12 Shuttle-Based Storage and Retrieval Systems with Robotic Order-Picking Shuttle Carrier

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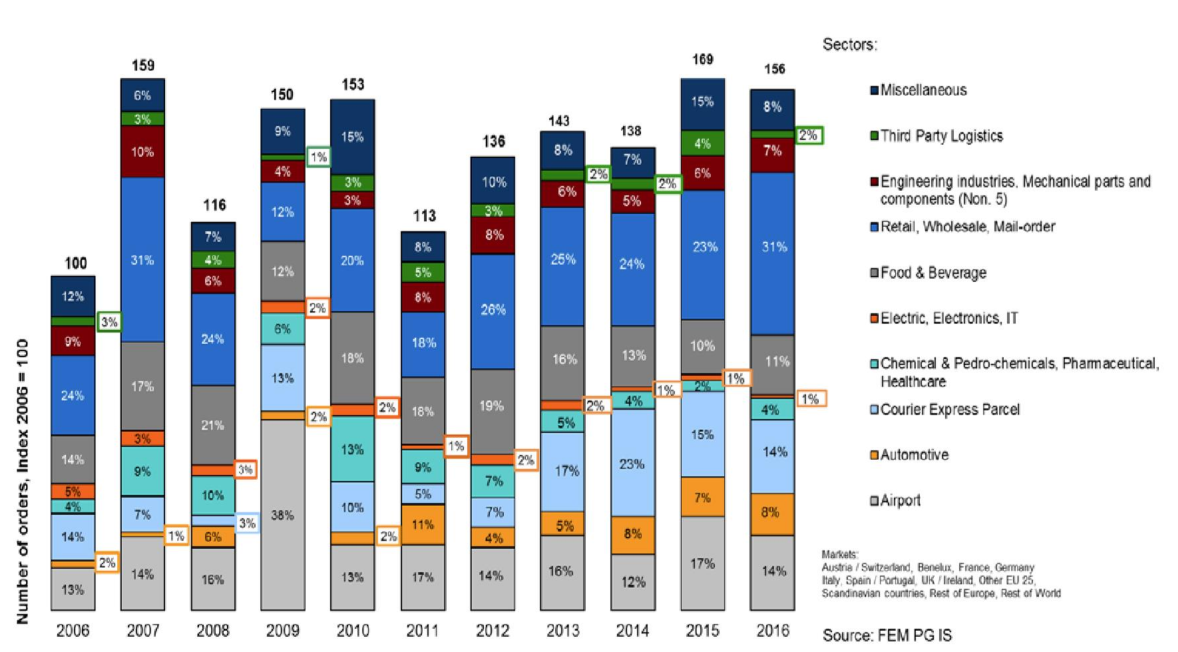
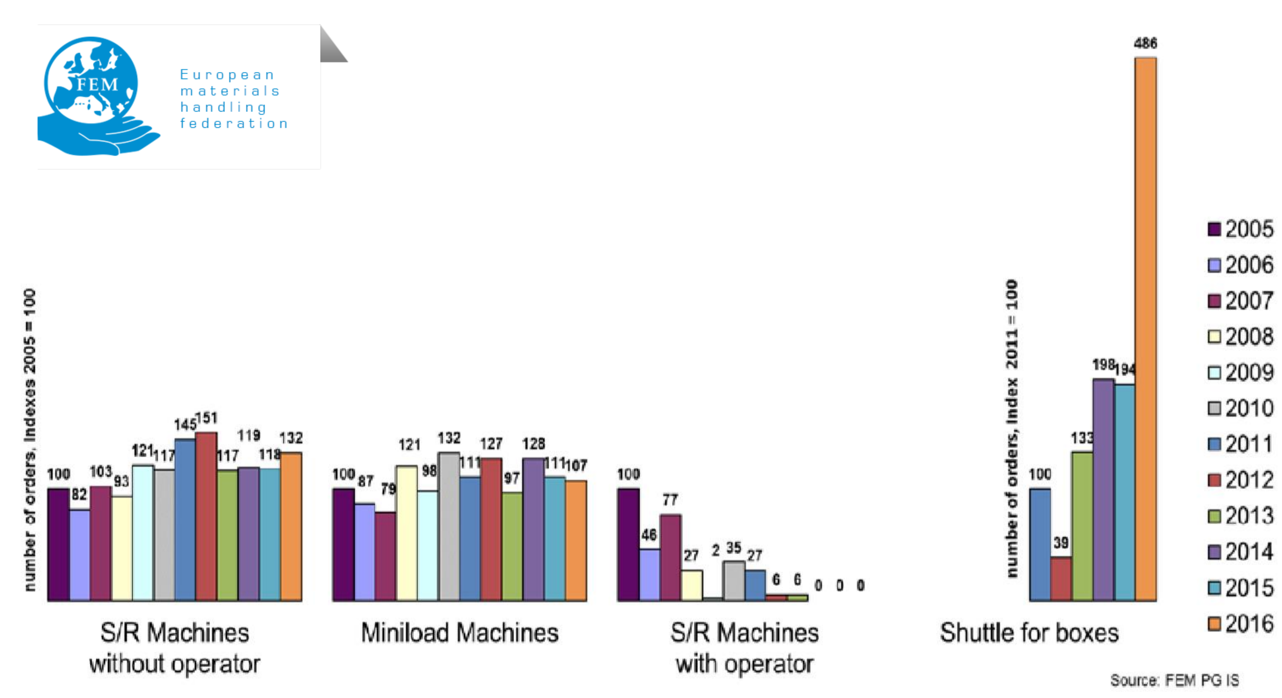
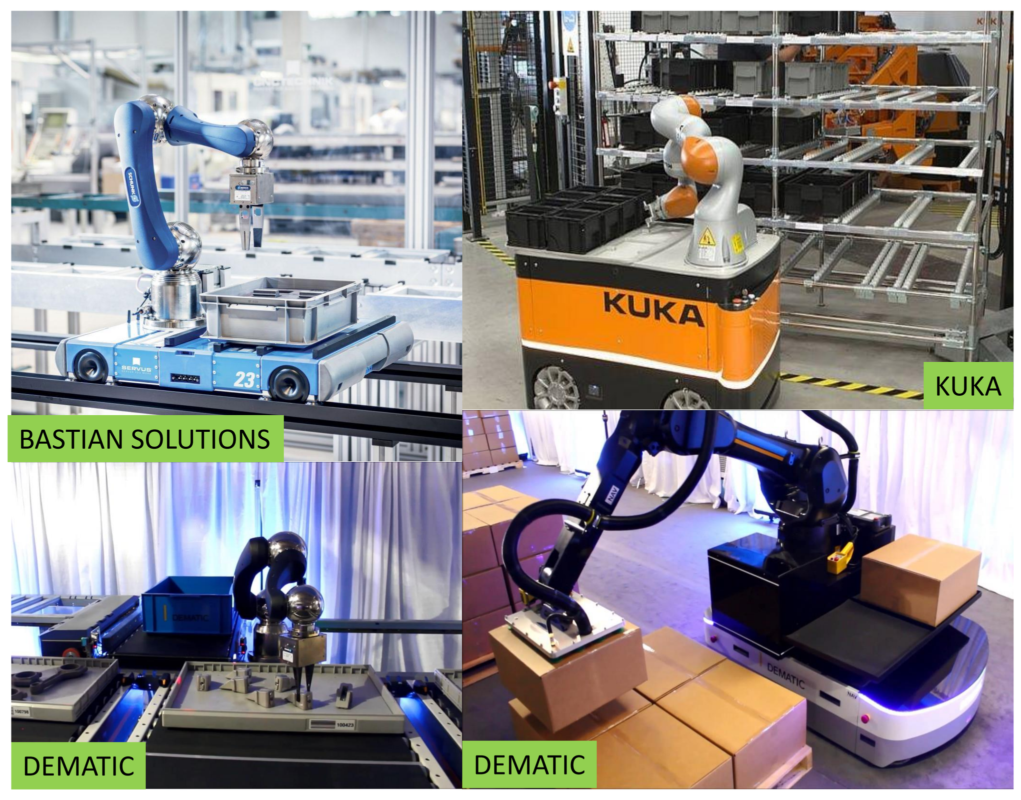
Motivation

FEM Statistics – Order Intake Intralogistics Systems

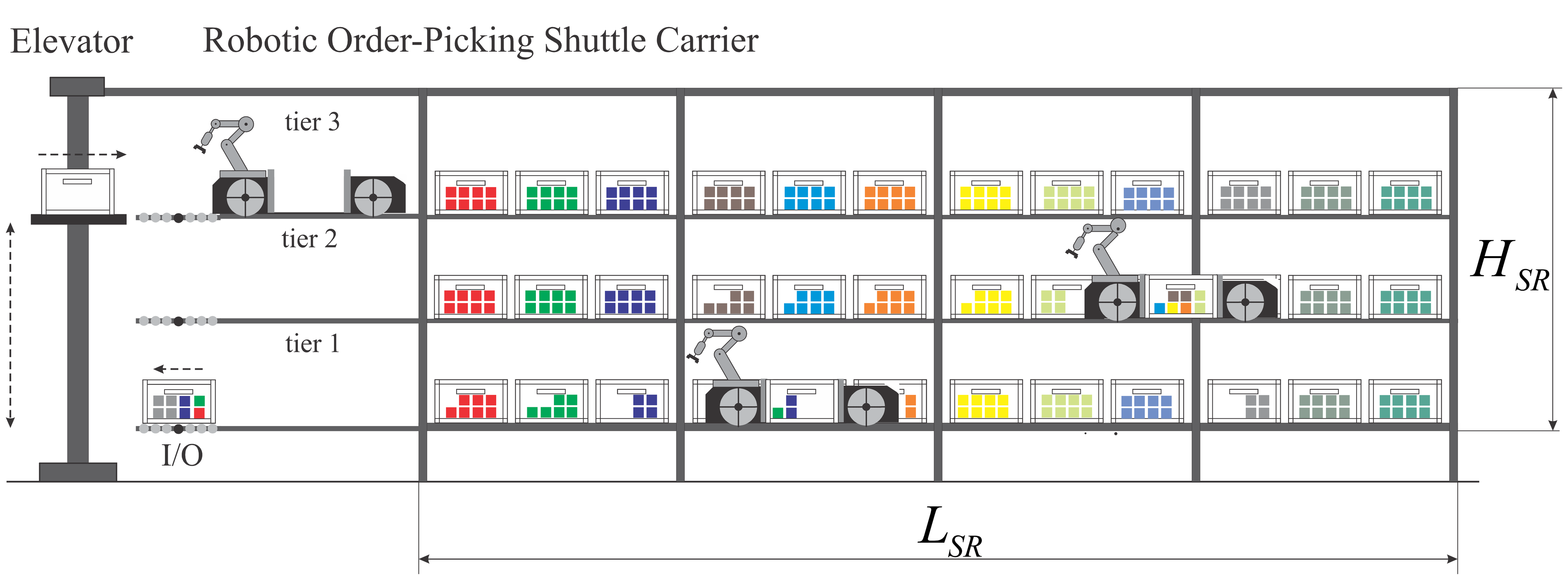


Statistics for S/R Machines Results





Robotic Order-Picking Shuttle Carrier



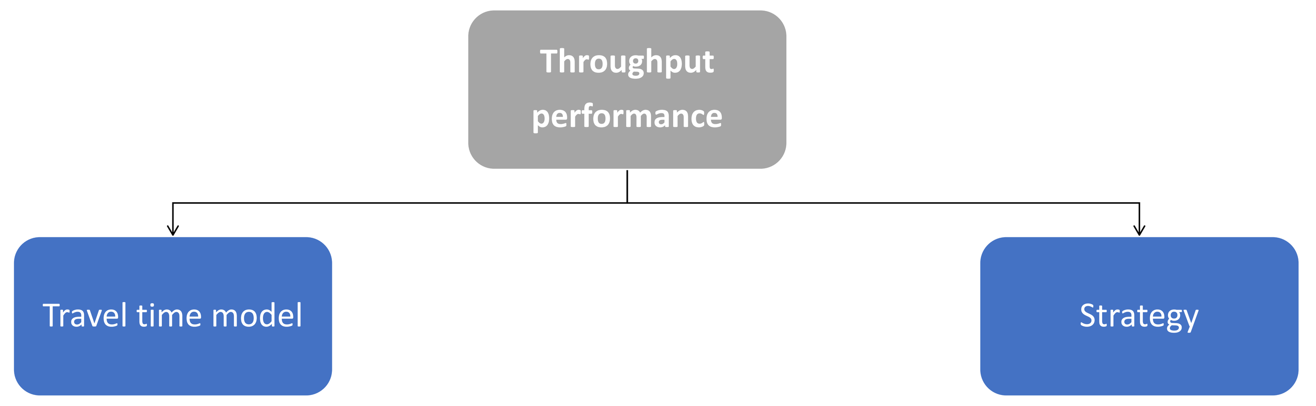
SBS/RS with robotic order-picking shuttle carrier differs from the classical SBS/RS. In this system the shuttle carrier is order picking (collecting) the items in the i^{th} tier of the storage rack by utilizing the robotic arm.

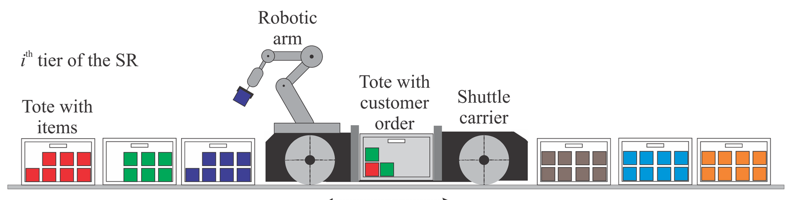
The complete working cycle would look as follows:

- The elevator's lifting table starts from the ground-floor, i.e., the first tier.
- The elevator's lifting table picks up the (empty) tote and moves to the i^{th} tier.
- When the elevator's lifting table reaches the i^{th} tier, it releases the tote in the buffer position.
- The shuttle carrier in the i^{th} tier picks-up the tote from the buffer position and starts picking the items.
- When the order is finished, the shuttle carrier travels to the buffer position of the i^{th} tier.
- The shuttle carrier releases the tote in the buffer position of the i^{th} tier.
- The elevator's lifting table moves to the the i^{th} tier and picks up the tote from the buffer position.
- The elevator's lifting table moves to the ground-floor (first tier), where the tote is released.

Note that the elevator is excluded from this study. Operations regarding the storage of full totes and retrieval of empty totes with the shuttle carrier is note studied in this research, as well.

Method





The assumptions that were used in analytical modelling are summarized as follows:

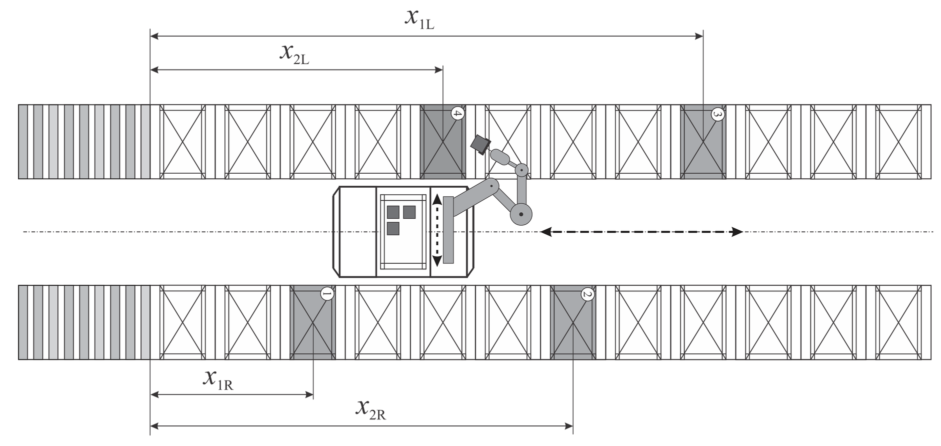
- The storage rack is divided into two sides (left and right), therefore totes with items are available on both side of the storage rack.
- The robotic order-picking shuttle carrier is operated on a multi command cycle collecting four (4) and six (6) items on four (4) and six (6) randomly selected locations.
- The sequences of (*i*) Acceleration, constant velocity and deceleration has been used.
- A randomized assignment policy is considered which means that any order-picking location is equally likely to be selected for picking the items with the robotic order-picking shuttle carrier.

The expected one way travel time E(SA) for travelling of the robotic order-picking shuttle carrier is equal to the next expression:

$$E(\mathrm{SA}) = \frac{v_x}{a_x} + \frac{1}{v_x}\int_0^{d_x} z f_x(z)\mathrm{d}z = \frac{v_x}{a_x} + \frac{d_x}{2v_x}$$

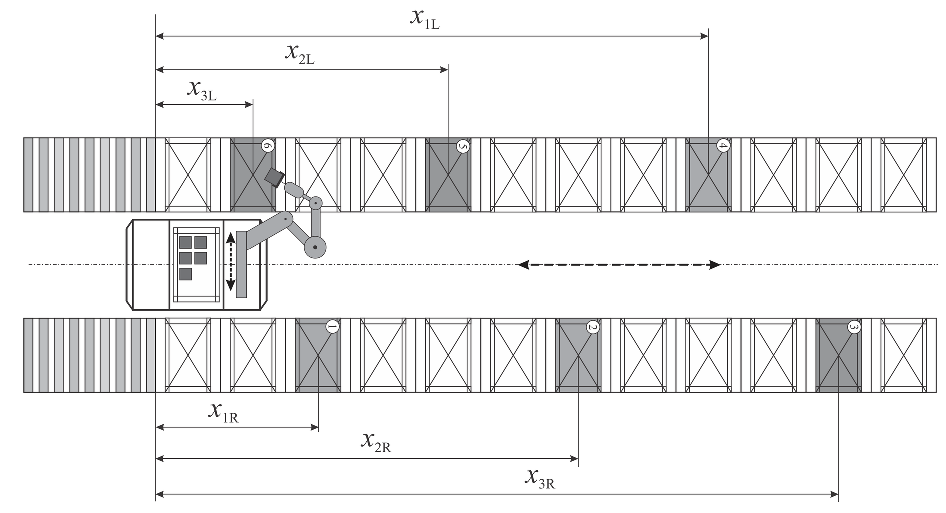
The expected travel-between time E(TB) for travelling of the robotic order-picking shuttle carrier between two randomly selected order-picking locations is equal to the following expression:

$$E(\mathrm{TB}) = \frac{v_x}{a_x} + \frac{1}{v_x}\int_0^{d_x} z f_x(z)\mathrm{d}z = \frac{v_x}{a_x} + \frac{d_x}{3v_x}$$



$$E(\mathrm{MC}_4) = 2E(SA) + 3E(TB) + 2t_{\mathrm{P/S\ tote}} + 4t_{\mathrm{P/S\ item}} + t_{\mathrm{robo\ move}}$$

$$\tau(\mathrm{MC}_4) = \frac{3600}{E(\mathrm{MC}_4)} \cdot 4 \left[\frac{\text{items}}{\text{hour}}\right]$$

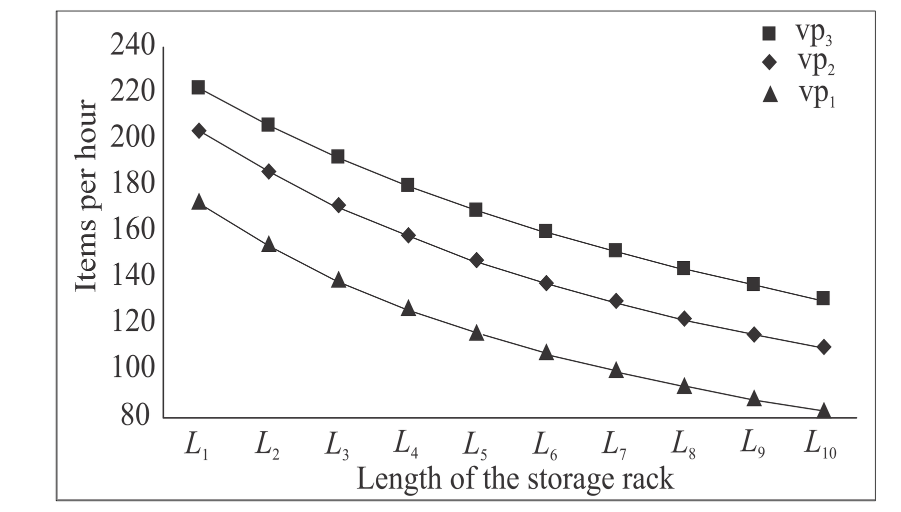


$$E(\mathrm{MC}_6) = 2E(SA) + 5E(TB) + 2t_{\mathrm{P/S\ tote}} + 6t_{\mathrm{P/S\ item}} + t_{\mathrm{robo\ move}}$$

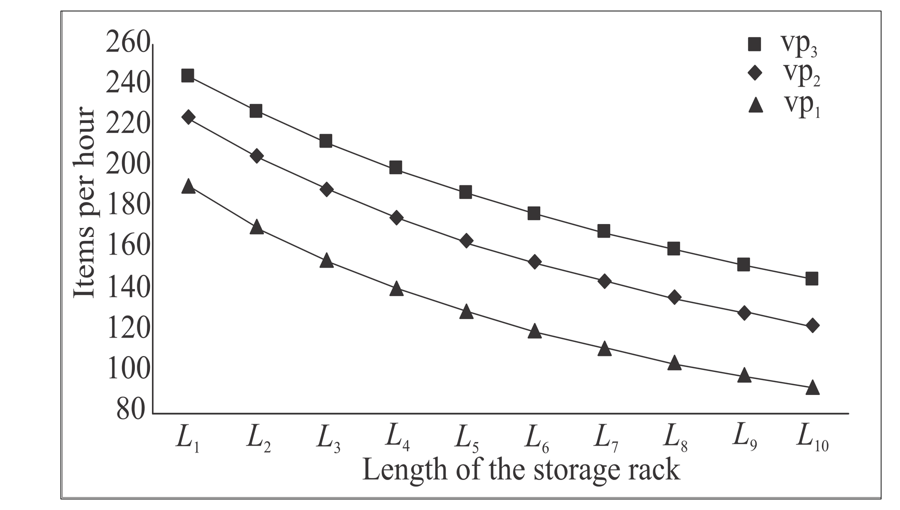
$$\tau(\mathrm{MC}_6) = \frac{3600}{E(\mathrm{MC}_6)} \cdot 6 \left[\frac{\text{items}}{\text{hour}}\right]$$

Results

- In this study totes with the following dimensions: length l_{tote} = 0.6 m, width w_{tote} = 0.4 m and height h_{tote} = 0.24 m have been used. With regard to the tote, the order-picking location has the following dimensions: length (depth) of the column l_{COM} = 0.6 m, width of the column w_{COM} = 0.5 m and height of one column (tier) h_{COM} = 0.5 m.
- For the calculation of the throughput performance of the robotic order-picking shuttle carrier, the following lengths (L_1 = 30 m, L_2 = 40 m, L_3 = 50 m, L_4 = 60 m, L_5 = 70 m, L_6 = 80 m, L_7 = 90 m, L_8 = 100 m, L_9 = 110 m, L_{10} = 120 m) of the storage rack were used.
- Since the throughput performance depends on the velocity characteristics of the robotic order-picking shuttle carrier, the following velocity profiles were used in this study vp_1 (v_x = 2 m/s and a_x = 1 m/s^2), vp_2 (v_x = 3 m/s and a_x = 2 m/s^2) and vp_3 (v_x = 4 m/s and a_x = 3 m/s^2).
- Constant times were used as follows: $t_{P/S\ tote}$ = 3 sec., $t_{P/S\ item}$ = 8 sec. and $t_{robo\ move}$ = 5 sec.



Throughput performance analysis of the robotic order-picking shuttle carrier for visiting four (4) locations



Throughput performance analysis of the robotic order-picking shuttle carrier for visiting six (6) locations

Conclusions

- The proposed model allows the calculation of the expected cycle time for multiple command cycles, from which the performance of the robotic order-picking shuttle carrier can be evaluated. Various parameters were examined such as: Velocity (v_x), acceleration / deceleration (a_x), length (L_i) of the storage rack.
- The proposed analytical model demonstrated good performances and satisfactory deviations and could be a very helpful tool for designing automated order-picking systems with robotic order-picking shuttle carriers. It could be of considerable help to professionals in practice, when making decisions in the early stages of design project and when deciding which type of the storage rack configuration or robotic order-picking shuttle carriers will be most promising.
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