Simulation model of a single-server order picking workstation using aggregate process times*

R. Andriansyah, L.F.P. Etman, and J.E. Rooda

Systems Engineering Group, Department of Mechanical Engineering
Eindhoven University of Technology

October 29, 2009

* This work has been carried out as part of the FALCON project under the responsibility of the Embedded Systems Institute with Vanderlande Industries as the industrial partner. This project is partially supported by the Netherlands Ministry of Economic Affairs under the Embedded Systems Institute (BSIK03021) program.

Outline

Motivation and objective

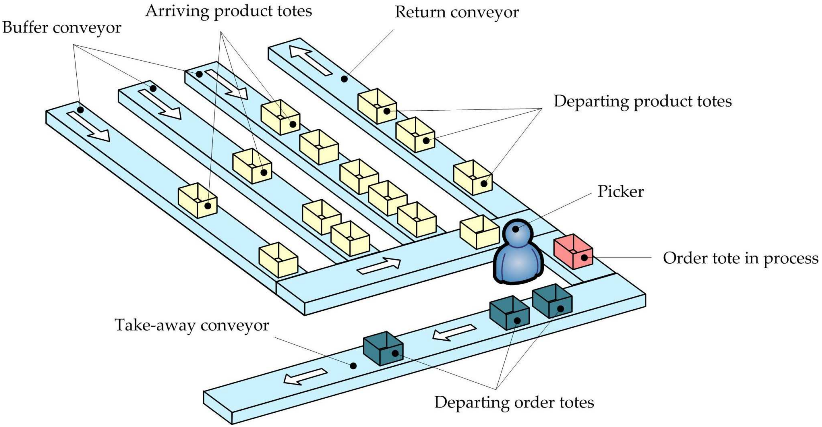
With regards to studies on automated warehouses:

- automated storage/retrieval system has been the focus of most research (Caputo and Pelagagge, 2006).
- design oriented research is lacking due to difficulties in quantifying stochastic behavior (Rouwenhorst *et al.*, 2000).

The objective of this study is:

- to develop a performance analysis method for order picking workstations that requires *little* but measurable shop-floor data.

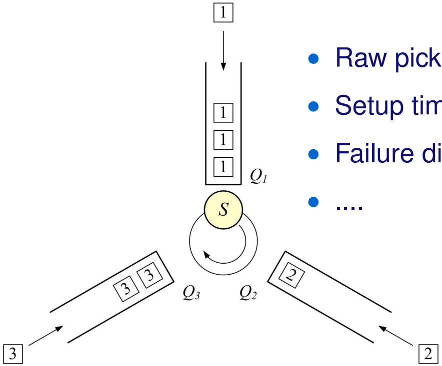
System description



Stochastic behavior:

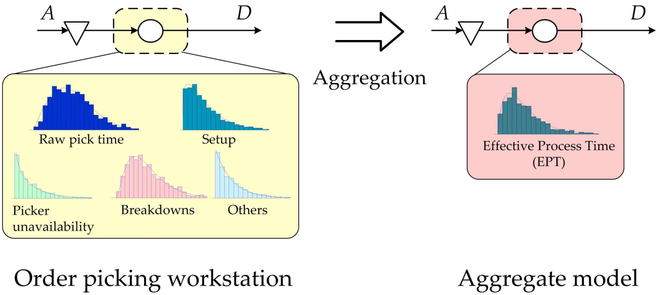
- setup
- operator unavailability
- breakdown

Common approach: detailed modeling



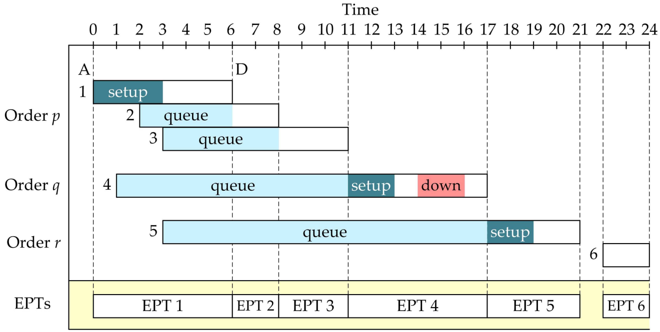
- Raw picking time distribution
- Setup time distribution
- Failure distribution
- ....

Alternative approach: process time aggregation



- The aggregate process time distribution is reconstructed from tote *arrival* times (A) and tote *departure* times (D) obtained from the shop-floor data.
- We refer to this aggregate process time as the Effective Process Time (EPT).

EPT measurement



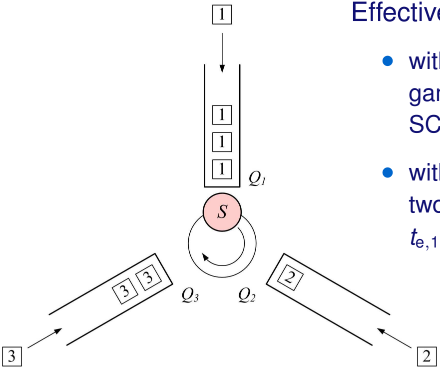
Sample path equation:

$$\text{EPT}_i = D_i - \max\{A_i, D_{i-1}\}$$

where:

- D_i = time of departure of the i^{th} departed tote.
- A_i = time of arrival of the corresponding i^{th} tote.

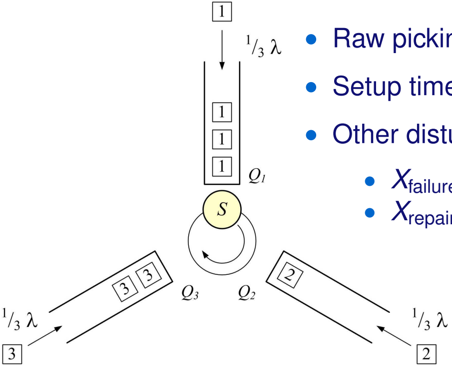
Proposed aggregate model



Effective process time distribution:

- without 1st tote difference: gamma distribution with mean t_e and SCV c_e^2
- with 1st tote difference: two gamma distributions with means $t_{e,1}$, $t_{e,2+}$ and SCVs $c_{e,1}^2$, $c_{e,2+}^2$

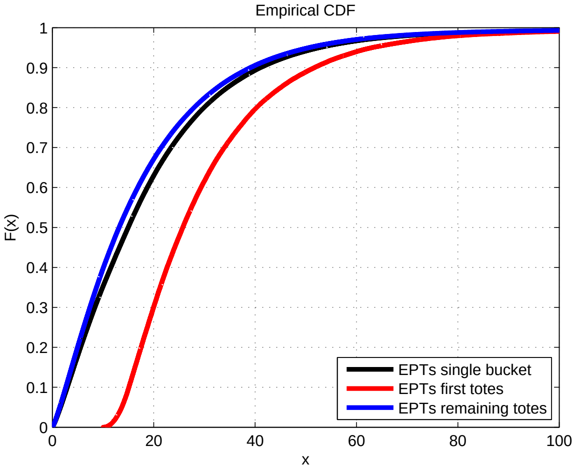
Proof of concept - detailed model



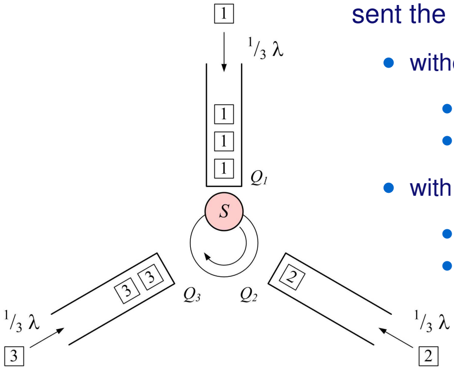
- Raw picking time = $B \sim$ gamma(1.25,14)
- Setup time = $S \sim$ uniform(10,15)
- Other disturbances:
  - $X_{\text{failure}} \sim$ exponential(1800)
  - $X_{\text{repair}} \sim$ exponential(120)

This model is used to generate tote arrival times (A) and tote departure times (D).

Proof of concept - EPTs from the detailed model



Proof of concept - aggregate model



A gamma distribution is used to represent the EPT distribution:

- without 1st tote difference ($\mathrm{Agg_A}$):
  - $t_e = 20.081$
  - $c_e^2 = 1.439$
- with 1st tote difference ($\mathrm{Agg_B}$):
  - $t_{e,1} = 31.148,\ c_{e,1}^2 = 0.590$
  - $t_{e,2+} = 18.688,\ c_{e,2+}^2 = 1.615$

Proof of concept - summary of findings[†]

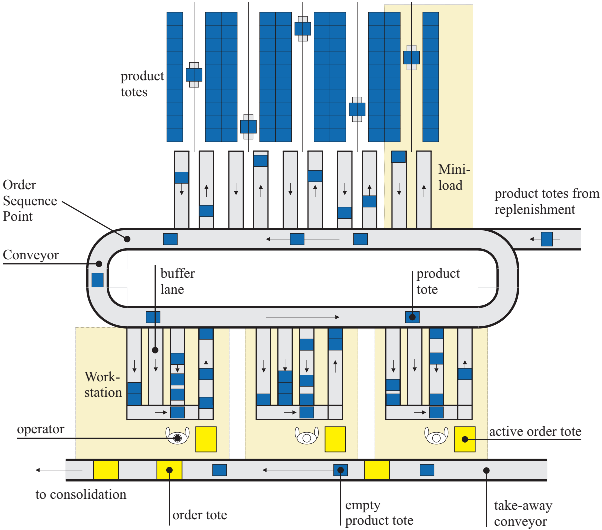
Table 1. Performance measures (utilization level = 0.9).

	$\bar{\varphi}_{\text{tote}}$	$\bar{\varphi}_{\text{order}}$	$c^2_{\bar{\varphi},\text{tote}}$	$c^2_{\bar{\varphi},\text{order}}$
Detail	1521.7 $\pm$ 8.6	2117.6 $\pm$ 9.3	0.264 $\pm$ 0.002	0.103 $\pm$ 0.002
Agg_A	1500.1 $\pm$ 8.6	2096.2 $\pm$ 9.0	0.269 $\pm$ 0.003	0.107 $\pm$ 0.002
Agg_B	1519.8 $\pm$ 8.2	2118.1 $\pm$ 8.6	0.261 $\pm$ 0.002	0.100 $\pm$ 0.002

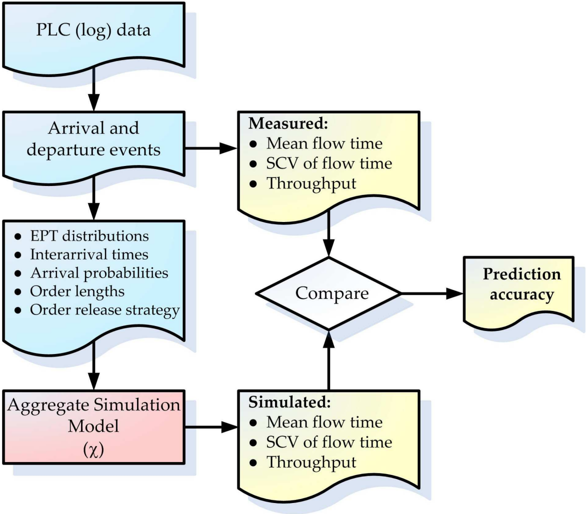
- Accuracy of Agg_B has significantly improved over Agg_A (two-sample t-test at $\alpha = 0.05$, on various utilization levels and order size distributions).
- Errors for mean and variability of flow time prediction are less than 0.5% and 3.0%, respectively for both tote and order flow times.

[†] Andriansyah, R., Etman, L.F.P., and Rooda, J.E., 2009. Simulation Model of a Single-Server Order Picking Workstation Using Aggregate Process Times. *In: Proceedings 1st International Conference on Advances in System Simulation*.

Case study

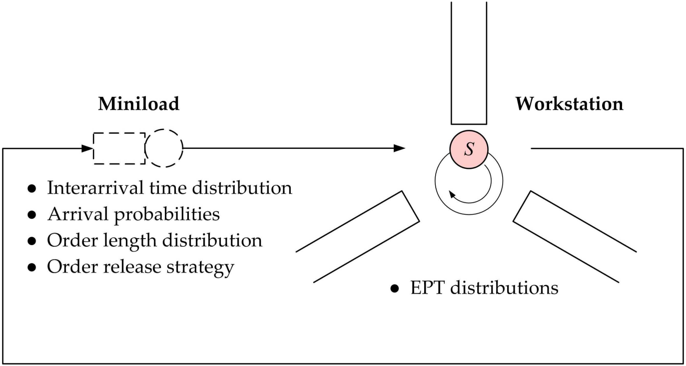

product
totes
Mini-
load
Order
Sequence
Point
product totes from
replenishment
Conveyor
buffer
lane
product
tote
Work-
station
operator
active order tote
to consolidation
order tote
empty
product tote
take-away
conveyor

Aggregate model building



Aggregate model

Closed queueing network model:



Results

Table 2. Prediction error (%).

	$\bar{\varphi}_{\text{tote}}$	$\bar{\varphi}_{\text{order}}$	$c^2_{\bar{\varphi},\text{tote}}$	$c^2_{\bar{\varphi},\text{order}}$	δ_{tote}
WS1	1.0	7.0	1.1	−7.5	12.6
WS2	0.7	6.7	1.3	−9.4	11.2
WS3	3.9	10.4	−4.5	−15.6	10.7

- The method performs well with a given data set.
- Prediction accuracy is being improved by modeling a better order release strategy.

Conclusions

- The proposed method is accurate for characterizing the effective process time of an order picking workstation.
- EPT measurement requires only few parameters that can be directly obtained from shop-floor data.
- Validation using real data from an operating warehouse shows promising results.

Future systems to investigate:

- Order picking workstations with overtaking of orders and multiple active orders.
- Automated storage/retrieval systems (miniloads).

Simulation model of a single-server order picking workstation using aggregate process times[‡]

R. Andriansyah, L.F.P. Etman, and J.E. Rooda

Systems Engineering Group, Department of Mechanical Engineering
Eindhoven University of Technology

October 29, 2009

TU/e Technische Universiteit Eindhoven University of Technology

[‡] This work has been carried out as part of the FALCON project under the responsibility of the Embedded Systems Institute with Vanderlande Industries as the industrial partner. This project is partially supported by the Netherlands Ministry of Economic Affairs under the Embedded Systems Institute (BSIK03021) program.