Simulative Throughput Calculation for Storage Planning

Atz Thomas, Lantschner Daniel, Prof. Dr. Günthner Willibald A.
Authors and Institute

Atz Thomas, M.Sc.
Research Assistant

Lantschner Daniel, M.Sc.
Research Assistant

Prof. Dr. Günthner
Willibald A. Head of the Institute

FML – Institute of Materials Handling, Material Flow, Logistics
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

number of storage slots

throughput

geometry

investment

AS/RS
- configuration
- strategies
- dimensioning

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

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 $t_{T1}, ..., t_{Tn}$, 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 $x_{Confidence}$
   \[
   2 \cdot z_{\left( 1 - \frac{\alpha}{2} \right)} \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left( T_i - \frac{1}{n} \sum_{i=1}^{n} t_{T_i} \right)^2} \leq x_{Confidence}
   \]
3. The termination criteria are calculated after every 1.000 samples.
I/O-travel time

Principle:

Key:
- occupied shelf
- empty shelf
- storage shelf
- removal shelf

Speed profiles:

Modeling:
- The I/O point $P_S$ is normally located in the corner of the rack
  $P_S \rightarrow$ Fixed location
- The end point $P_E$ is either a storage or a retrieval shelf and randomly distributed across the surface of the rack
  $P_E \rightarrow$ 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 $t_{XY}$
Modeling of different types of travel between times:

- Travel from the storage shelf to the retrieval shelf with random selection of the storage shelf
  \[ P_s \rightarrow \text{Random location} \]
  \[ P_e \rightarrow \text{Random location} \]

- Travel from the storage shelf to the retrieval shelf with selection of the storage shelf near the retrieval shelf
  \[ P_s \rightarrow \text{Random location} \]
  \[ P_e \rightarrow \text{nearest possible location to } P_s \]

- Travel between storage shelves and retrieval shelves with travel path optimization (S/R machine is able to handle more than one load contemporary)
  \[ P_s \rightarrow \text{Random location} \]
  \[ P_e \rightarrow \text{nearest of } n \text{ random locations} \]

Key:
- occupied shelf
- empty shelf
- storage shelf
- removal shelf

Principle:
- Speed profiles:
  - removal shelf
  - storage shelf
  - full shelf
  - occupied shelf

Key:
- I/O rack section
Comparison with analytical models

- Kinematic characteristics of the S/R machine:
  
<table>
<thead>
<tr>
<th></th>
<th>S/R machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_x$</td>
<td>4 m/s</td>
</tr>
<tr>
<td>$a_x$</td>
<td>1 m/s²</td>
</tr>
<tr>
<td>$v_y$</td>
<td>2 m/s</td>
</tr>
<tr>
<td>$a_y$</td>
<td>1 m/s²</td>
</tr>
</tbody>
</table>

- FEM: FEM 9.851 (2003) a practice-related directive based on a stochastic analytical travel distance model $\rightarrow$ best accuracy is achieved when the shape factor $b = 1$. The model is valid within the limits $2 \leq b \leq 0.5$

- BW&G: Bozer and White (1984) and Gudehus (1972) a stochastic analytical travel time model $\rightarrow$ valid independently of the shape factor $b$

- CWL: Chang et al. (1995) a further development of the model of Bozer and White $\rightarrow$ time for acceleration and deceleration is included in the model
Synthesis of cycle times

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

<table>
<thead>
<tr>
<th>Storage strategy</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of command cycle</td>
<td>Single storage cycle</td>
</tr>
<tr>
<td>Selection of storage shelf</td>
<td>Random selection</td>
</tr>
<tr>
<td>Selection of relocation shelf</td>
<td>Random selection</td>
</tr>
<tr>
<td>Selection of retrieval shelf</td>
<td>Strict FIFO</td>
</tr>
<tr>
<td>I/O point strategy</td>
<td>Separate pick-up and deposit</td>
</tr>
<tr>
<td>Sequence strategy</td>
<td>No.</td>
</tr>
</tbody>
</table>

- Example 1: $t_{CT} = 63.33s$
- Example 2: $t_{CT} = 57.86s$ (+9.5%)
- Example 3: $t_{CT} = 112.57s$ (+68.8%)
Integration of the model in a planning tool

- 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!
ご清聴ありがとうございます
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!
감사합니다!
Takk for oppmerksamheten!
Dziękuję za uwagę!
Tak for din opmærksomhed!
Obrigado por sua atenção!