Simulative Throughput Calculation for Storage Planning

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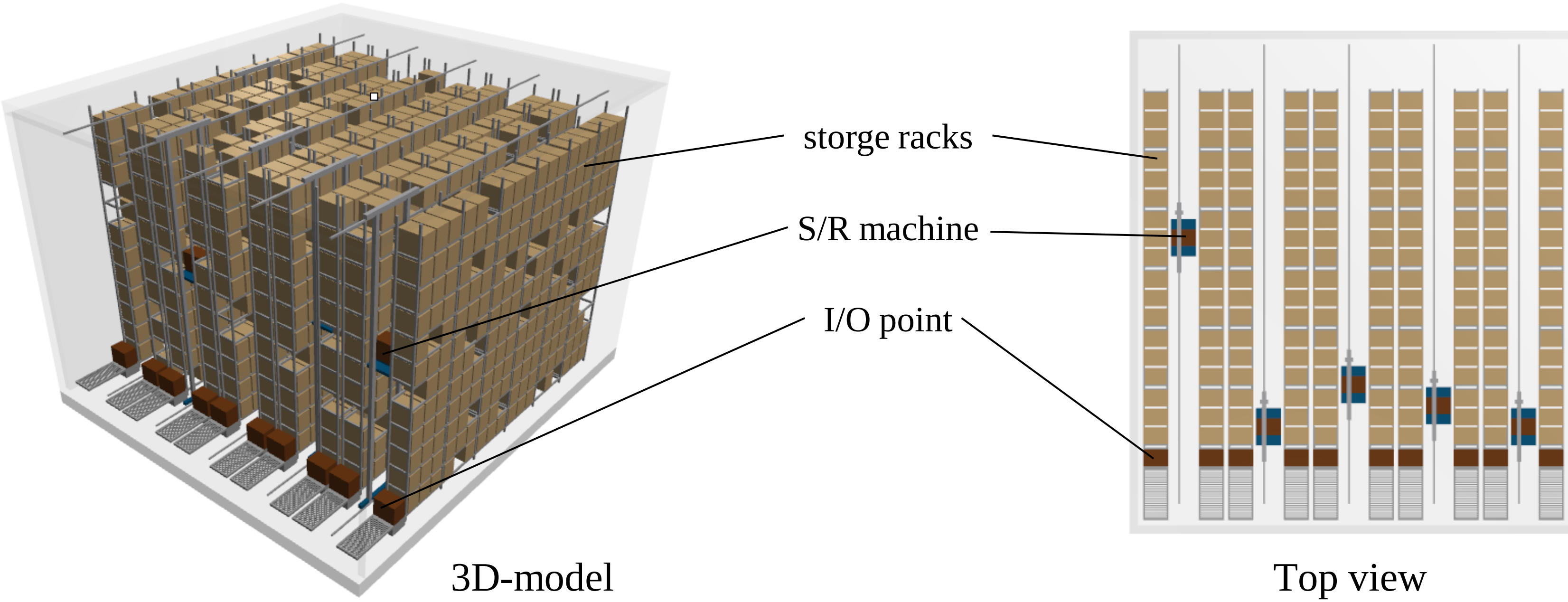
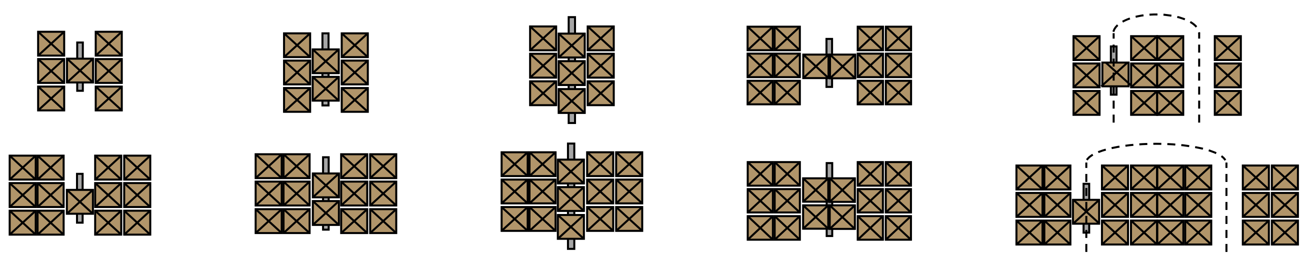
Automated storage and retrieval systems



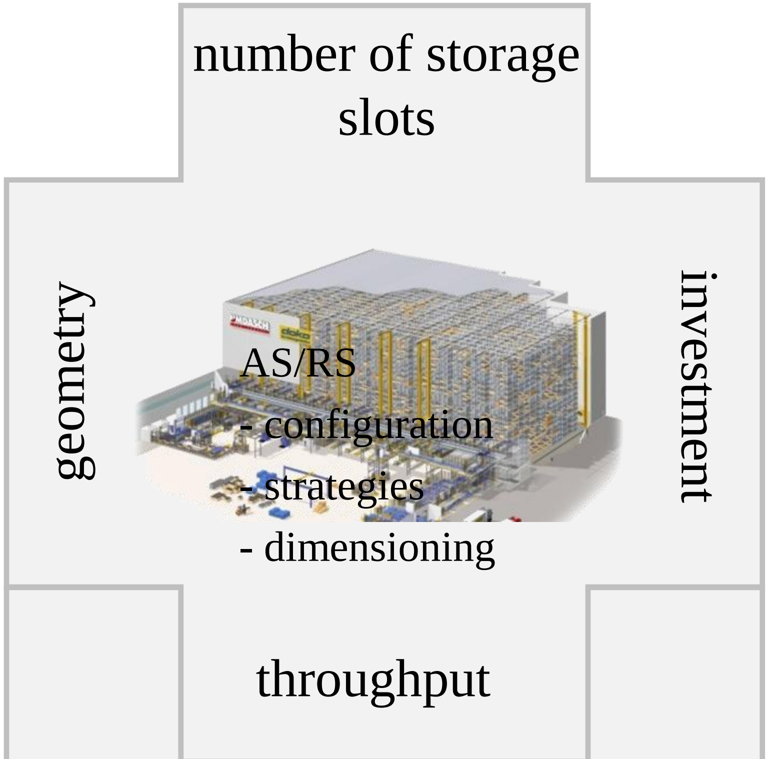
The design of an AS/RS depends on

- configuration
- strategies
- dimensioning



Planning and throughput calculation

- Planning depends on a variety of parameters
- The interdependent key performance indicator (KPI) are
  - number of storage slots
  - geometry
  - throughput
  - and investment
- There is no exact mathematical model for this decision making problem
- The sequential planning process is still largely manually and considers the KPI separately
- Finding the optimum for the system's performance and the cost is difficult and time consuming



- The throughput calculation is the most complex part of the planning
- There is a lack of a uniform calculation model for different design variants

Agenda

1) Unified approach for the throughput calculation
2) Calculation of cycle time components
3) Modeling
   a. I/O-travel time
   b. Travel between times
4) Comparison with analytical models
5) Synthesis of cycle times
6) Integration of the model in a planning tool
7) Summary and conclusions

Unified approach for the throughput calc.

Steps:

- pickup of a load
- I/O station → a storage shelf (P1)
- deposit of the load
- storage shelf (P1) → retrieval shelf (P2)
- pickup of the load
- retrieval shelf (P2) → I/O station
- deposit of the load

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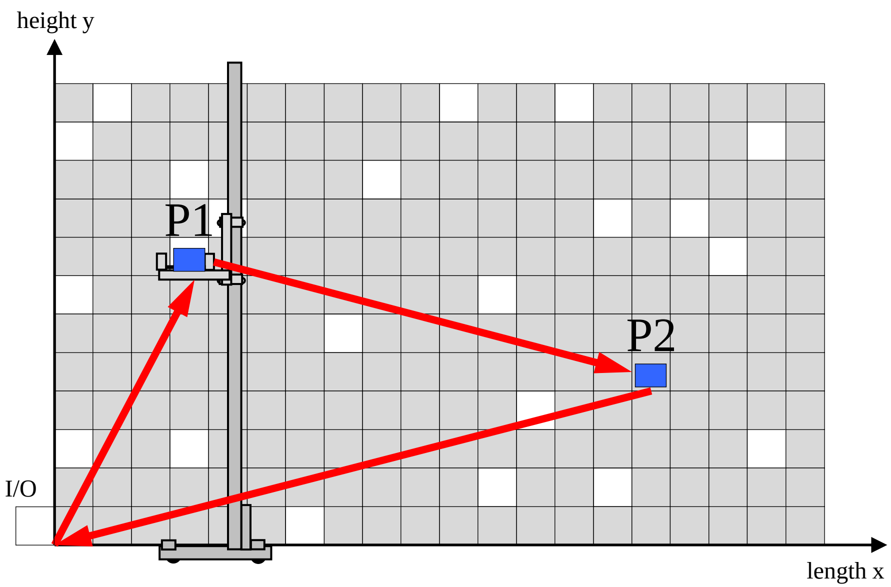


combined command cycle

Cycle time components:

- I/O travel time $t_{I/O,P}$: This is the average travel time from an I/O point (which is usually at the edge of the rack) to any storage shelf in the rack or vice versa
- travel between time $t_{P,P}$: This is the average travel time from any storage shelf in the rack to another storage shelf in the rack
- Different strategies and configurations require a variety of different time components to describe a whole command cycle

Calculation of cycle time components

- The Monte Carlo simulation (MC simulation) method is suitable for the calculation of a large amount of different cycle time components
- In comparison to analytical models the MC simulation modeling is more simple and less restrictive. It is possible to represent various storage strategies. The computation time is longer, the results more accurate

Calculation steps:

1. initialization of the two racks representing an aisle
2. starting point $P_S = (x_S, y_S)$ and end point $P_E = (x_E, y_E)$ are determined
3. The travel time between the two points is then calculated repeatedly (resulting measured travel time samples are $t_{T1}, \dots, t_{Tn}$, a random sample from t_T)
4. The arithmetic mean approximates the expected value of the cycle time component t_{ctc}

Termination criteria:

1. convergence of the arithmetic mean value $x_{Convergence}$

$$\left| \frac{1}{n-1000} \sum_{i=1}^{n-1000} t_{T\,i} - \frac{1}{n} \sum_{i=1}^{n} t_{T\,i} \right| \leq x_{Convergence}$$

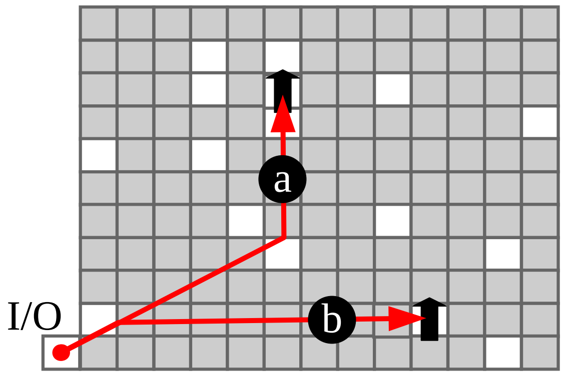
2. confidence interval $x_{Confidence}$

$$2 \cdot z_{\left(1-\frac{\alpha}{2}\right)} \cdot \sqrt{\frac{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(T_i - \frac{1}{n} \sum_{i=1}^{n} t_{T\,i} \right)^2}{n}} \leq x_{Confidence}$$

- the termination criteria are calculated after every 1.000 samples

I/O-travel time

Principle:

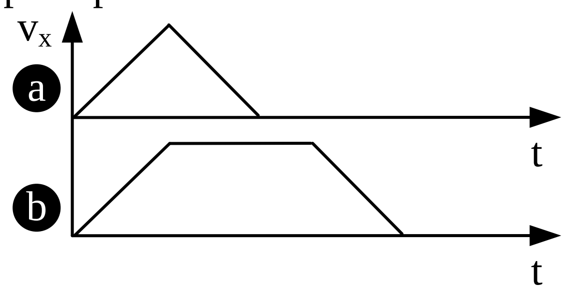


rack section

Key:

- occupied shelf
- storage shelf
- empty shelf
- removal shelf

Speed profiles:



Modeling:

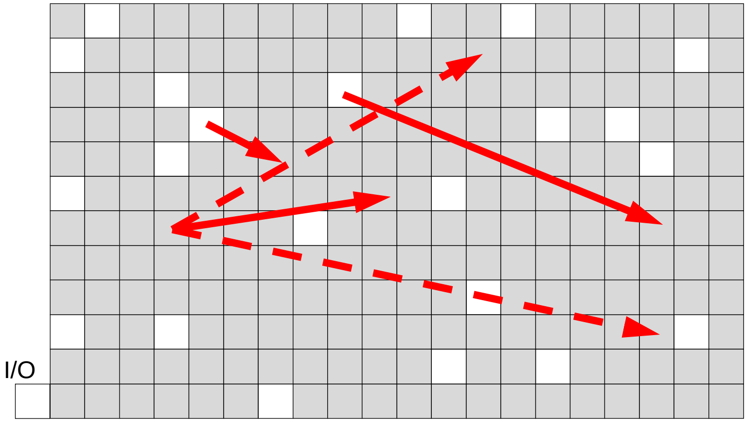
- The I/O point P_S is normally located in the corner of the rack
  P_S → Fixed location
- The end point P_E is either a storage or a retrieval shelf and randomly distributed across the surface of the rack
  P_E → Random location

Calculation of a travel time:

1. The travel time t_S depending on the travel distance s is derived from the laws of motion for constant velocity and constant acceleration
2. Depending on the distance s different speed profiles are possible
3. The travel time t_T is given by the longer duration of the simultaneous travels t_{SX} and t_{XY}

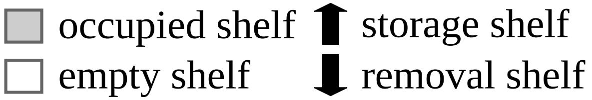
Travel between times

Principle:



rack section

Key:



Modeling of different types of travel between times:

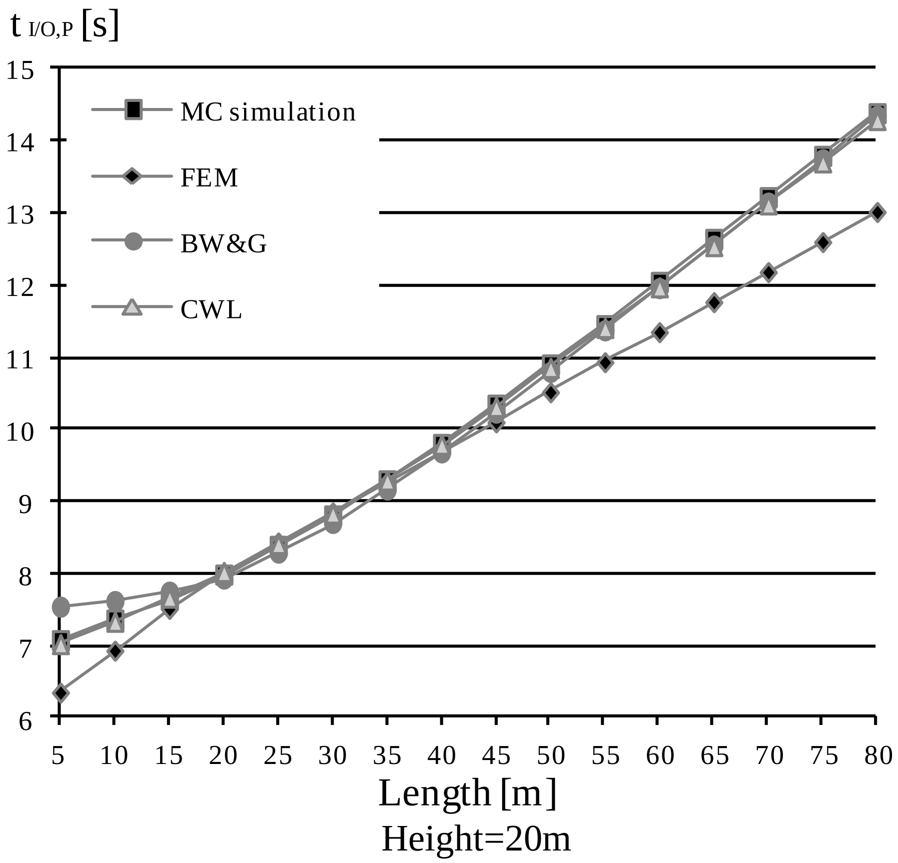
- Travel form the storage shelf to the retrieval shelf with random selection of the storage shelf
  P_S → Random location
  P_E → Random location
- Travel form the storage shelf to the retrieval shelf with selection of the storage shelf near the retrieval shelf
  P_S → Random location
  P_E → nearest possible location to P_S
- Travel between storage shelves and retrieval shelves with travel path optimization (S/R machine is able to handle more than one load contemporary)
  P_S → Random location
  P_E → nearest of n random locations

Comparison with analytical models

- kinematic characteristics of the S/R machine:

	S/R machine
v_x	4 m/s
a_x	1 m/s²
v_y	2 m/s
a_y	1 m/s²

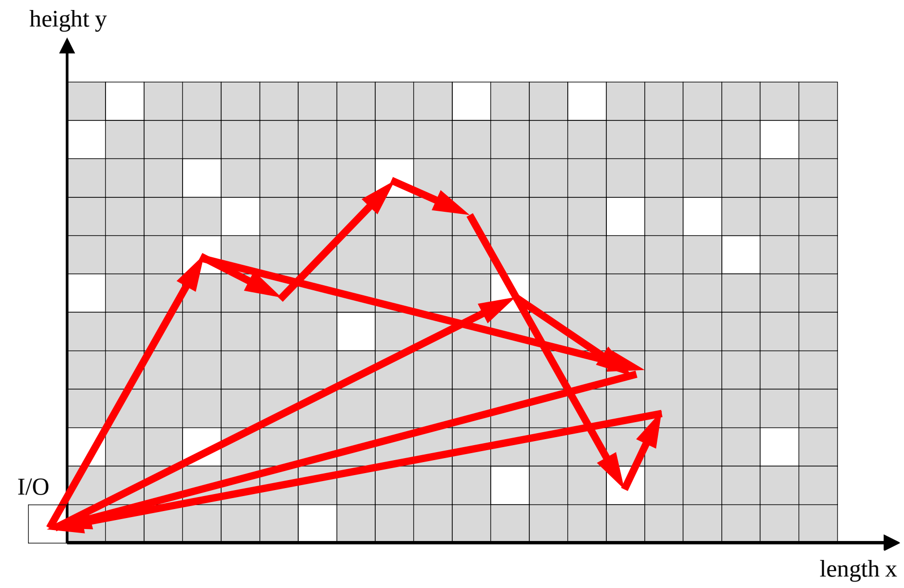
- FEM: FEM 9.851 (2003) a practice-related directive based on a stochastic analytical travel distance model → best accuracy is achieved when the shape factor *b = 1*. The model is valid within the limits *2 ≤ b ≤ 0.5*
- BW&G: Bozer and White (1984) and Gudehus (1972) a stochastic analytical travel time model → valid independently of the shape factor *b*
- CWL: Chang et al. (1995) a further development of the model of Bozer and White → time for acceleration and deceleration is included in the model



Synthesis of cycle times

Configuration parameter	Specifications		
Depth of the rack	Single-deep (sd)	Double-deep (dd)	
Number of load handling devices on a S/R machine	1	2	3
Width of the load handling device	Single-width	Double-width	
S/R machine type	Fixed-aisle	Multi- aisles	
Position of the I/O point	In the corner of the rack	Staggeredin x- or y-direction	

Storage strategy	Specifications		
Type of command cycle	Single storage cycle	Single retrieval cycle	Combined cycle
Selection of storage shelf	Random selection	Near the retrieval shelf	Zoning
Selection of relocation shelf	Random selection	Near the retrieval shelf	Zoning
Selection of retrieval shelf	Strict FIFO	Alleviated FIFO	
I/O point strategy	Separate pick-up and deposit	Parallel pick-up and deposit	
Sequence strategy	No / Random sequence	Travel path optimization	



- Example1: t_{CT}=*63.33s*
- Example2: t_{CT}=*57.86s* (+9.5%)
- Example3: t_{CT}=*112.57s* (+68.8%)

Integration of the model in a planning tool

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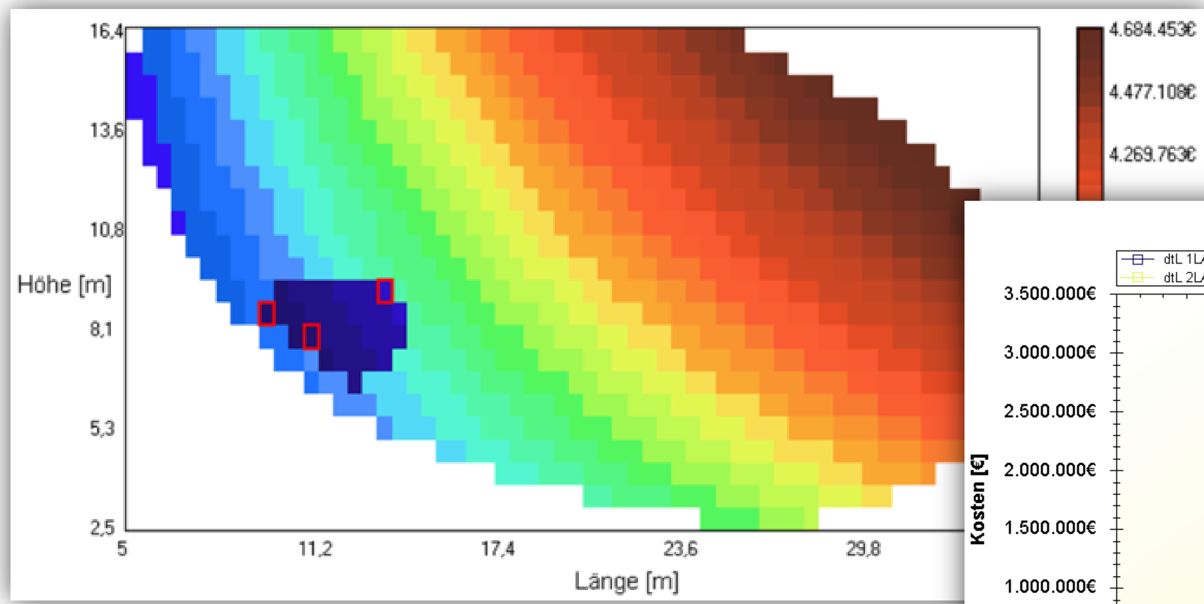
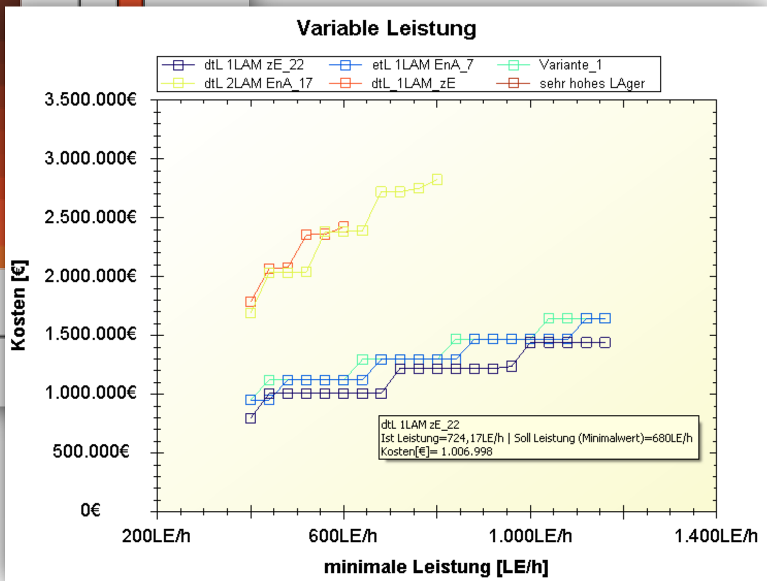
- In addition to the presented model for throughput calculations, own models for storage capacity, building geometry and investment characteristics were developed and merged into the database-aided software tool LSP
- The software allows mathematical optimization for the dimensioning of design variants and therefore the easy comparison of the latter





Summary and conclusions

- The throughput calculation of many different practice-relevant storage configurations and storage strategies is covered with a unified approach
- Specific command cycles are synthesized from different cycle time components
- They represent typical movements and load handling steps of a S/R machine
- The different cycle time components can be modeled and calculated with Monte Carlo simulation
- The results are congruent to the expected behavior of analytical models and reproduce reality very closely. Advantages over analytical models consist in the discrete modeling the good reproduction of the different speed profiles of the S/R machine. These advantages result in more general validity and a better accuracy.
- The approach has been implemented in a computer routine and merged with other models in a database-aided software tool. This allows mathematical optimization for the dimensioning of design variants

Thank you for your attention!

Vielen Dank für Ihre Aufmerksamkeit!

Je vous remercie de votre attention!

Gracias por su atención!

感谢您的关注

Grazie per la vostra attenzione!

ご清聴ありがとう

Благодарю вас за внимание!

Dank u voor uw aandacht!

Tack för er uppmärksamhet!

σας ευχαριστώ για την προσοχή σας!

İlginiz için teşekkür ederim!

Děkuji vám za pozornost!

관심에 감사드립니다

Takk for oppmerksomheten!

Dziękuję za uwagę!

Tak for din opmærksomhed!

Obrigado por sua atenção!