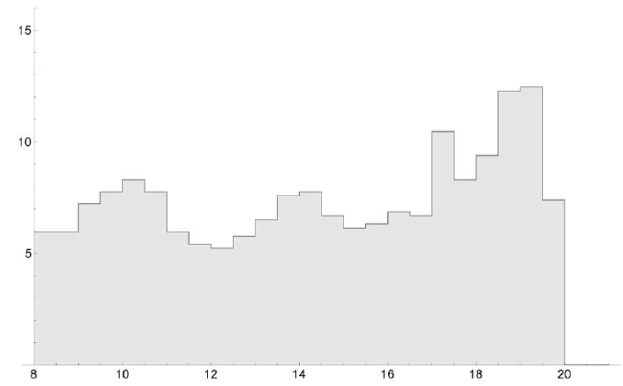
- Minimize Staffing ⟺ Waiting delays

2.2 Approach

Step 1. Transient queuing analysis



$$\mathbb{P}[W_i > t] = \tfrac{1}{2}\left(C_{a_i}^2 + C_{s_i}^2\right) e^{-(1-\rho_i) s_i \mu_i t}$$



Step 2. Flexible (2 - 8 hours) shifts

$$\min \quad \sum_{d=\text{mon}}^{\text{fri}} \sum_{j=1}^{n} X_{dj}$$

$$\text{s.t.} \quad \sum_{j=1}^{n} b_{jk} X_{dj} \geq a_{dk} \quad \forall d, k$$

2.3 Results

- 3 real-life blood collection sites (S,M,XL)
- Staffing Delay (waiting times)
  ⇓ 0 - 40% **⇓ 20 - 70%**

Brummelen, S.P.J. van, Kort, W.L.A.M. de, & Dijk, N.M. van (2015). Waiting time computation for blood collection sites. *Operations research for health care*, *7*, 70-80.

3. Selective Donor Recruitment

3.1 Next of kin

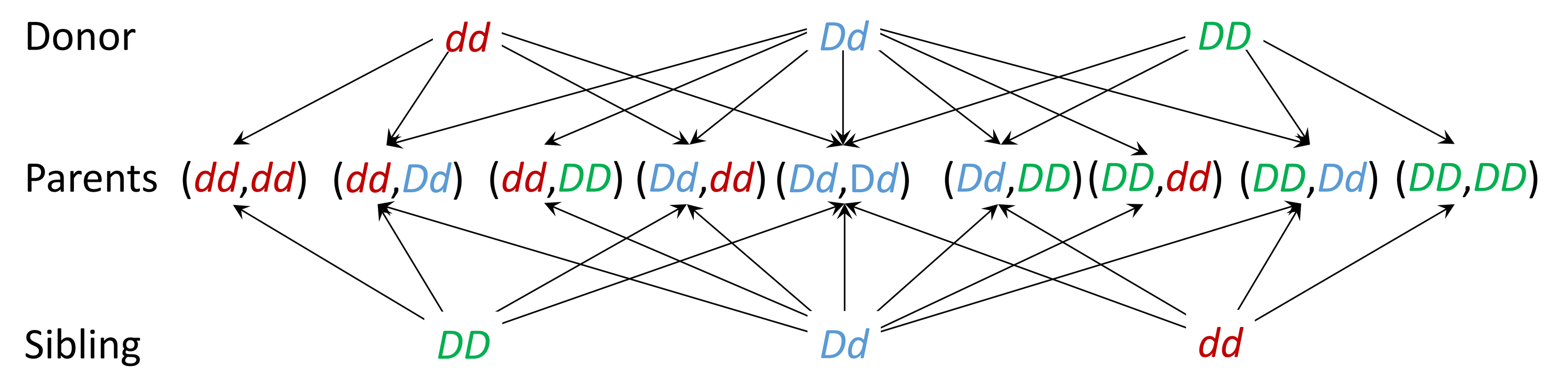
- Arbitrary population
- Donor relatives useful?
- Genotype distributions standardly unknown

Goal

- Effectiveness of selective recruitment (e.g. siblings, parents)

3.2 Approach

Step 1. Step-up-down



$$\mathbb{P}[\gamma_j | \gamma_i] = \sum_{\gamma_v,\gamma_w \in \mathcal{G}} \left(\mathbb{P}[(\gamma_v,\gamma_w)|\gamma_i] \cdot \mathbb{P}[\gamma_j | (\gamma_v,\gamma_w)] \right)$$

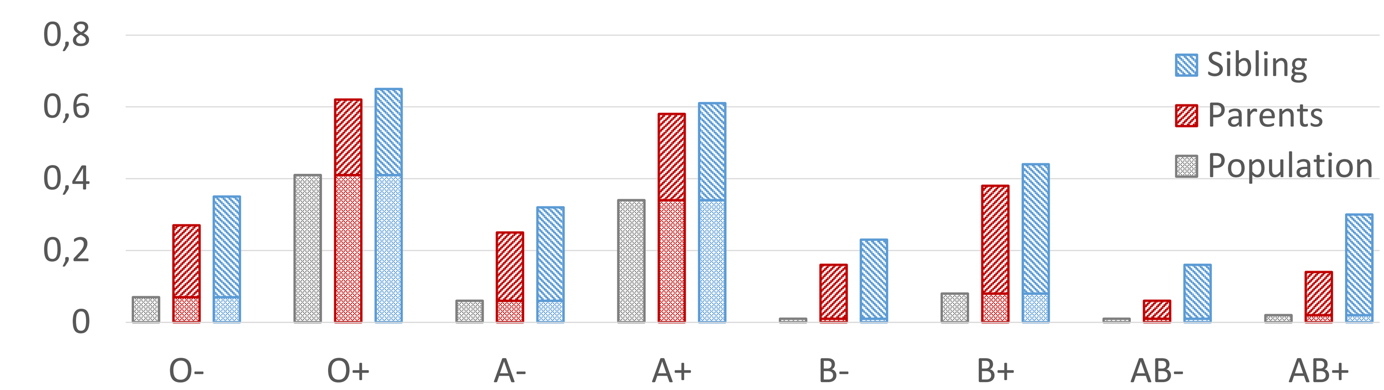
Step 2. Solving stochastic quadratic equation

$\boldsymbol{x}$: genotype distribution

$$\boldsymbol{x}_{\text{father}}^T P \boldsymbol{x}_{\text{mother}} = \boldsymbol{x}_{\text{child}} \implies \boldsymbol{x}^T P \boldsymbol{x} = \boldsymbol{x}$$

3.3 Results

- Approach applicable for arbitrary blood groups (> 300)



Sambeeck, J.H.J. van, Dijk, N.M. van, Kort, W.L.A.M. de, Schonewille, H., & Janssen, M.P. (2018). Blood group probabilities by next of kin. *Probability in the Engineering and Informational Sciences*, 1-21.

Conclusion: The mathematical discipline of Operations Research (OR) offers concepts and techniques (tooling) to balance (and optimize) capacities and service per.