Der Blockplanungsansatz: Eine Fallstudienanwendung aus der Getränkeindustrie

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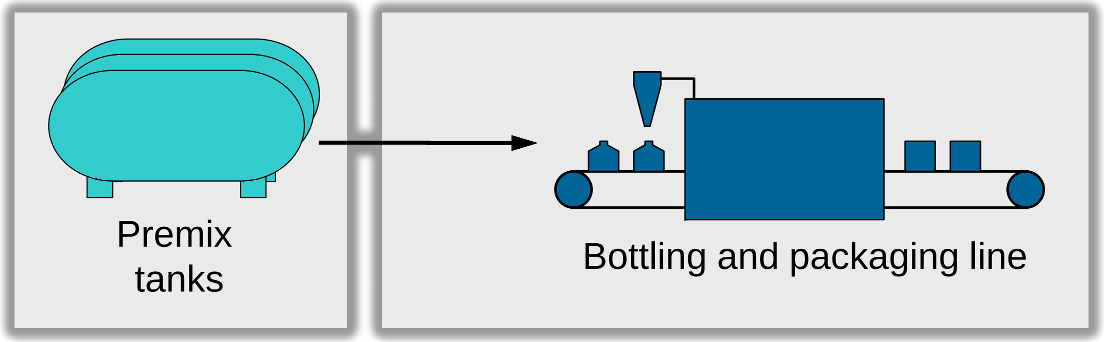
Outline

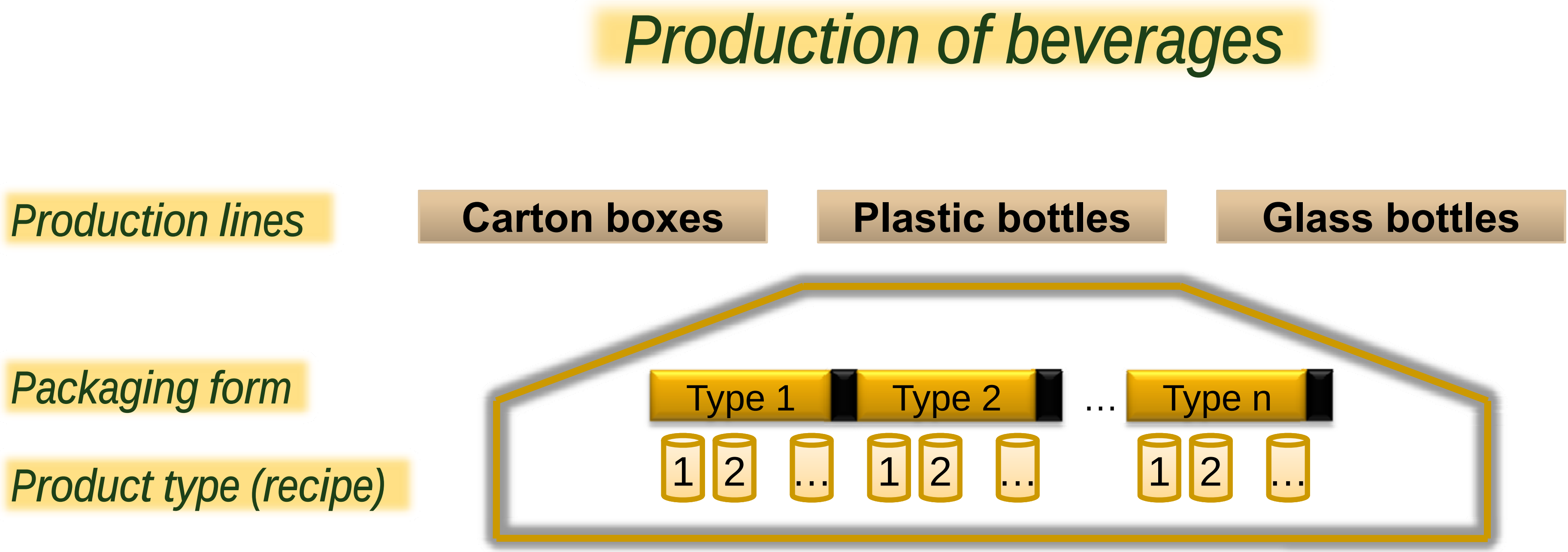
- Background: make-and-pack production
- Block planning principle
- Model formulation
- Computational results
- Conclusions

Make-and-pack production



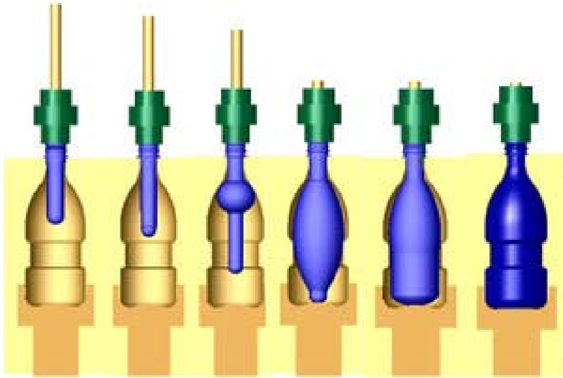
- To be found in the consumer goods industry, e.g. in the production of food, beverages, detergents, cosmetics.
- There is often a single bottleneck stage, e.g. a combined final bottling and packaging stage.
- Often highly capital-intensive production equipment used, e.g. investment of € 20 Mio for a bottling and packaging line.

Product-line assignment



Setup drivers

- **Major setup times** for changing the packaging format
  - e.g. 14 hours for setting up a stretch blow molding machine

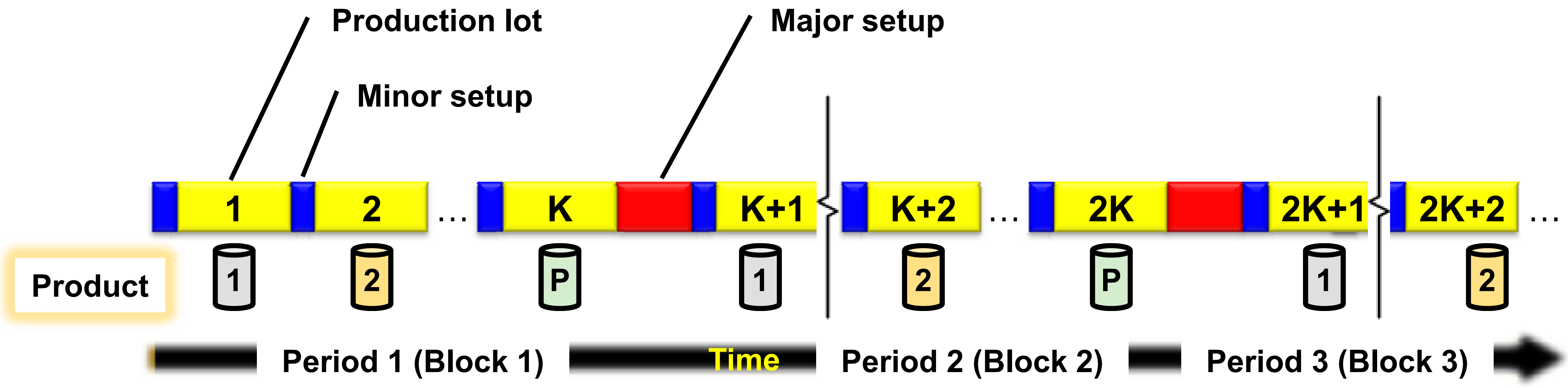


- **Minor setup times** for changing the product type (recipe)
  - e.g. 90 minutes for cleaning pipelines and adjusting tanks

Sources: http://www.horapolytech.com/ http://www.answers.com/topic/blow-molding

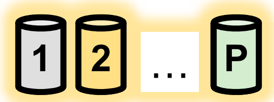
Basic block planning principle

- Natural production sequence, e.g. from light to dark



- Establishment of cyclical production patterns
- One block per week with flexible start-off time

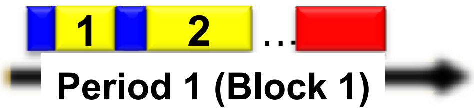
Key issues of block planning



- Given setup families and fixed setup sequences within a family

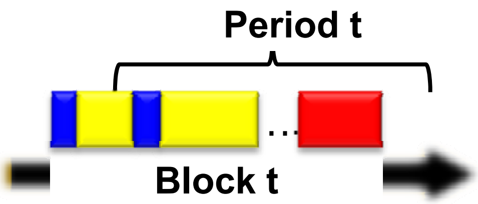
- Binary variables for product setups and variable lot sizes

- Each block is assigned to a macro-period, e.g. a week.



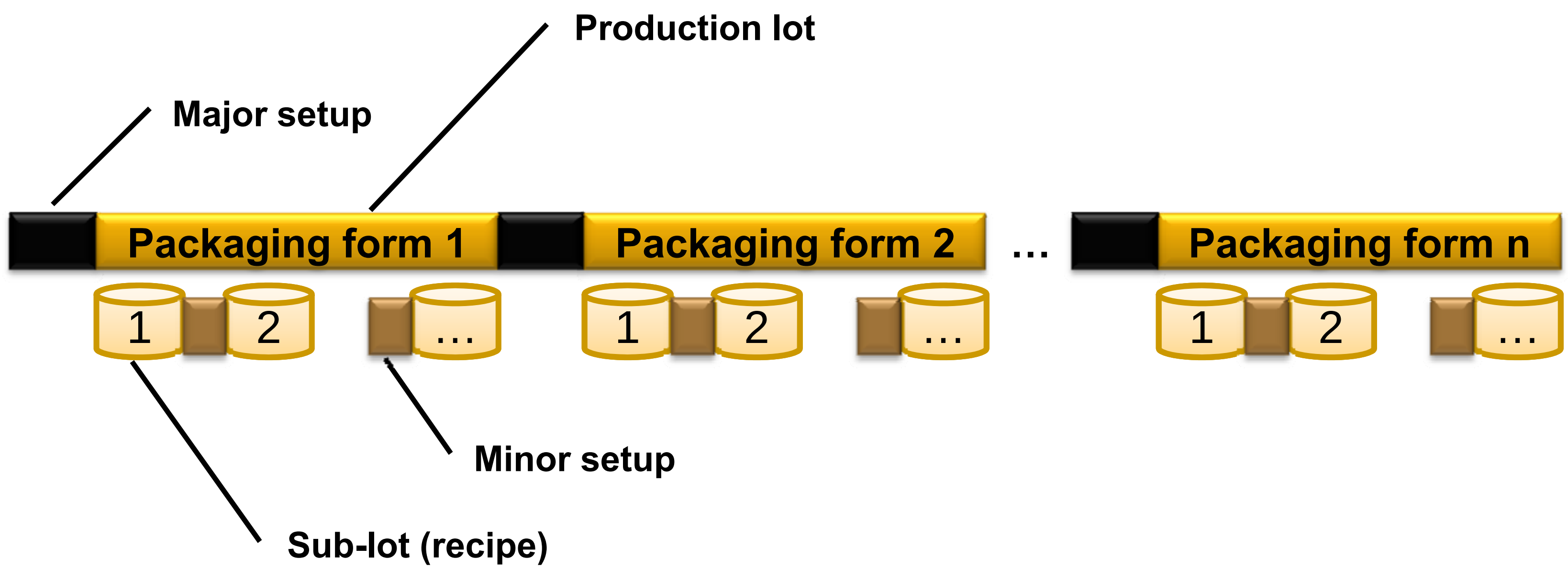
- Demand is assigned to micro-periods, e.g. days.

- The start and ending times of the blocks are variable, i.e. blocks may start in a previous period, but have to be completed before the end of the period they are assigned to.



- Objective function: Minimize total processing, setup and holding costs

Block pattern for a bottling line



- Applications in consumer goods industry:
  - yoghurt production (cf. Lütke Entrup et al. 2005)
  - hair dye production (cf. Günther et al. 2006)

MILP model formulation

$$\rho_{kl} \in \{0,1\}$$

$$\sigma_{lt} \in \{0,1\}$$

$$X_{kl} \geq 0$$

Production lots only activated if the block is set up

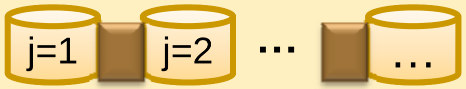
$$\sum_{k \in K_{lt}} \rho_{kl} \leq \sigma_{lt} \cdot |K_{lt}| \qquad \forall l \in L, t \in T$$

Lot size enforced to zero if no setup takes place

$$X_{kl} \leq M_{kl} \cdot \rho_{kl} \qquad \forall k \in K_l, l \in L$$

MILP model formulation

$$\pi_{jkl} \in \{0,1\}$$



$$x_{jkl} \geq 0$$

$$\rho_{kl} \in \{0,1\}$$

Sub-lots only activated if the production lot is set up

$$\sum_{j \in J_{kl}} \pi_{jkl} \leq \rho_{kl} \cdot |J_{kl}| \qquad \forall k \in K_l, l \in L$$

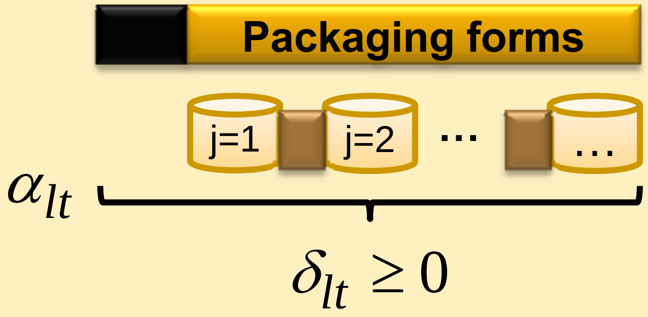
Sub-lot size enforced to zero if no setup takes place

$$x_{jkl} \leq m_{jkl} \cdot \pi_{jkl} \qquad \forall j \in J_{kl}, k \in K_l, l \in L$$

Allocation of production lot size between sub-lots

$$\sum_{j \in J_{kl}} x_{jkl} = X_{kl} \qquad \forall k \in K_l, l \in L$$

MILP model formulation



$$\rho_{kl} \in \{0,1\}$$

$$\pi_{jkl} \in \{0,1\}, \quad x_{jkl} \geq 0$$

Duration of a block

$$\delta_{lt} = \sum_{k \in K_{lt}} \left(S_l \cdot \rho_{kl} + \sum_{j \in J_{kl}} \left(s_l \cdot \pi_{jkl} + a_{jkl} \cdot x_{jkl} \right) \right) \qquad \forall l \in L, t \in T$$

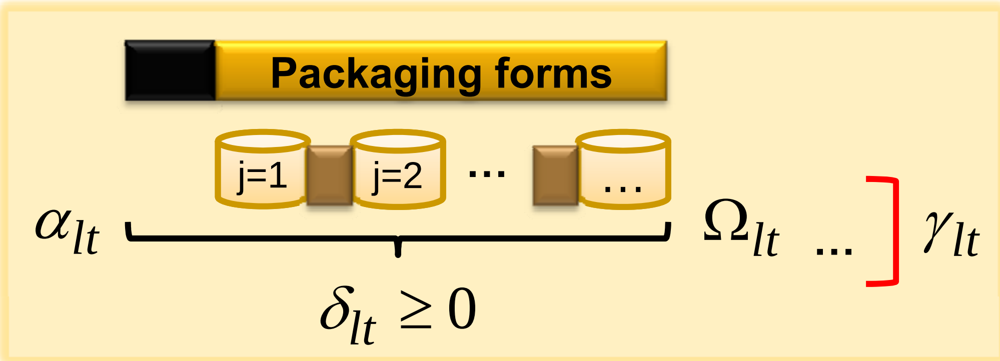
Start time of a block

$$\alpha_{lt} \geq \underline{\alpha}_{lt} \qquad \forall l \in L, t \in T$$

Succession of blocks

$$\alpha_{lt} \geq \alpha_{l,t-1} + \delta_{l,t-1} \qquad \forall l \in L, t = 2, \ldots, |T| \text{ with } \alpha_{l1} = 0$$

MILP model formulation



Blocks with production lots must be completed before the end of the week.

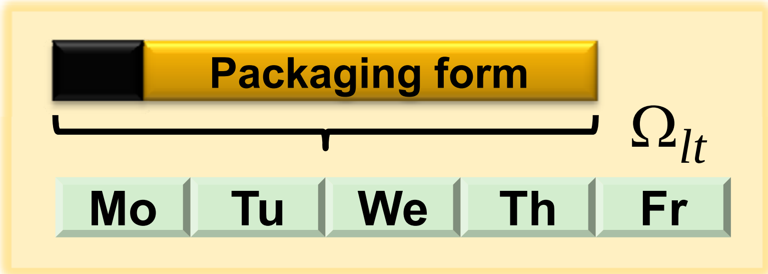
$$\alpha_{lt} + \delta_{lt} \leq \gamma_t \qquad \forall l \in L, t \in T$$

End time of production lots relative to the start time of the block

$$\Omega_{kl} = \Omega_{k-1,l} + S_l \cdot \rho_{kl} + \sum_{j \in J_{kl}} \left(s_l \cdot \pi_{kl} + a_{jkl} \cdot x_{jkl} \right)$$

$$\forall k \in K_{lt}, l \in L, t \in T \text{ with } \Omega_{0l} = \alpha_{lt}$$

MILP model formulation

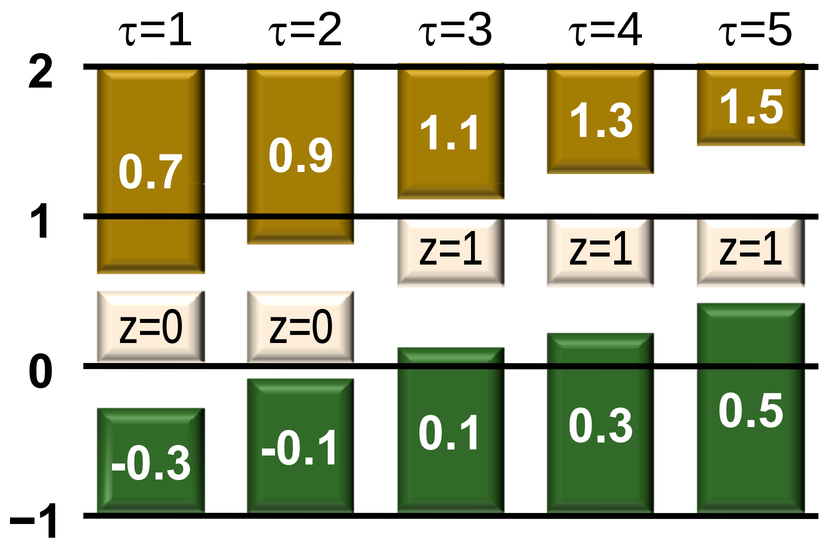


Heaviside function for tracing the daily completion of production lots

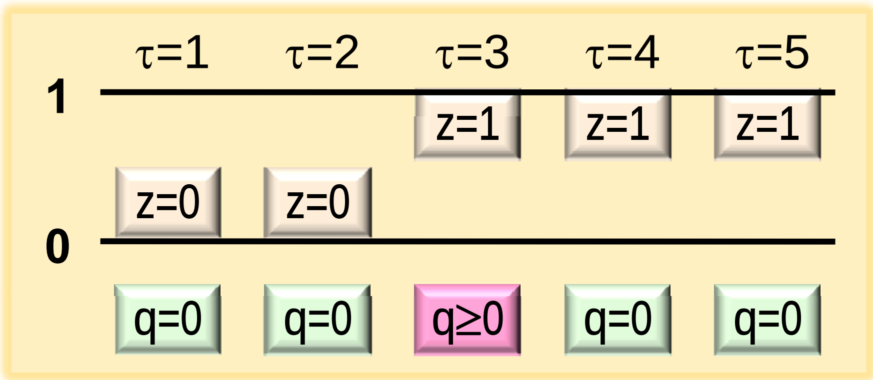
$$\frac{\tau-\Omega_{kl}}{d_{kl}} \le z_{kl\tau} \le 1+\frac{\tau-\Omega_{kl}}{d_{kl}}$$

$$\forall k \in K_l, l \in L, \tau \in D_{kl}$$

- Example: Ω = 2.5; τ = 1,…,5



MILP model formulation



Production output achieved when the heaviside variable switches from 0 to 1

$$\sum_{j\in J_{kl}} q_{jl\tau} \le M_{kl}\cdot\left(z_{kl\tau} - z_{kl,\tau-1}\right) \qquad \forall k\in K_l, l\in L, \tau\in D_{kl} \text{ with } z_{kl\underline{d}_{kl}} = 0$$

$$\sum_{\tau\in D_{kl}} q_{jl\tau} = x_{jkl} \qquad \forall j\in J_{kl}, k\in K_l, l\in L$$

Inventory balances for each product and day

$$F_{p\tau} = F_{p,\tau-1} + \sum_{l\in L_p}\sum_{j\in J_{pl}} q_{jl\tau} - E_{p\tau} \qquad \forall p\in P, \tau\in D \text{ with } F_{p0} = \text{given}$$

MILP model formulation

Objective function: Minimize total costs for production, clean-outs, major and minor setups, and inventory holding

$$\min \left[\begin{array}{l} \sum_{l \in L} \sum_{t \in T} c_l^{Prod} \cdot \delta_{lt} + \sum_{l \in L} \sum_{t \in T} c_l^{Clean} \cdot \sigma_{lt} + \sum_{l \in L} \sum_{k \in K_l} c_l^{Maj} \cdot \rho_{kl} + \\ \sum_{l \in L} \sum_{k \in K_l} \sum_{j \in J_{kl}} c_l^{Min} \cdot \pi_{jkl} + \sum_{p \in P} \sum_{\tau \in D} c_p^{Inv} \cdot F_{p\tau} \end{array} \right]$$

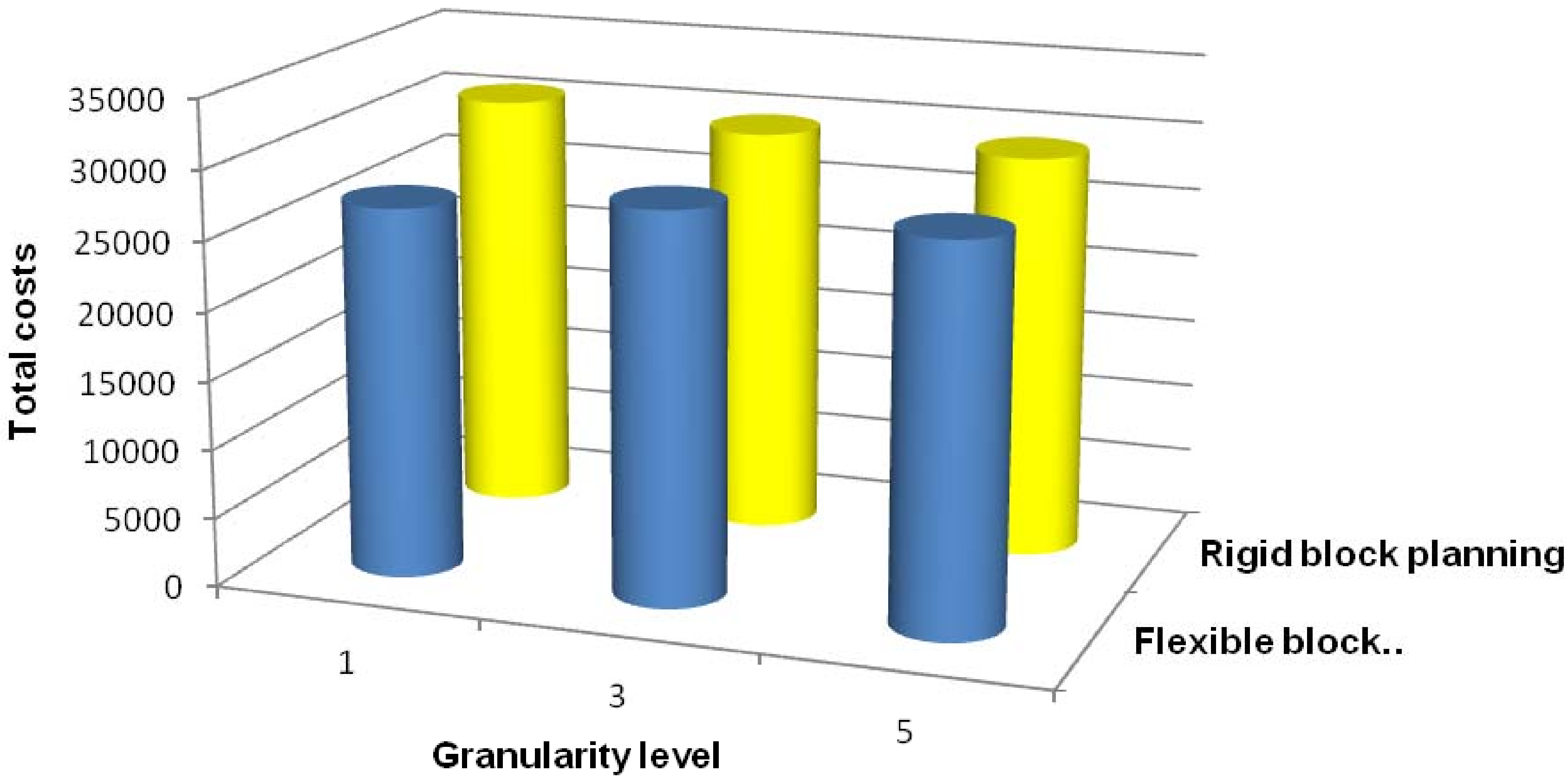
Computational Experiments

- Product-line assignments in the FRUTADO case study

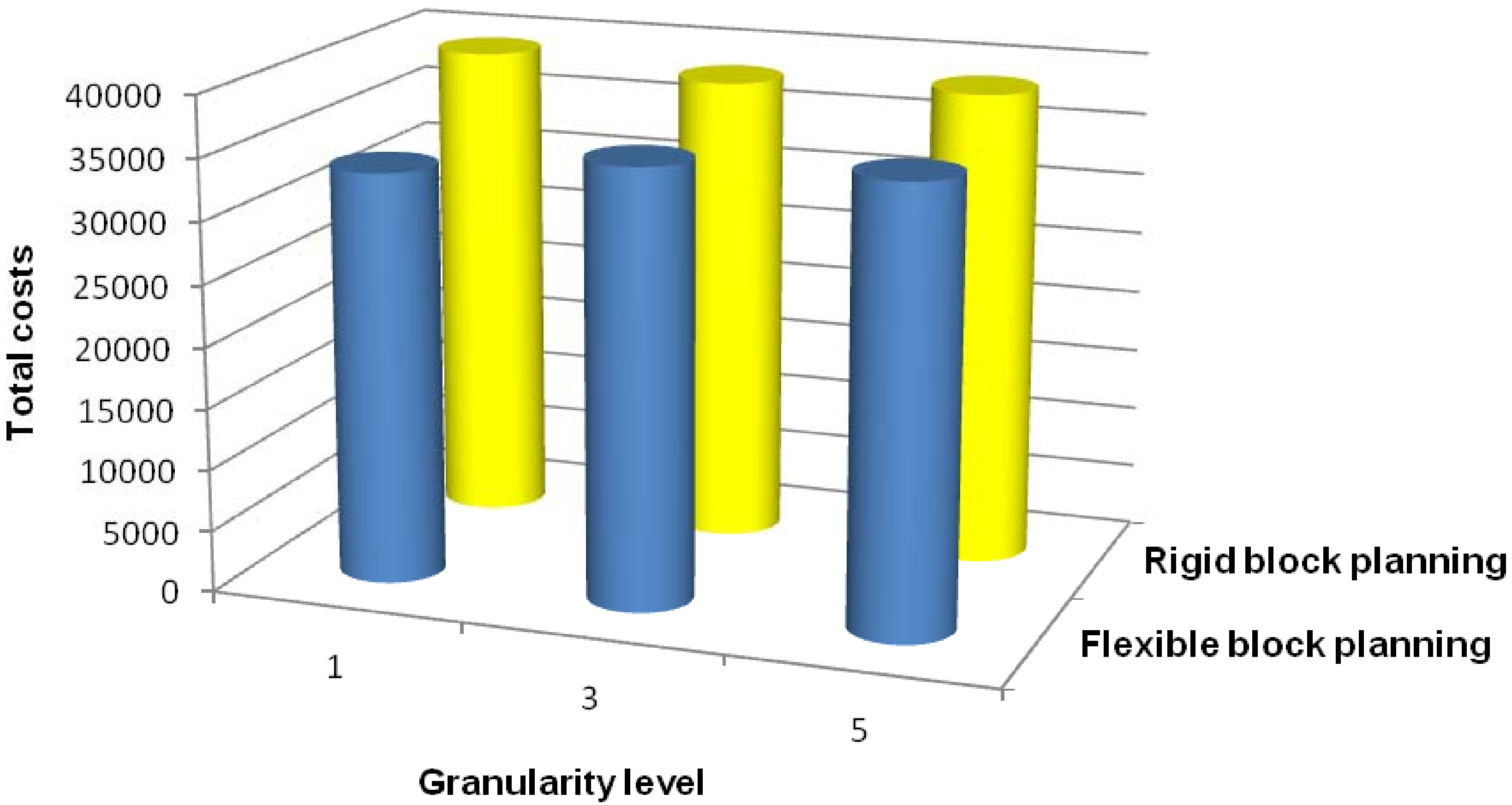
Experimental setting

- Implementation using ILOG OPL Studio 6.1.1 with CPLEX 11.2
- PC: Dual Xeon Quad Core 2.5 GHz processor and 4 GB RAM
- Two capacity load scenarios: 75% and 90%
- Three demand granularities: 1 (low), 3 (medium) ,5 (high)
- Daily demand randomly assigned to DCs
- All other data taken from the FRUTADO case
- Comparison of rigid vs. flexible block planning, i.e. one-week vs. two-week time window per block

Numerical results: 75% capacity load scenario



Numerical results: 90% capacity load scenario



CPU times for an extended model formulation

- 75% capacity load

Granularity level	CPU time (flexible / rigid block planning) in sec	
	min	max
1	4 / 5	7 / 358
3	10 / 9	102 / 88
5	10 / 16	69 / 109

- 90% capacity load

Granularity level	CPU time (flexible / rigid block planning) in sec	
	min	max
1	3 / 8	6 / 1991
3	16 / 38	56 / 1080
5	70 / 94	983 / 560

Conclusion

- To support block planning in a make-and-pack environment a novel MILP model formulation based on a continuous representation of time has been developed.
- The model formulation exploits human expertise on the definition of setup families and the sequence of production runs within a block.
- The model considers the daily assignment of demand elements.
- Flexible block planning appears to be superior compared to rigid block planning.
- MILP modelling provides a flexible framework to integrate many application-specific features.