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Platelet inventory management using stochastic programming and Lagrangian decomposition

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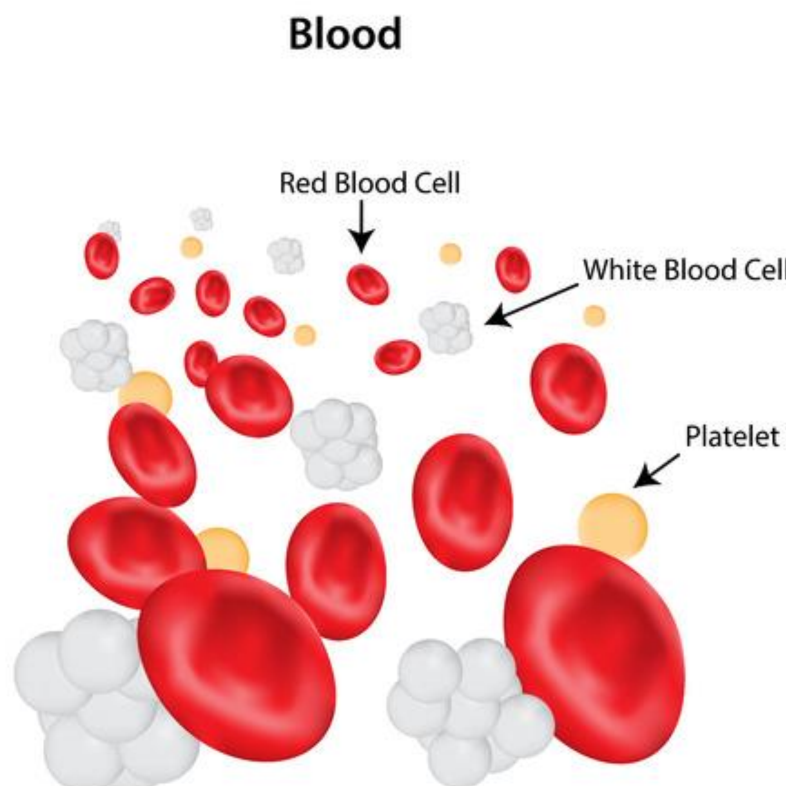
Systeemianalyysin laboratorio

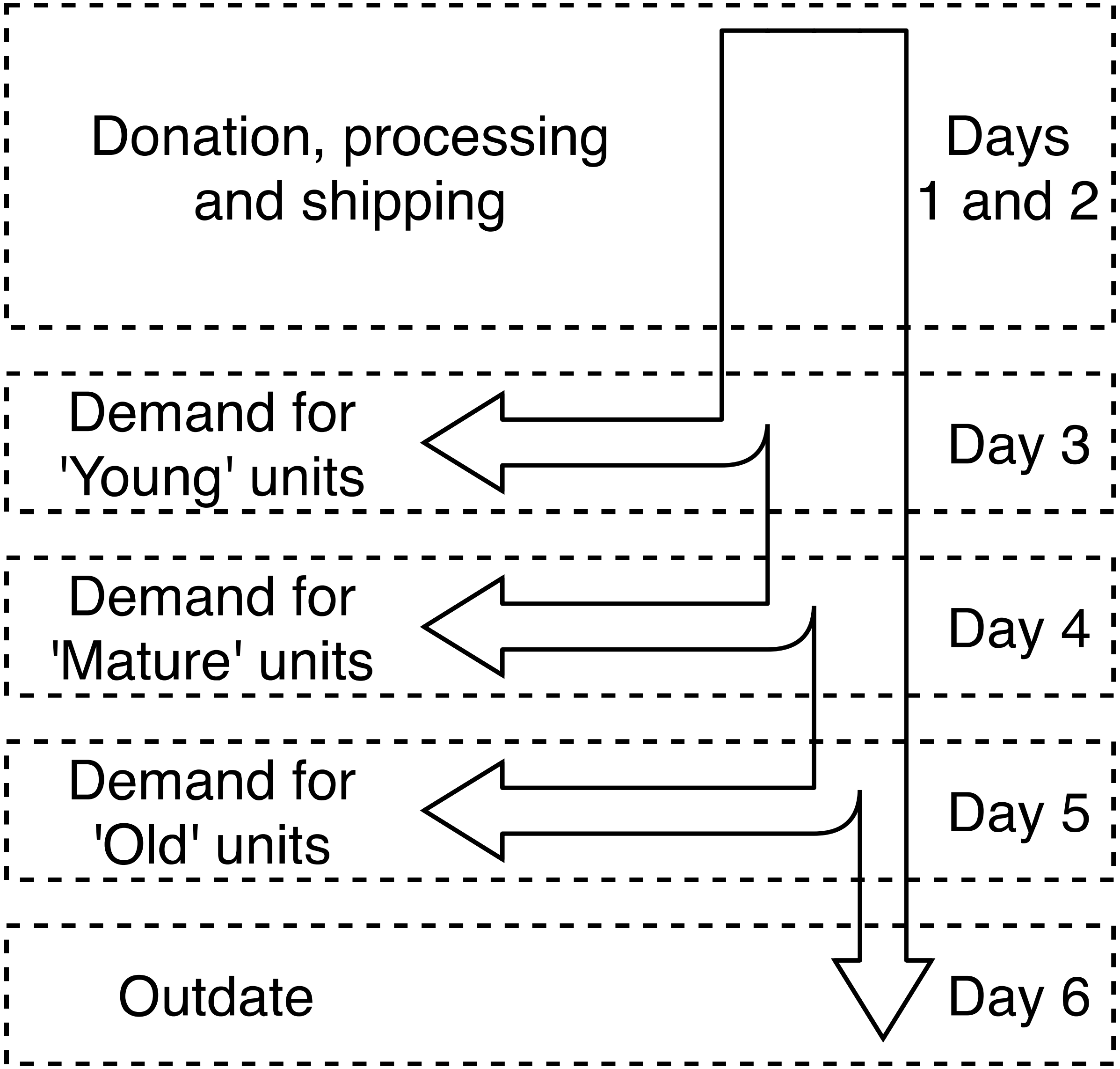
Why platelets?

- Inventory echelon for platelets *(thrombocytes).*
- Used in cancer treatments and to prevent and treat bleeding.
- Certain patients benefit from "fresher" units.

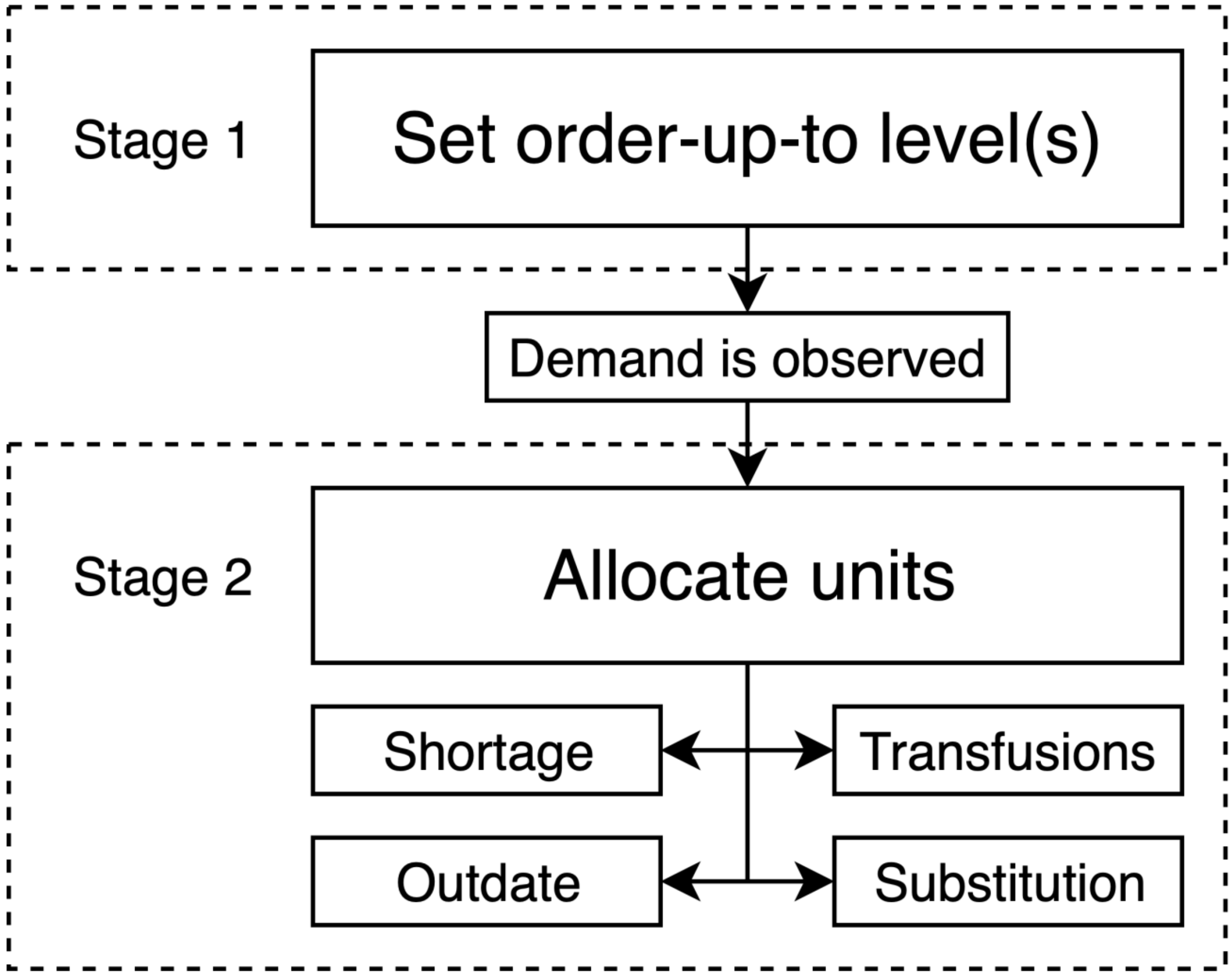


Challenges in managing the platelet SC

- Short shelf life (3-5 days), high outdate rate
- Processing and inventory management is expensive
- Throwing products away is morally problematic
- A shortage may lead to loss of life
- **Bias**: satisfy demand but keep costs low simultaneously


Donation, processing and shipping
Days 1 and 2
Demand for 'Young' units
Day 3
Demand for 'Mature' units
Day 4
Demand for 'Old' units
Day 5
Outdate
Day 6

A 2SSP model for platelet inventory (1/2)



A 2SSP model for platelet inventory (2/2)

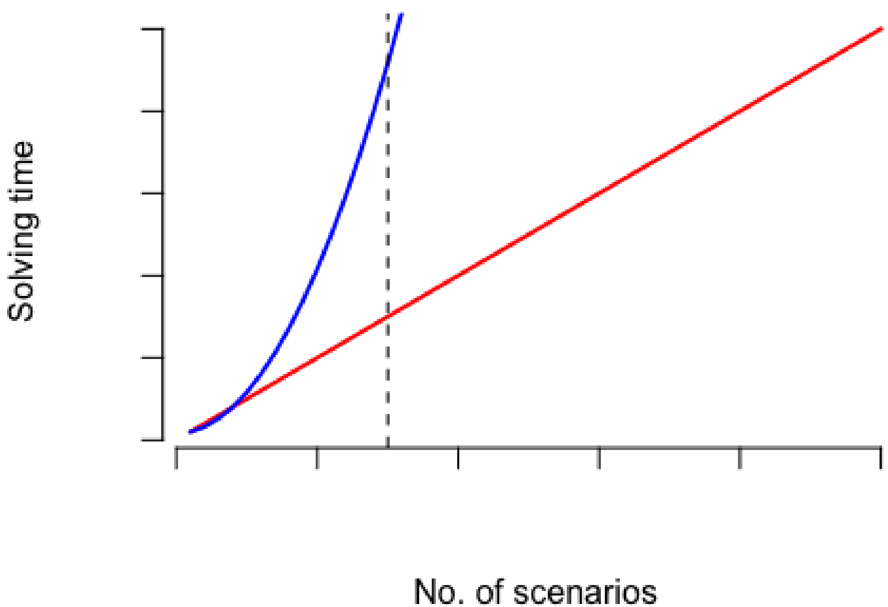
- Stochasticity: uncertain demand
  - Often modelled as a Poisson process
  - Many possible realisations (scenarios)

- Constraints, for example:
  - A proportion of the demand must be satisfied at all times
  - Order amount = amount given to patients + outdate (etc.)

Challenges with optimizing the problem

- Solving time grows as the complexity increases
- Solution? Split into easier subproblems
  - the required time would only grow linearly
  - parallelisation could be exploited

→ Main focus of this study



Primal min. → dual max. problem

Exp. value 1st stage 2nd stage

$$\min.\ z = \Sigma_\xi P(\xi)[c^T x(\xi) + q^T y(\xi)]$$

$$\text{s.t. } x(\xi) = x \text{ for all } \xi$$

Create Lagrangian function:

→ move constraints into the objective using Lagrangian multipliers

$$\min.\ L(x, y, \lambda) = z + \Sigma_\xi \lambda_\xi (x - x(\xi))$$

Note: can be split into a sum of independent scenario-wise terms

Primal min. → dual max. problem

Dual function: $\phi(\lambda)$ = $\min_{x,y}$ L $\precsim$ $\min_{x,y}$ z (for all x,y)

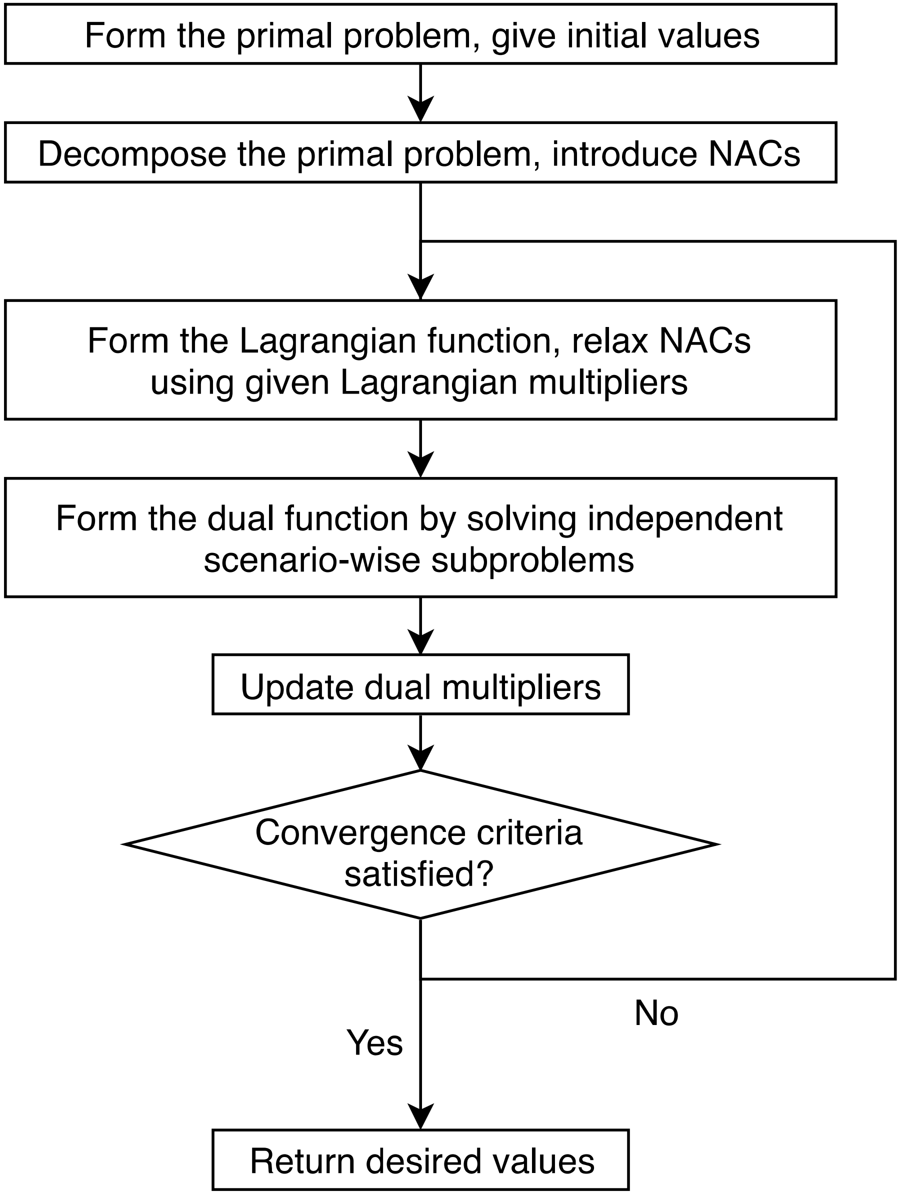
So: $\boxed{\max_{\lambda}\phi = \max_{\lambda} \{\min_{.x,y} L\} \precsim \min_{x,y} z}$

Thus we get a **lower bound** for the primal problem

Challenges with $\max_\lambda \phi$

- Closed form might be hard to obtain
- Complex problems often solved iteratively instead of brute-force
- Various algorithms were implemented, based on:
  - Gradient ascent direction (subgradient algorithms)
  - Constraint planes & quadratic approximation of ϕ (bundle method)

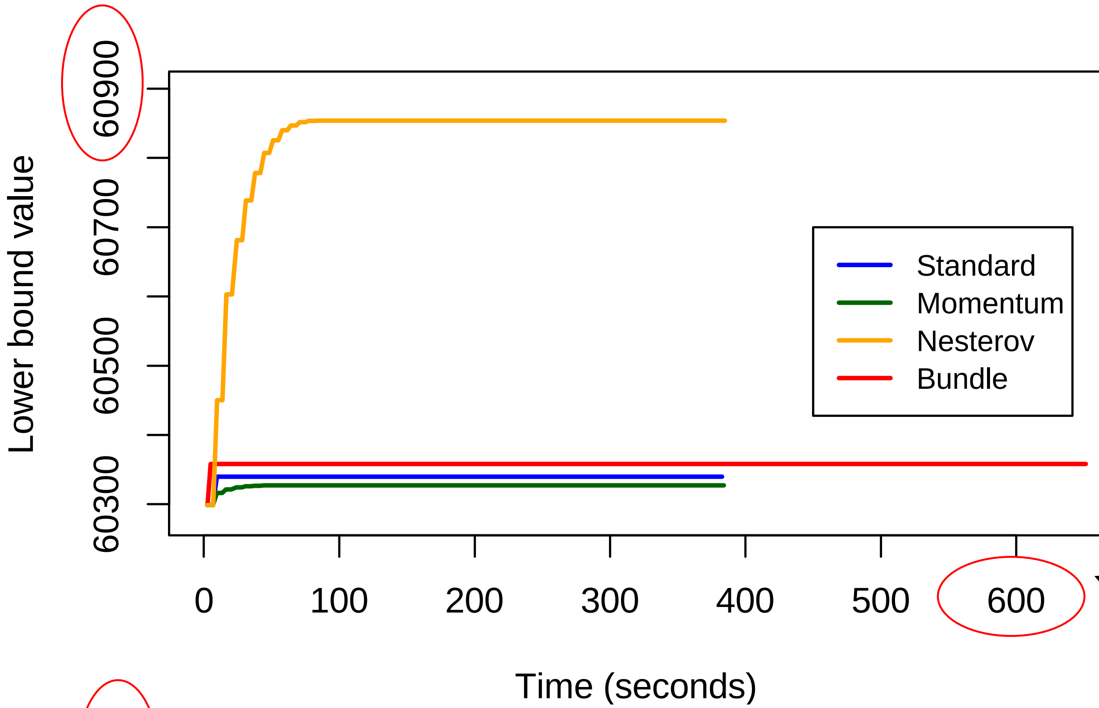
A general algorithm for the Lag. dual problem



Results

- **Standard Lagrangian did not force all $x(\xi)$ to be equal $\rightarrow$ LB values not as good as possible**
- **Augmented Lagrangian: additional quadratic penalty term to L (worked correctly)**
- Dual maximisation algorithms varied by:
  - speed of convergence
  - best LB value
- Duality gaps < 2% (20 scenarios) and < 5% (50 scenarios)

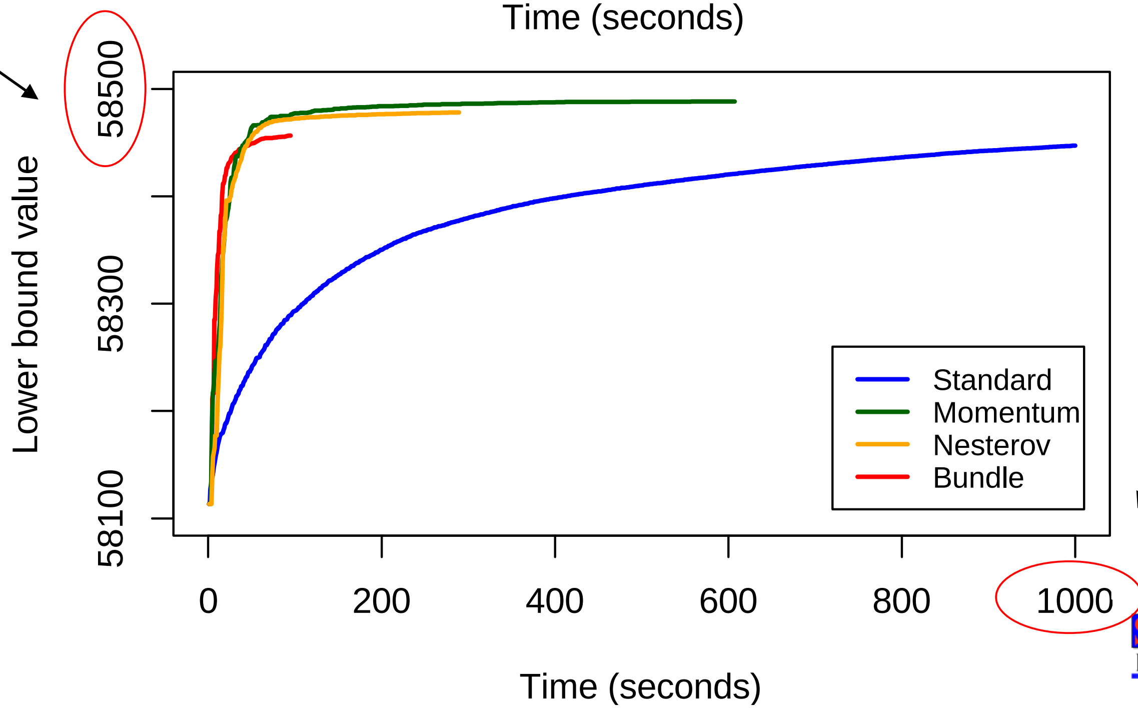
Augmented Lagrangian

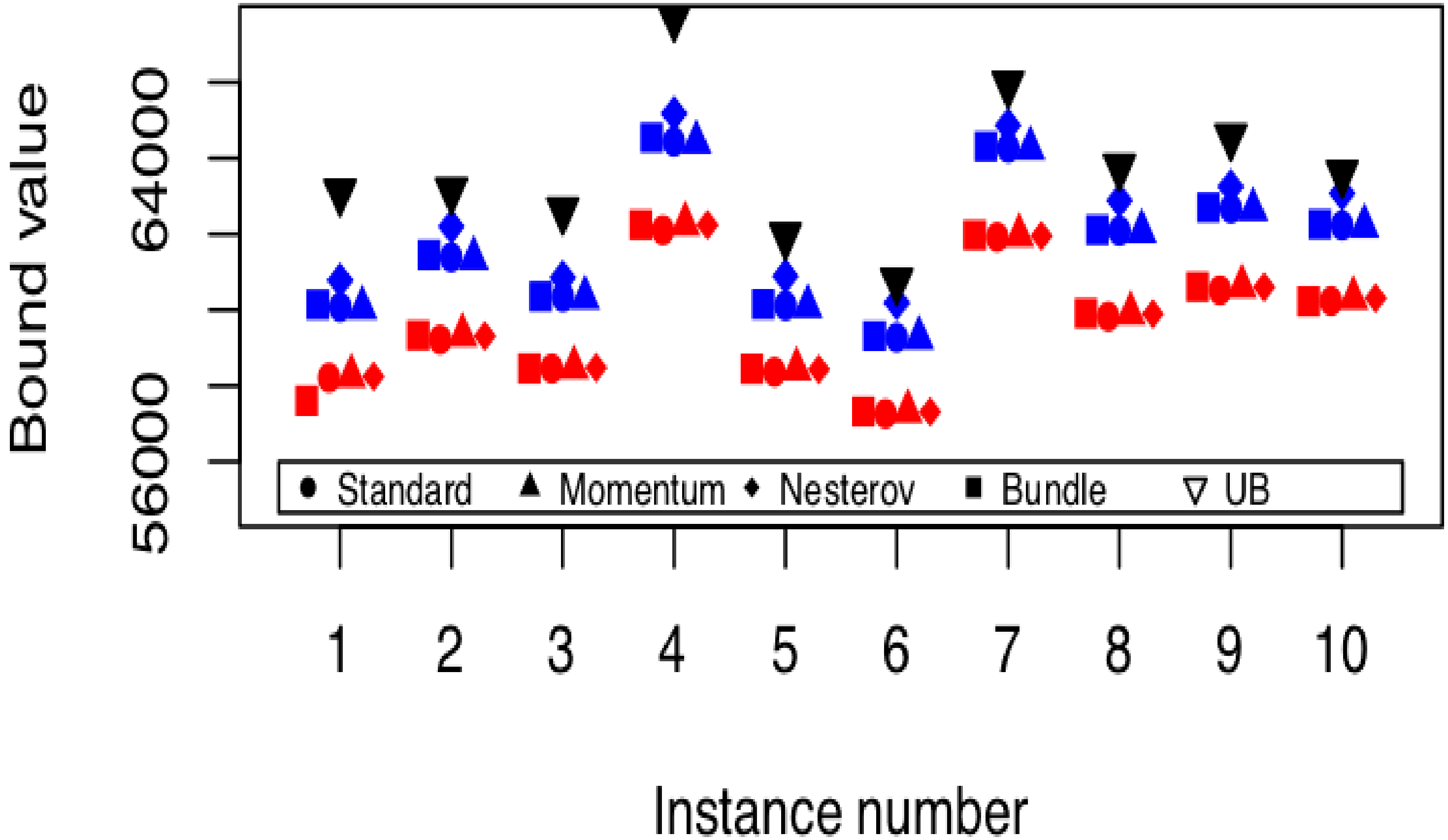


Note: converge to different LB values

Note: different solving times

Standard Lagrangian





	Duality gap (%)
1	3.68
2	1.51
3	2.83
4	3.73
5	1.72
6	0.94
7	1.64
8	1.38
9	2.03
10	0.83

Literature and references

- Oliveira et al. *A Lagrangean decomposition approach for oil supply chain investment planning under uncertainty with risk considerations* (2013)
- Dillon et al. *A two-stage stochastic programming model for inventory management in the blood supply chain* (2017)
- Civelek et al. *Blood platelet inventory management with protection levels* (2015)
- Kanerva. *A stochastic programming model for inventory management of blood products with age-specific demand* (2018)

QUESTIONS?