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Automated Digital Twins Generation for Manufacturing Systems: a Case Study

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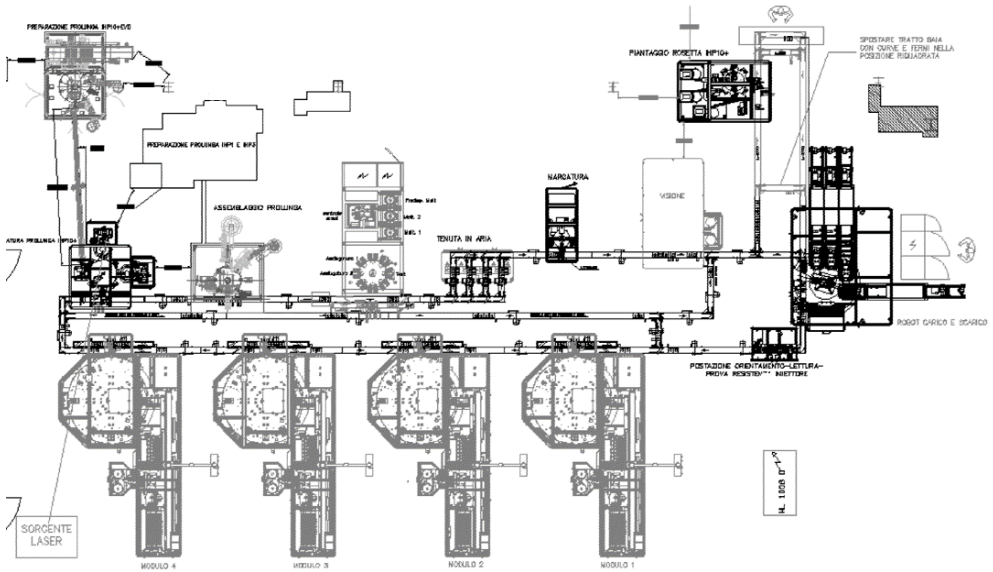
POLITECNICO
MILANO 1863

CONTENTS

INDUSTRIAL RELEVANCE

CHALLENGES:

- **Pressure from market demand**
- **Complexity increases events' impact**
- **Pressures on cost reduction**



OPPORTUNITIES:

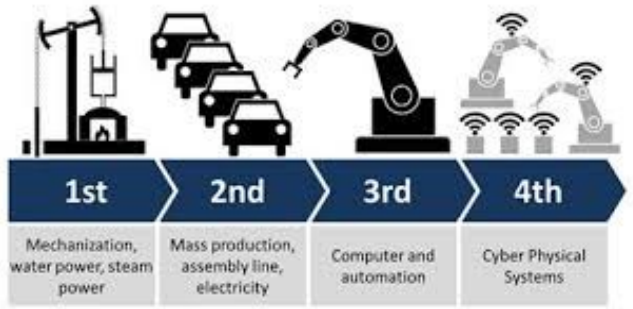
Collecting information with high frequency

Understanding **emerging behaviors**

Evaluating alternative **scenarios**

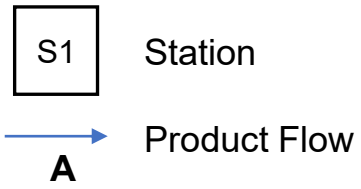
Affordable **data analytics**

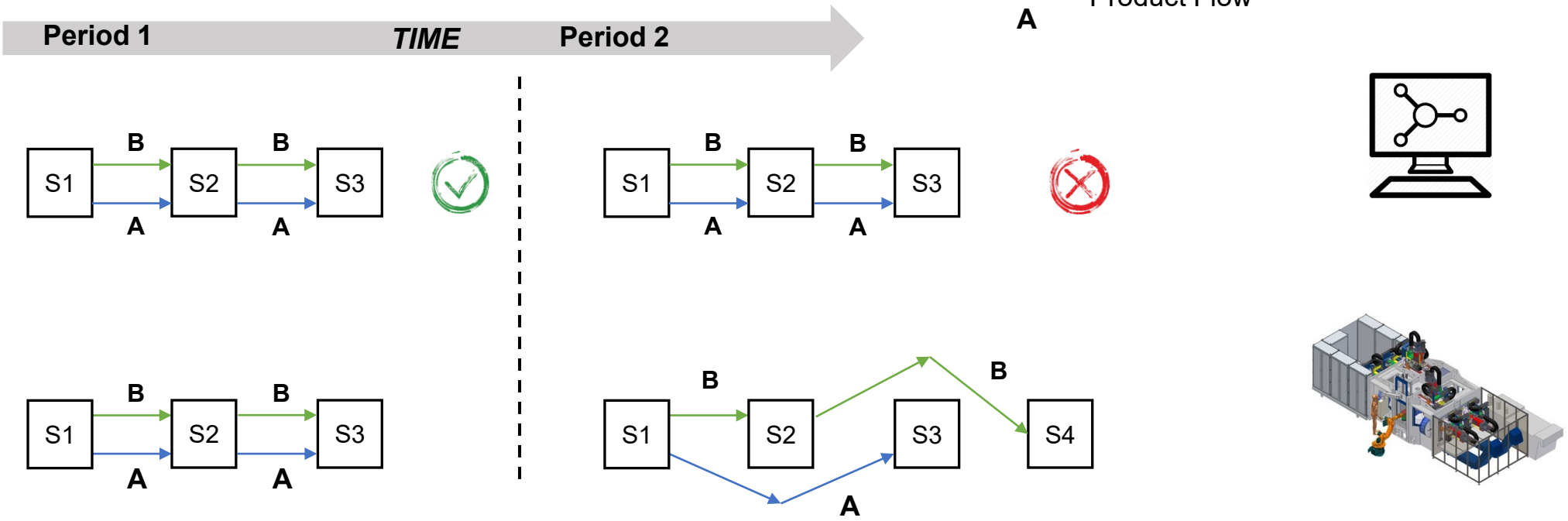
ONLINE SUPPORT TOOLS FOR PRODUCTION PLANNING AND CONTROL



PROBLEM INTRODUCTION

At the time the physical manufacturing system changes, the simulator might be out of date.

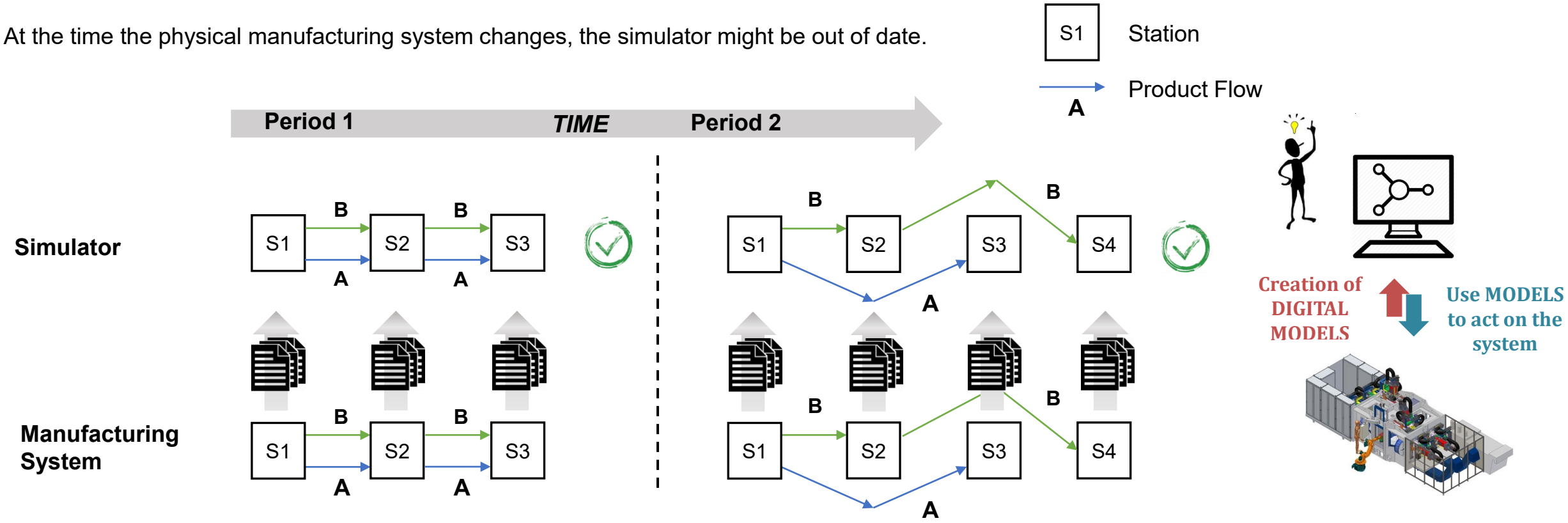




Manufacturing systems change frequently due to external drivers (e.g. demand, price uncertainty). Hence, **current simulation techniques are poor** as tools for **short-term decision making**.

PROBLEM INTRODUCTION

At the time the physical manufacturing system changes, the simulator might be out of date.



By exploiting the data produced by the parts and resources, it is possible to achieve higher reactivity in the simulation model building phase.

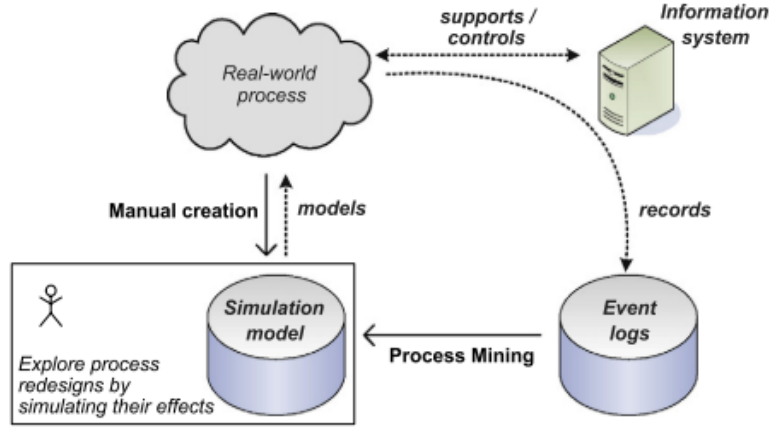
STATE OF THE ART

Applications of Process Mining in manufacturing:

Reference	Framework	Graph	Policies	Formal Model	Parameters
W.M.P. Van der Aalst., 2016	X	X			
A.K. Alves de Medeiros et al., 2006	X	X			
A.L. Wolf and J.E. Cook, 1995		X			
A. Rozinat et al., 2009	X				
Bergmann et al. 2015			X		
Farooqui et al. 2019				X	
Milde and Reinhart, 2019			X		X
Martin et al. 2015					X
Martin et al. 2016					X
Martin et al. 2017			X		X
Peter Denno et al. 2018		X			
Ferreira and Vasilyev 2015					X

Existing approaches of Model Tuning:

- ✗ Finite capacity **resources** cannot be recognized automatically
- ✗ User is not free in the choice of **aggregation level**
- ✗ Highly sensitive to **rare or wrong sequences** of events;
- ✗ No **relationship with performance** estimation from the obtained model

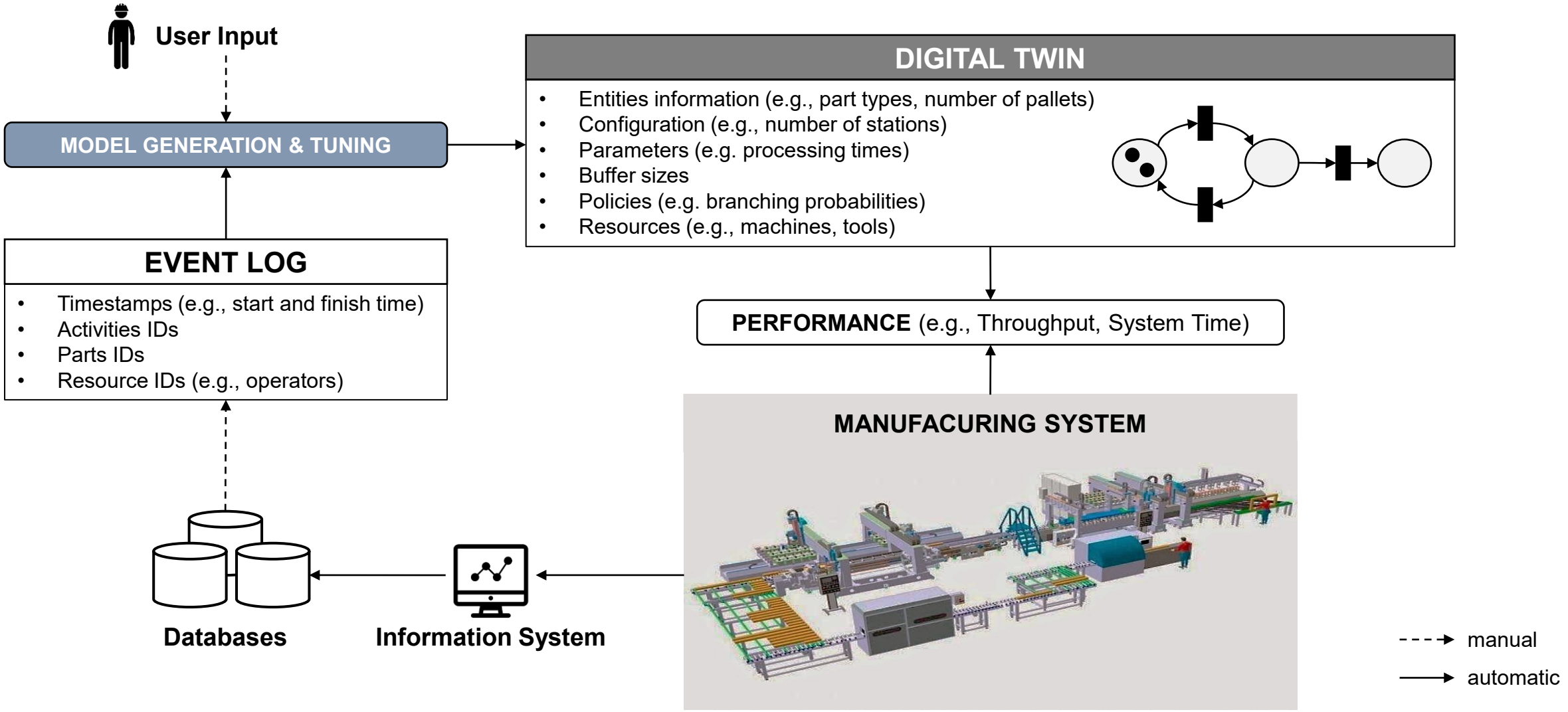


A. Rozinat, R.S. Mans, M. Song, W. Van der Aalst. "Discovering simulation models." Information systems 34.3 (2009): 305-327.

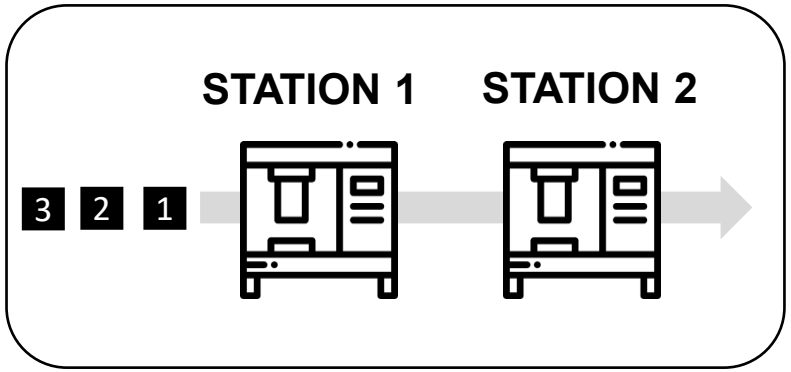
Specific contributions aimed at DES for manufacturing are missing in the literature.

SCOPUS: 0 results for the query: *"process mining"* AND *"manufacturing"* AND *"discrete event simulation"*

OVERVIEW


User Input
MODEL GENERATION & TUNING
DIGITAL TWIN
• Entities information (e.g., part types, number of pallets)
• Configuration (e.g., number of stations)
• Parameters (e.g. processing times)
• Buffer sizes
• Policies (e.g. branching probabilities)
• Resources (e.g., machines, tools)
EVENT LOG
• Timestamps (e.g., start and finish time)
• Activities IDs
• Parts IDs
• Resource IDs (e.g., operators)
PERFORMANCE (e.g., Throughput, System Time)
MANUFACURING SYSTEM
Databases
Information System
manual
automatic

MODEL GENERATION BASICS



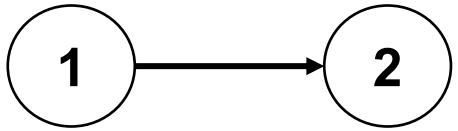
MANUFACURING SYSTEM

EVENT LOG

Timestamp	Part-ID	Activity-ID
2020-11-23T16:37:40Z	1	S1
2020-11-23T16:37:44Z	1	S2
2020-11-23T16:37:47Z	2	S1
2020-11-23T16:37:51Z	2	S2
2020-11-23T16:37:52Z	3	S1
…	…	…

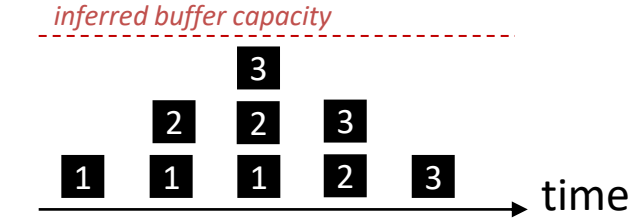
TRACES: 1 {S1, S2}
2 {S1, S2} …

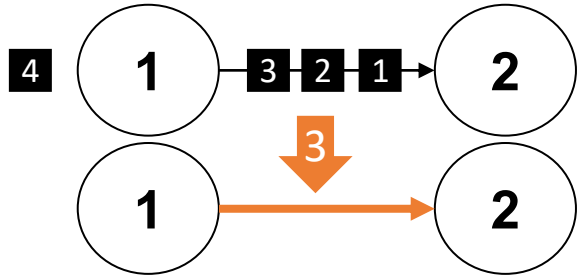
ACTIVITY RELATIONSHIPS:
“Station 2 follows Station 1”, …



PARAMETERS (SYSTEM PROPERTIES)

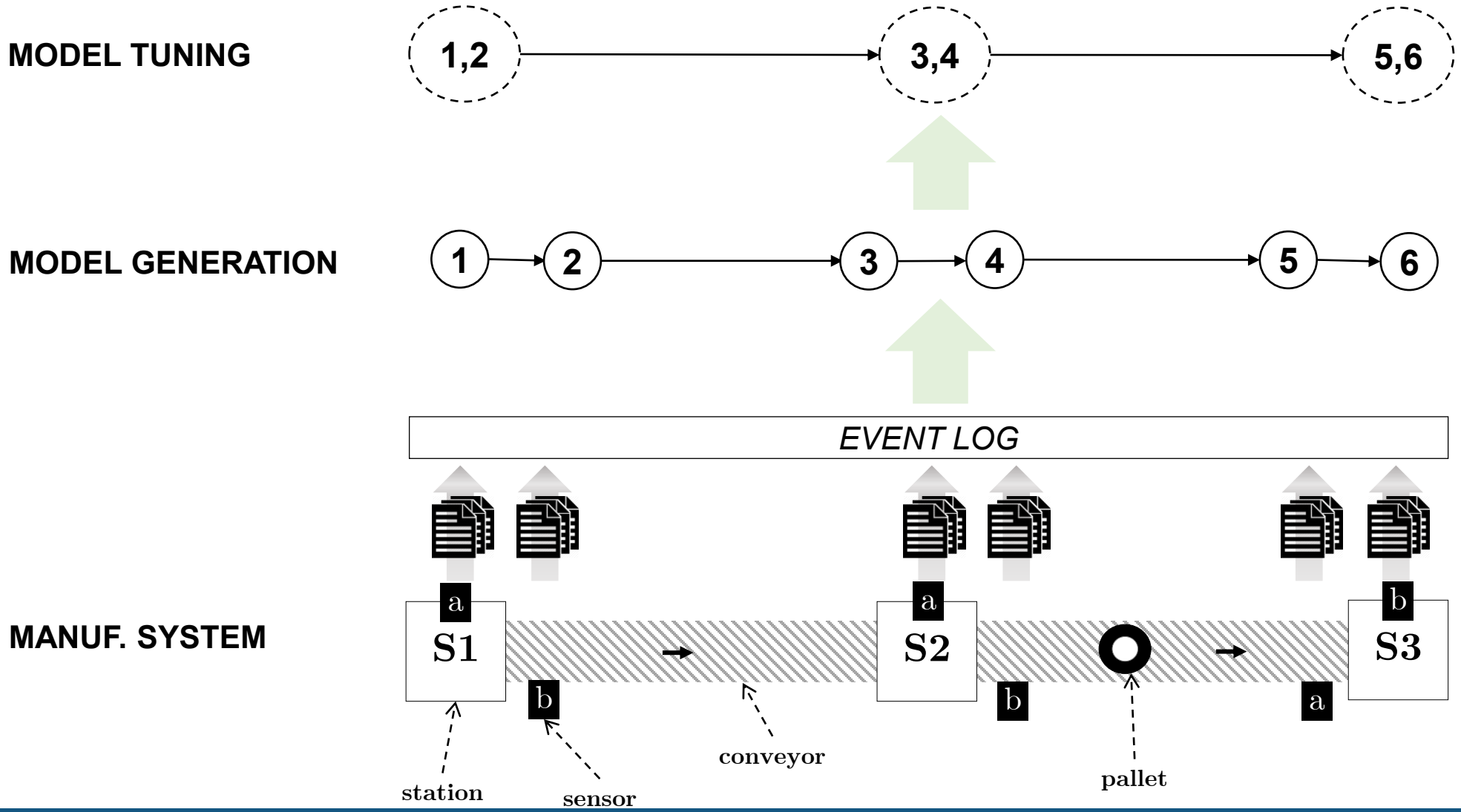
EXAMPLE: CAPACITY





MODEL TUNING

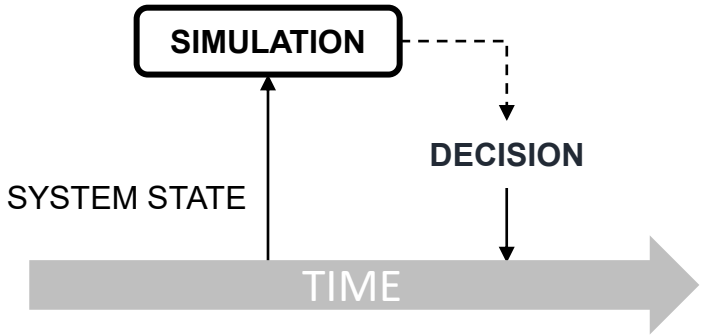
Lugaresi, Giovanni, and Andrea Matta. "Automated manufacturing system discovery and digital twin generation." *Journal of Manufacturing Systems* 59 (2021): 51-66.



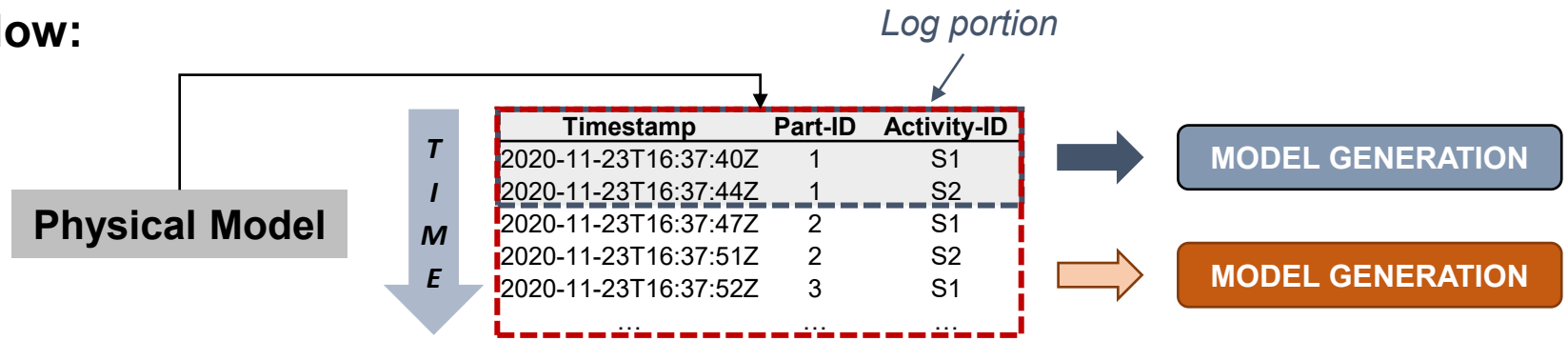
CASE STUDY

Research Questions:

- *Model Structure:*
  - *How many parts are necessary to **discover the system structure** (graph-model)*
- *Buffer Capacities:*
  - *Observe the **transitory** to discover the correct values*
  - *Can Buffer Capacities always be discovered?*
- *Processing Times:*
  - *Which **fitting method** is most suitable with few data*
  - *Observe the transitory to discover the correct model parameters*
- *Policies (not in this work)*
- *Reliability Models (not in this work)*



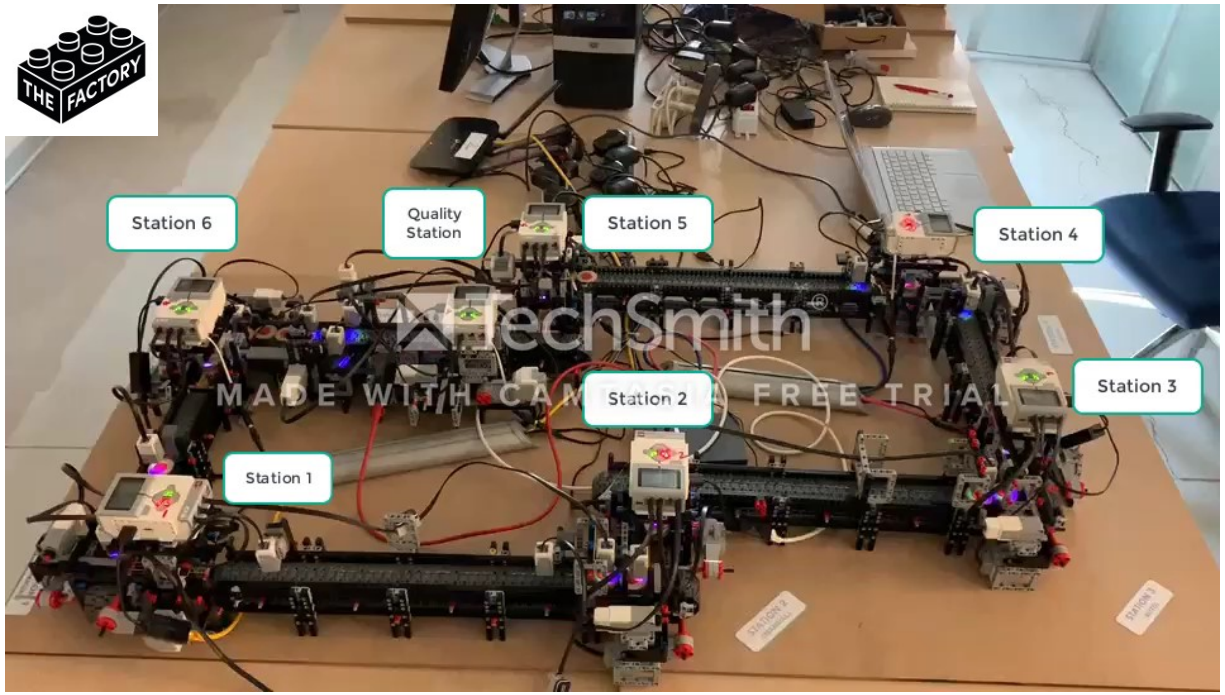
How:



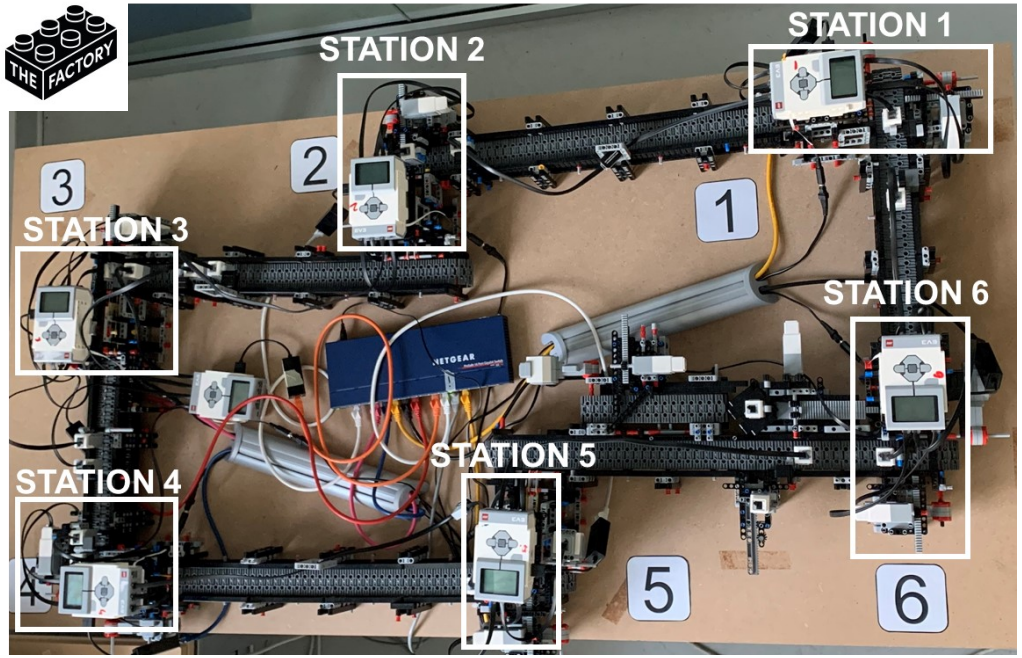
LAB-SCALE MODELS

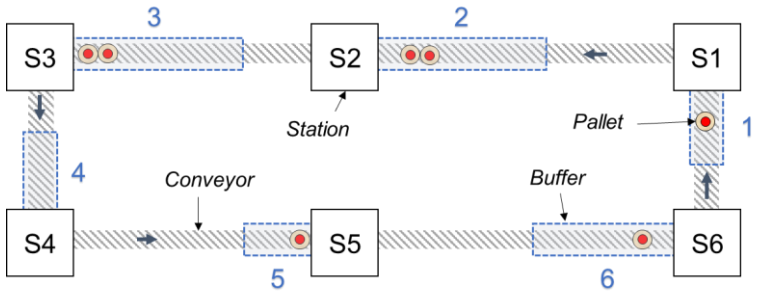
Lugaresi, Giovanni, Vincenzo Valerio Alba, and Andrea Matta. "Lab-scale Models of Manufacturing Systems for Testing Real-time Simulation and Production Control Technologies." *Journal of Manufacturing Systems* 58 (2021): 93-108.

- @POLIMI: Laboratory for testing Real-Time Simulation based on the needs from the literature and considering I4.0 developments (e.g., Internet of Things, Cyber Physical Systems).
- Stations controlled by LEGO® EV3® intelligent bricks
- Each station has sensors for entrance checking, processing, blocking.
- Wooden circles tagged with red plates represent pallets/parts.



Physical Model for Case Study



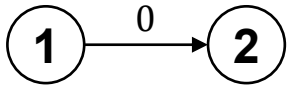


CASE STUDY

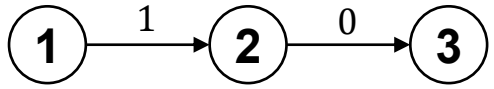
Test: Model Generation while the system is running, observing the warm-up phase

- *Model Structure:*

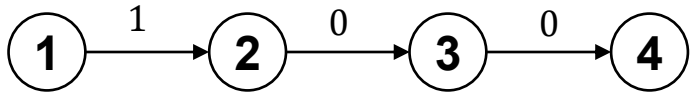
$4\ parts$



$5\ parts$

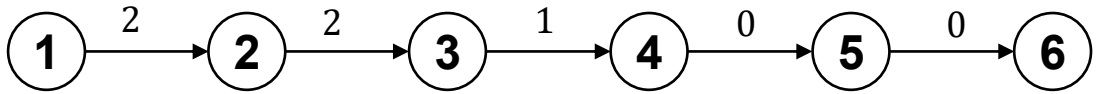


$7\ parts$



$9\ parts$

$11\ parts\ (100\ s)$

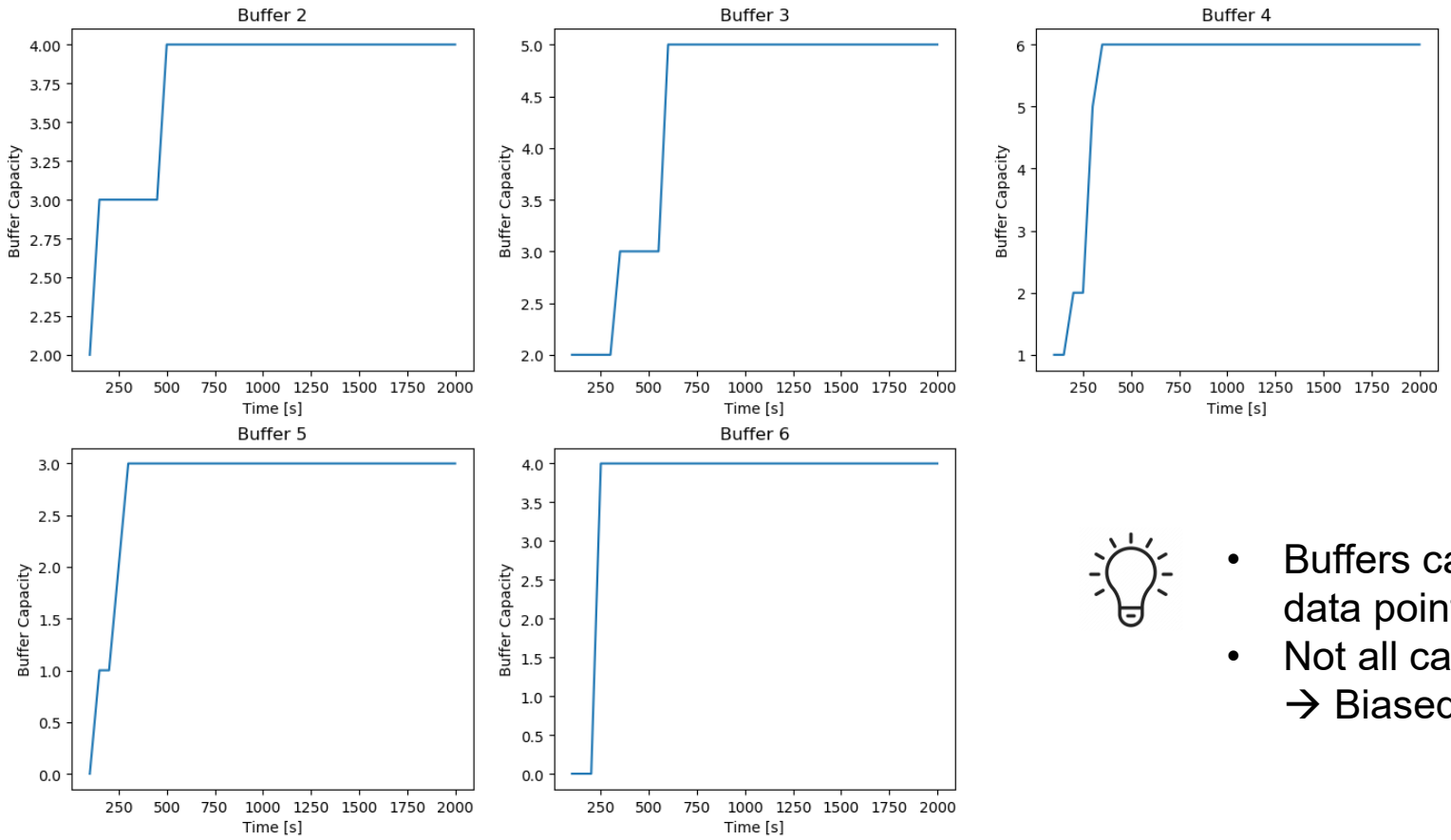


- Initial transient determines the capability of discovering the correct model of the system;
- Model structure can be infered correctly with very few parts;
- Parameters (buffer capacities) require more data points.

CASE STUDY

Test: Model Generation while the system is running, observing the warm-up phase

- *Buffer Capacities*

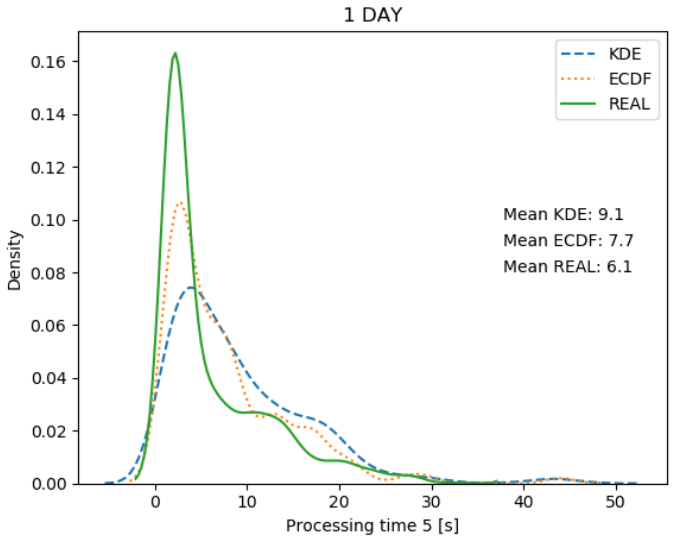


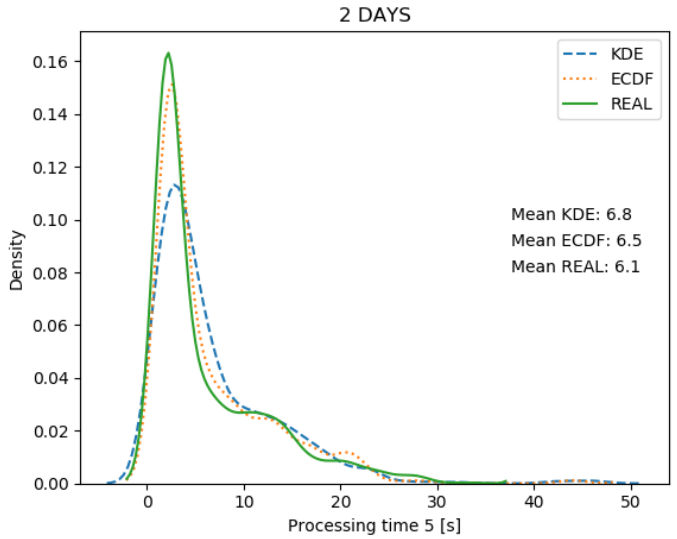
- Buffers can be identified with enough data points.
- Not all capacities may be saturated → Biased estimation.

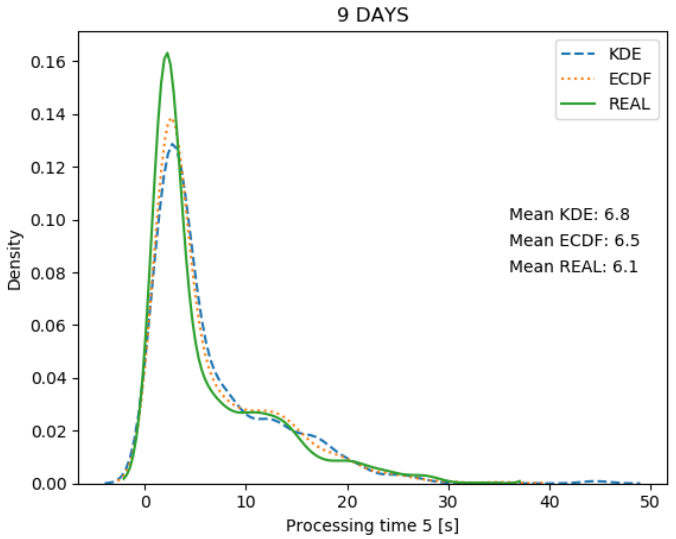
CASE STUDY

Test: Model Generation while the system is running, observing the warm-up phase

- *Processing Time on Station 5: comparison between (1) Kernel Density Estimation and (2) Empirical Cumulative Distribution Function.*







- With few data points, both KDE and ECDF perform badly
- ECDF performs well even without very large datasets
- With large datasets, both methods may be used

LIMITATIONS AND FUTURE DEVELOPMENTS

LIMITATIONS

- Hypothesis of **single Part-IDs** (limited for assembly/disassemly operations)
- **Limited information** in the log translates in less descriptive models (e.g., reliability model)
- **Manual log-preprocessing is still necessary** (e.g., events with same timestamp are removed)

FUTURE DEVELOPMENTS

- Investigate the **value of prior information;**
- Test on realistic datasets, real manufacturing systems;
- Extend the analysis to unexplored model elements (policies, resource utilization);
- Understand the behavior with **very large logs;**
- Investigate **Simulation-Optimization** applications.

Q&A

Selected References

G. Lugaresi and A. Matta. *Real-time simulation in manufacturing systems: Challenges and research directions.* 2018 Winter Simulation Conference, pp. 3319–3330, IEEE.

Günther, Christian W., and Wil MP Van Der Aalst. "*Fuzzy mining–adaptive process simplification based on multi-perspective metrics*." *International conference on business process management*. Springer, Berlin, Heidelberg, 2007.

M. Prodel, *Modelisation automatique et simulation de parcours de soins a partir de bases de donnees de sante.* Ph.D. Thesis, 2017.

M. Mesabbah and S. McKeever. *Presenting a hybrid processing mining framework for automated simulation model generation.* Winter Simulation Conference, pp. 1370–1381, IEEE, 2018.

A. Rozinat, R.S. Mans, M. Song, W. Van der Aalst. "Discovering simulation models." Information systems 34.3 (2009): 305-327.

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OTHER PUBLICATIONS