# GENERATION AND TUNING OF DISCRETE EVENT SIMULATION MODELS FOR MANUFACTURING APPLICATIONS

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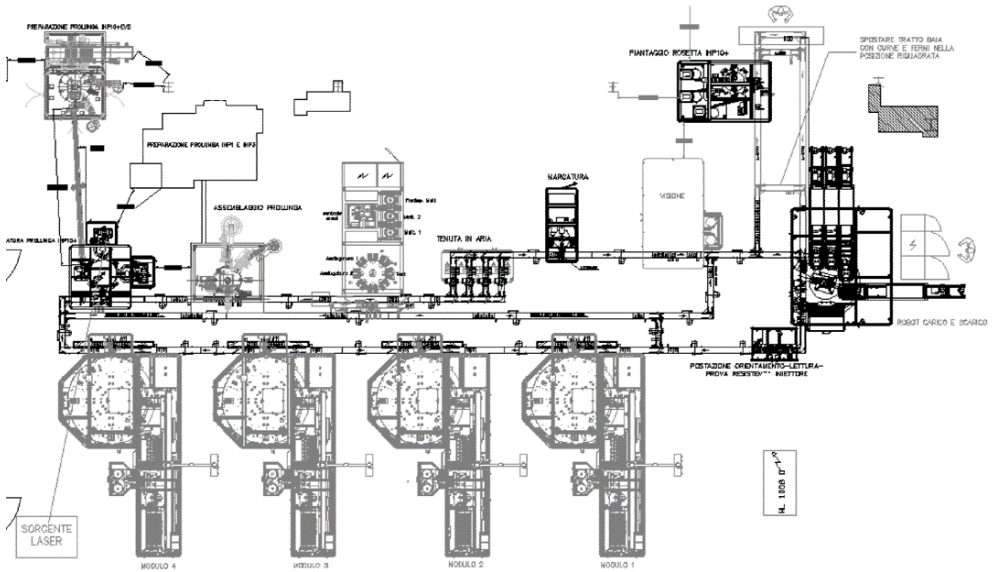
# INDUSTRIAL RELEVANCE

## CHALLENGES:

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




## OPPORTUNITIES:

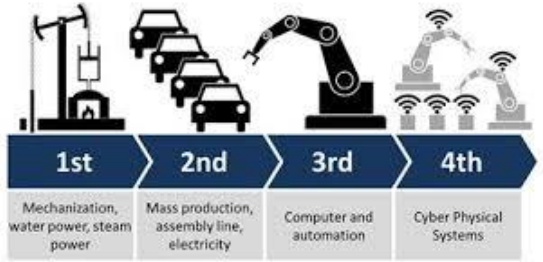
**Collecting information** with high frequency

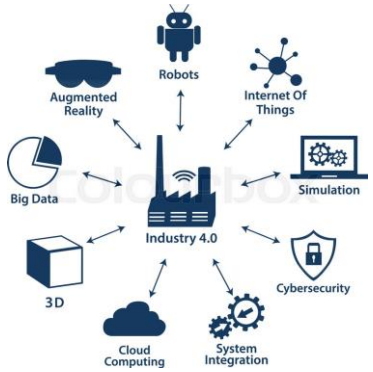
Understanding **emerging behaviors**

Evaluating alternative **scenarios**

Affordable **data analytics**

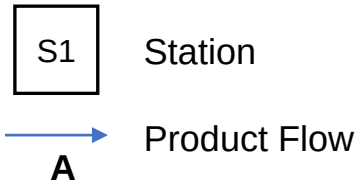
**ONLINE SUPPORT TOOLS** FOR PRODUCTION PLANNING AND CONTROL

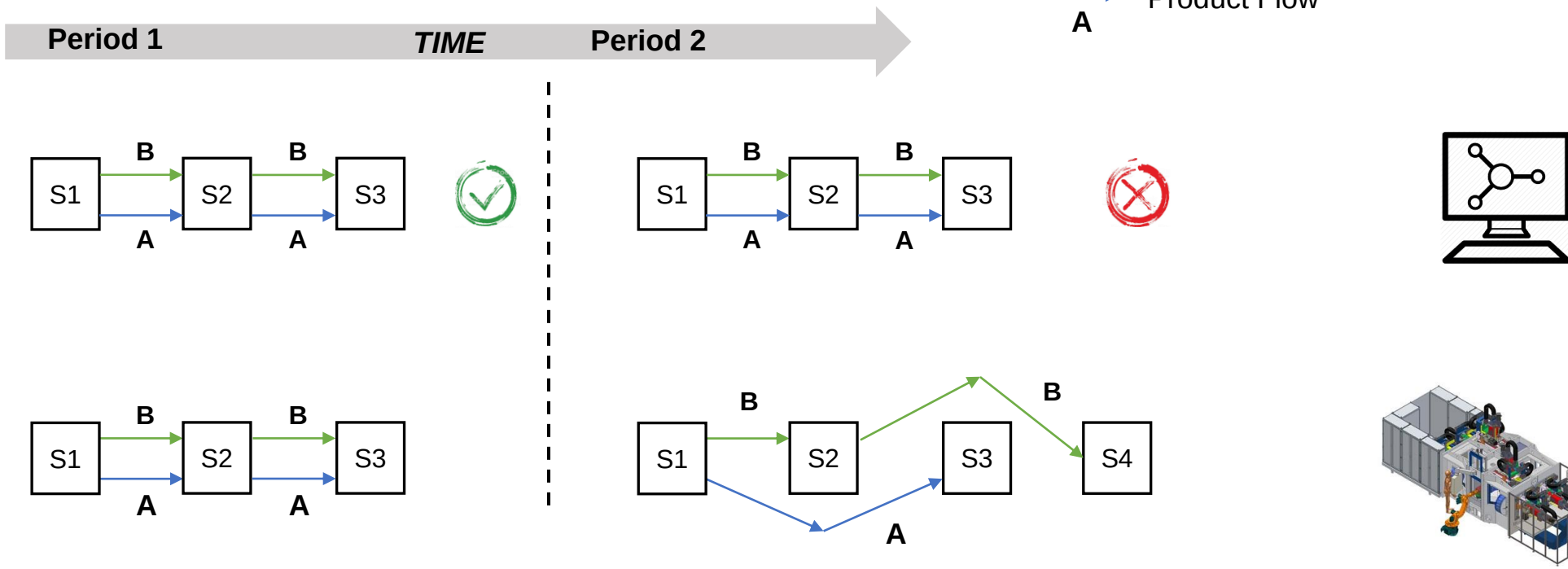


# PROBLEM INTRODUCTION

At the time the physical manufacturing system changes, the simulator might be out of date.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

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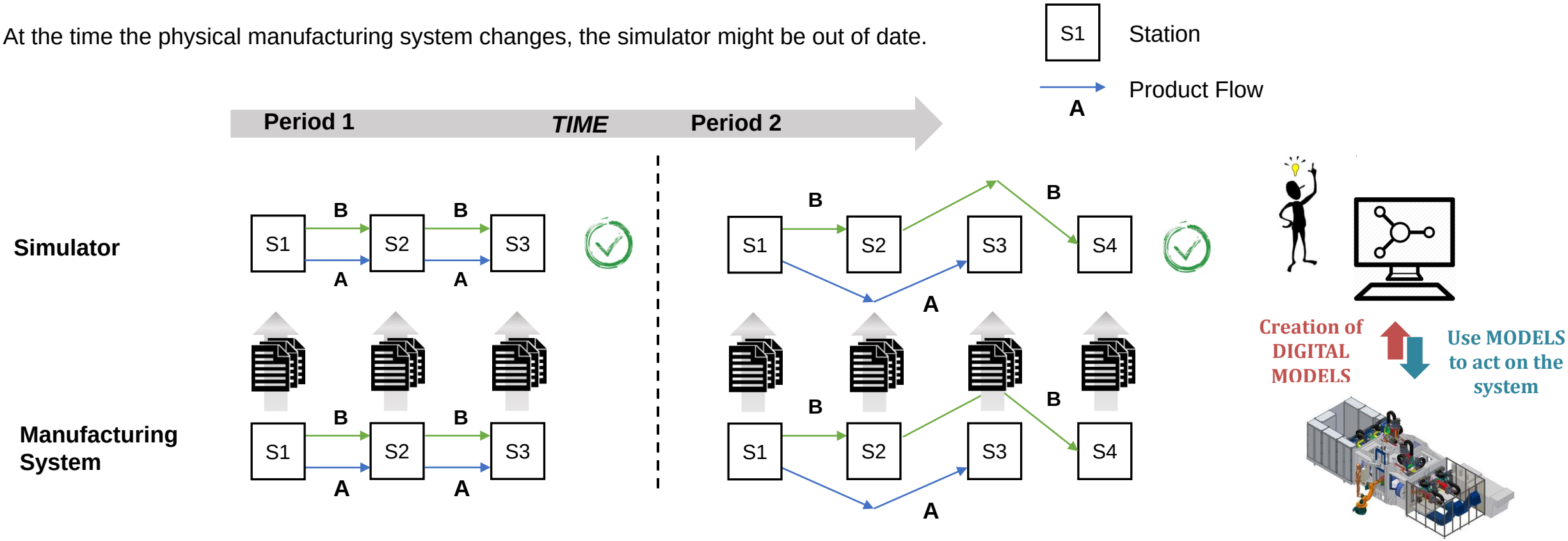
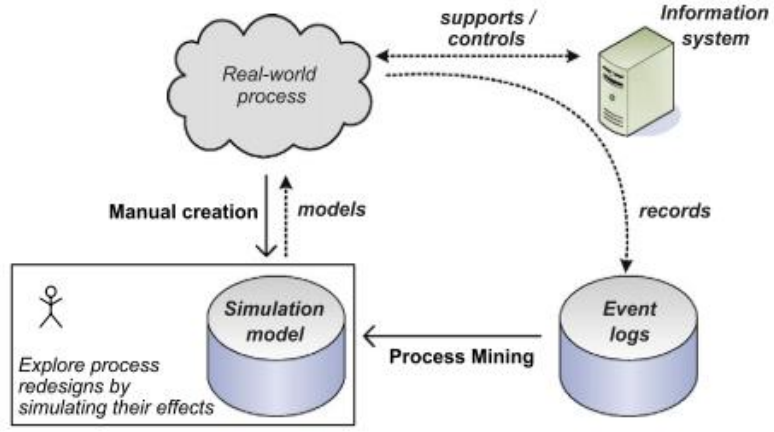



**By exploiting the data produced by the parts and resources, it is possible to achieve higher reactivity in the simulation model building phase.**

# 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 |




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

## 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

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

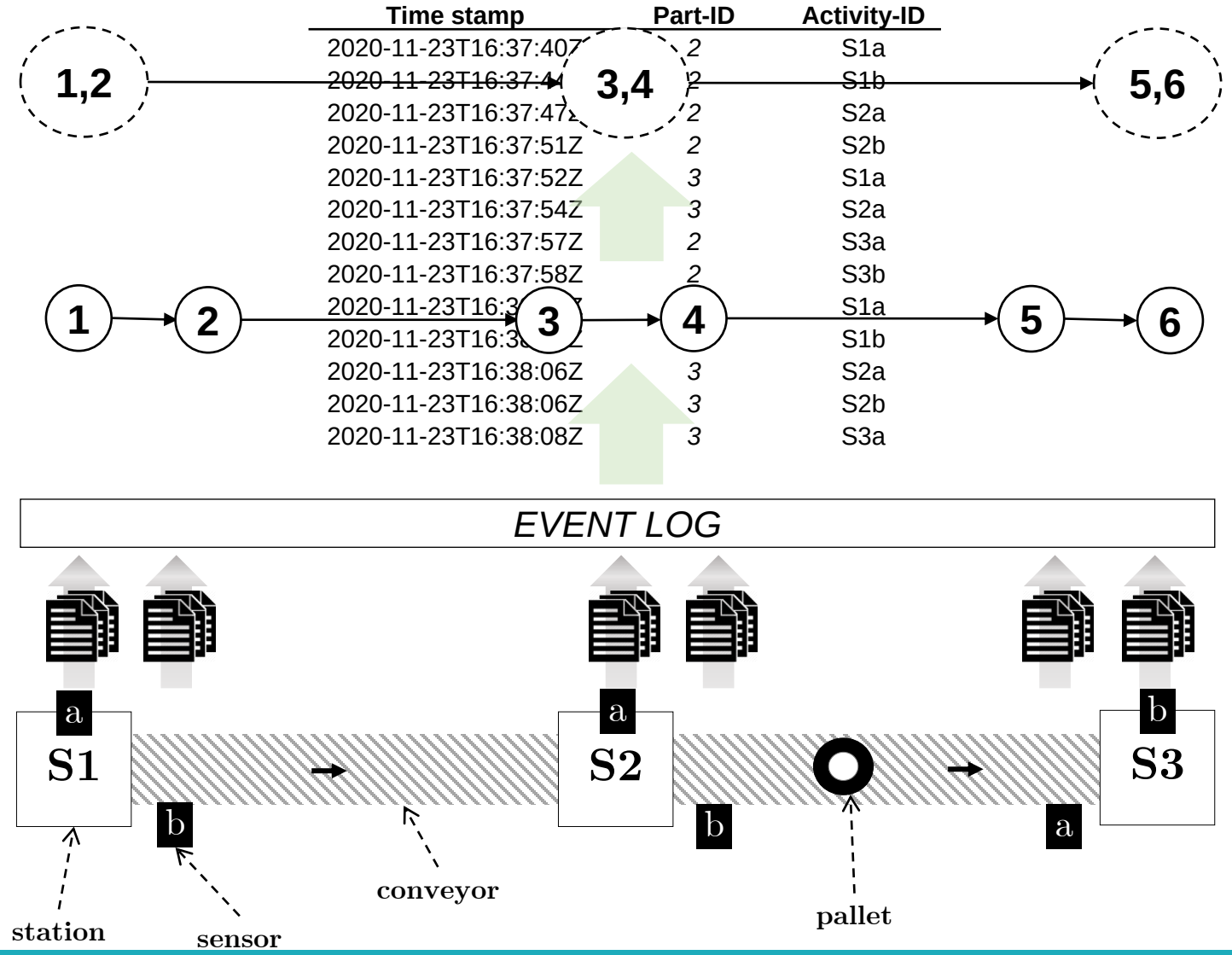
**SCOPUS: 0 results for the query:**
***"process mining"* AND *"manufacturing"* AND *"discrete event simulation"***

# OVERVIEW

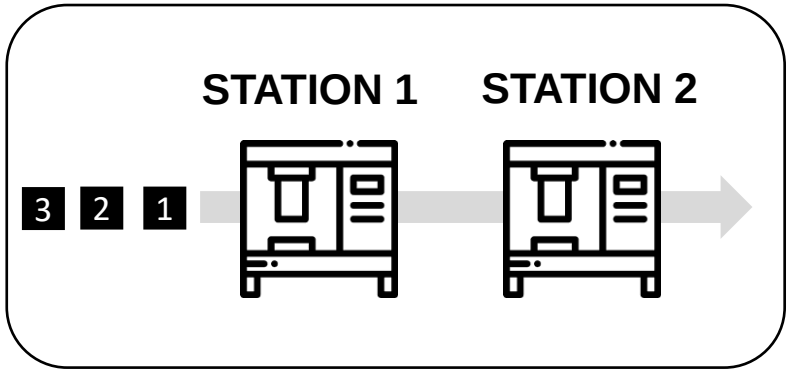
**MODEL TUNING**

**MODEL GENERATION**

**MANUF. SYSTEM**



# MODEL GENERATION BASICS



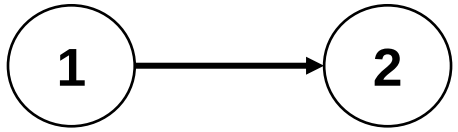

MANUFACURING SYSTEM

**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 |
| … | … | … |

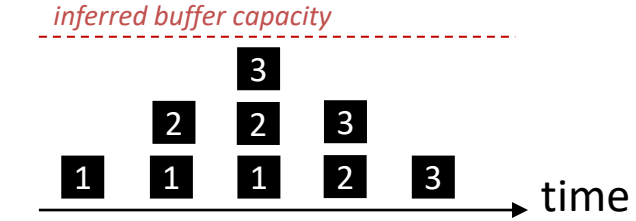
**TRACES:** 1 **{S1, S2}**
2 **{S1, S2}** **…**

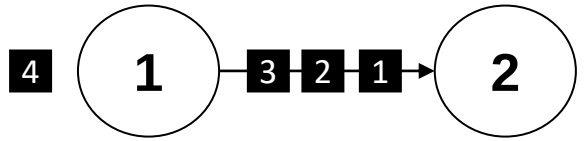
**ACTIVITY RELATIONSHIPS:**
**“Station 2 follows Station 1”, …**




**PARAMETERS (SYSTEM PROPERTIES)**

EXAMPLE: CAPACITY



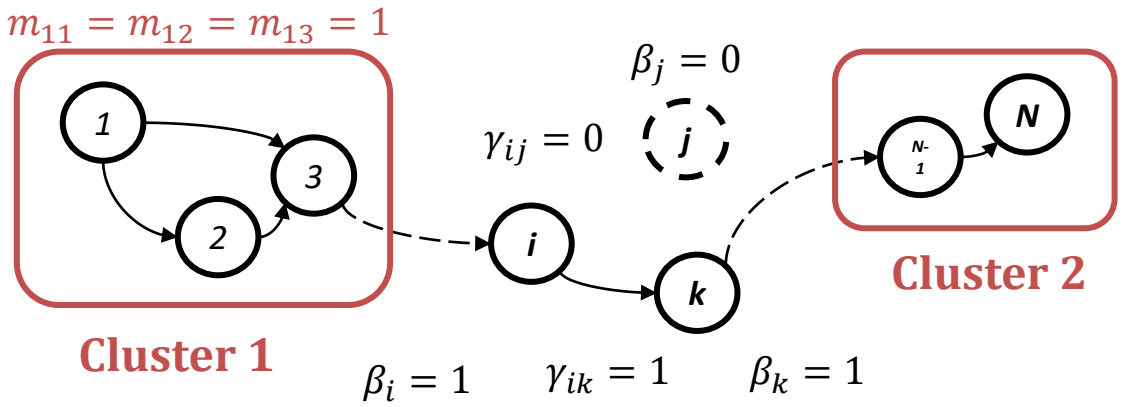




# MODEL TUNING METHODOLOGY

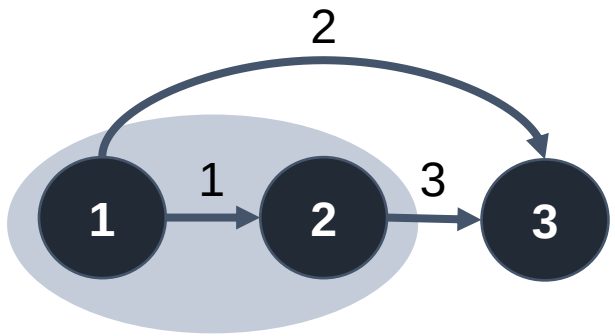
**OBJECTIVE: Tune the model toward a reasonable size.**

IDEA: Find **the model that maximizes a score** (*How well does it represent systems features?*):

$$R = \frac{Close\ Events(\ Reduced\ Model)}{Close\ Events\ (Full\ Model)}$$

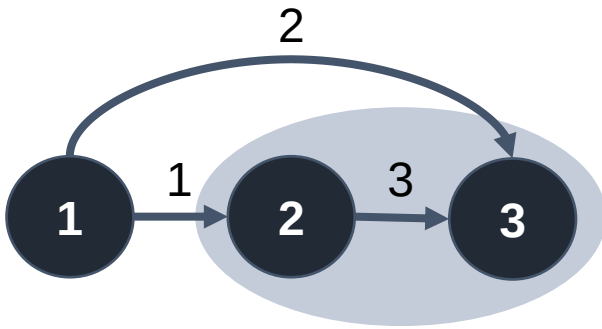



$S_N^{max} = 2$

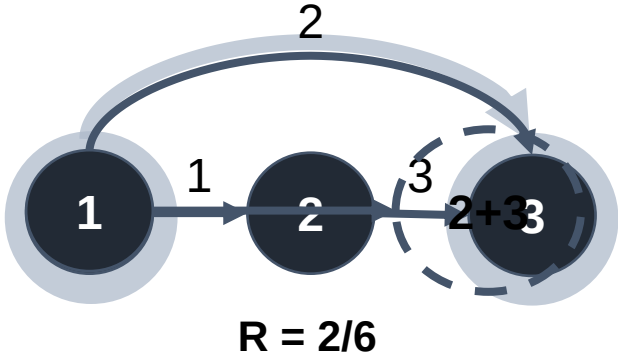



R = 1/6

BEST




R = 3/6




R = 2/6

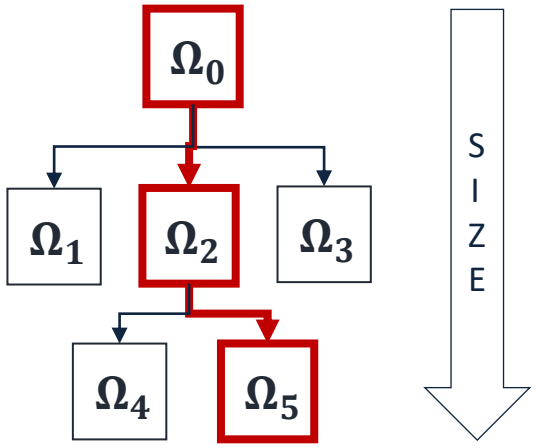
→ 5 SCORES BASED ON: FREQUENCY, CAPACITY, EVENTS CLOSE IN TIME, ROUTING, LOOPS

# MODEL TUNING: SOLUTION METHOD

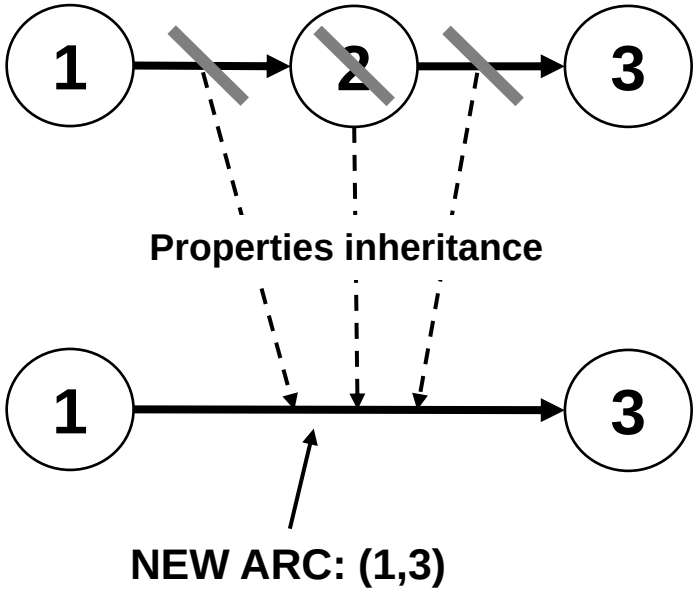
**LOCAL SEARCH**

*Heuristic*

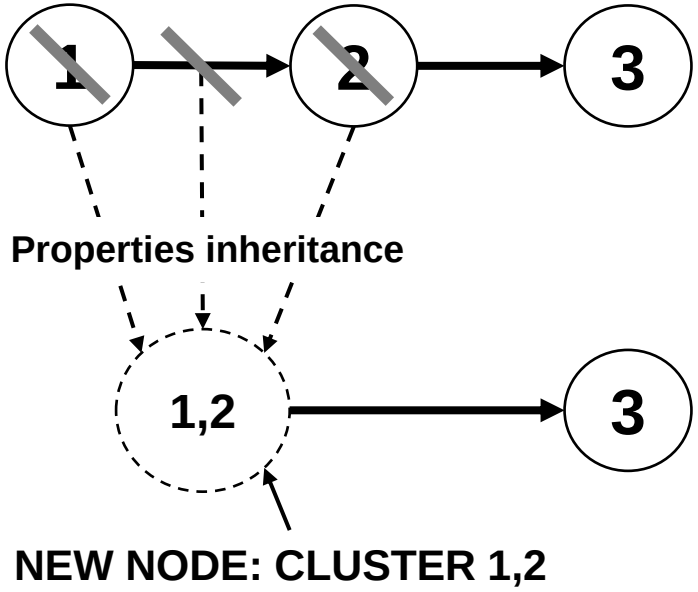
Depth-first approach



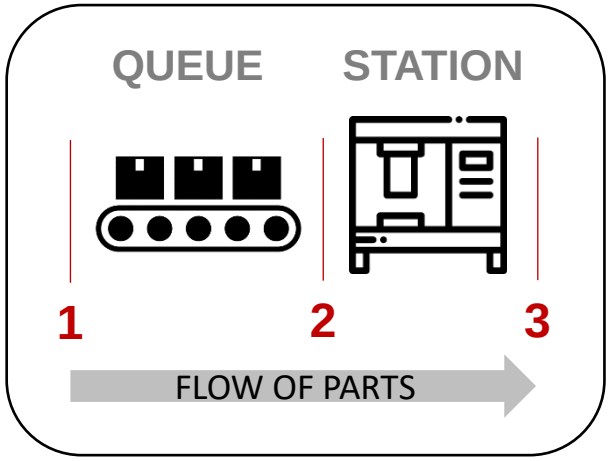

***REDUCTION***




***AGGREGATION***



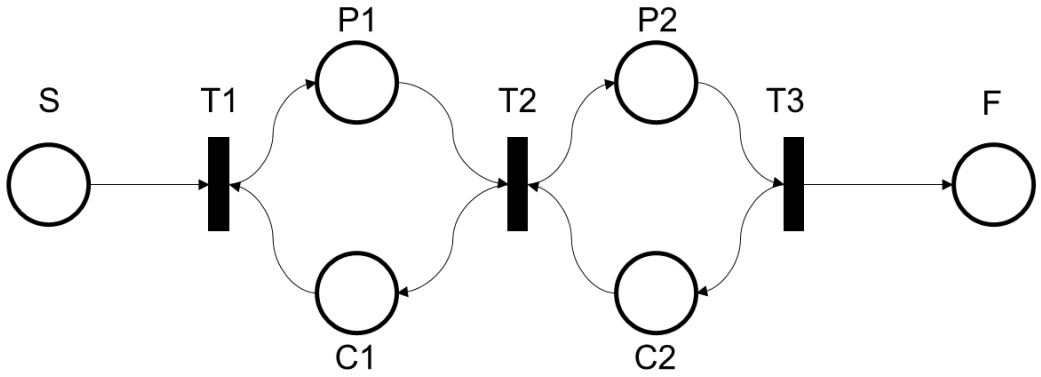
# ILLUSTRATIVE EXAMPLE: M/M/1/10 QUEUE



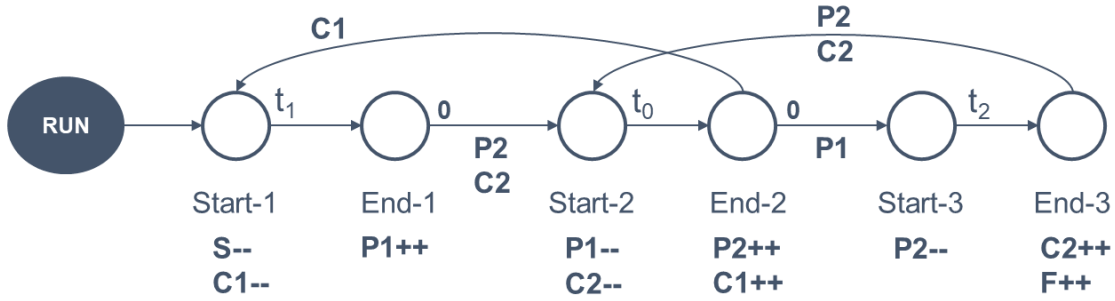

MANUFACURING SYSTEM

**Process model $\Omega_{final}$**


**Petri Net Model**




**Event Relationship Graph***



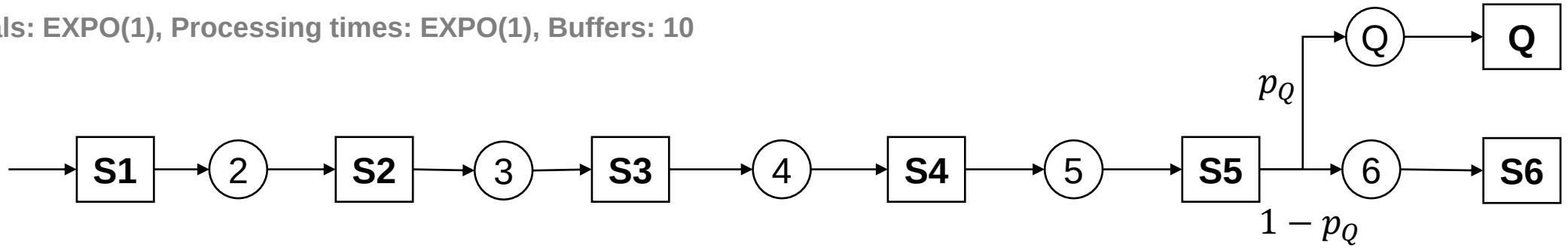

*** further reduction may be applied**

*Schruben, Lee, and Enver Yucesan. "Transforming Petri nets into event graph models." *Proceedings of Winter Simulation Conference*. IEEE, 1994.

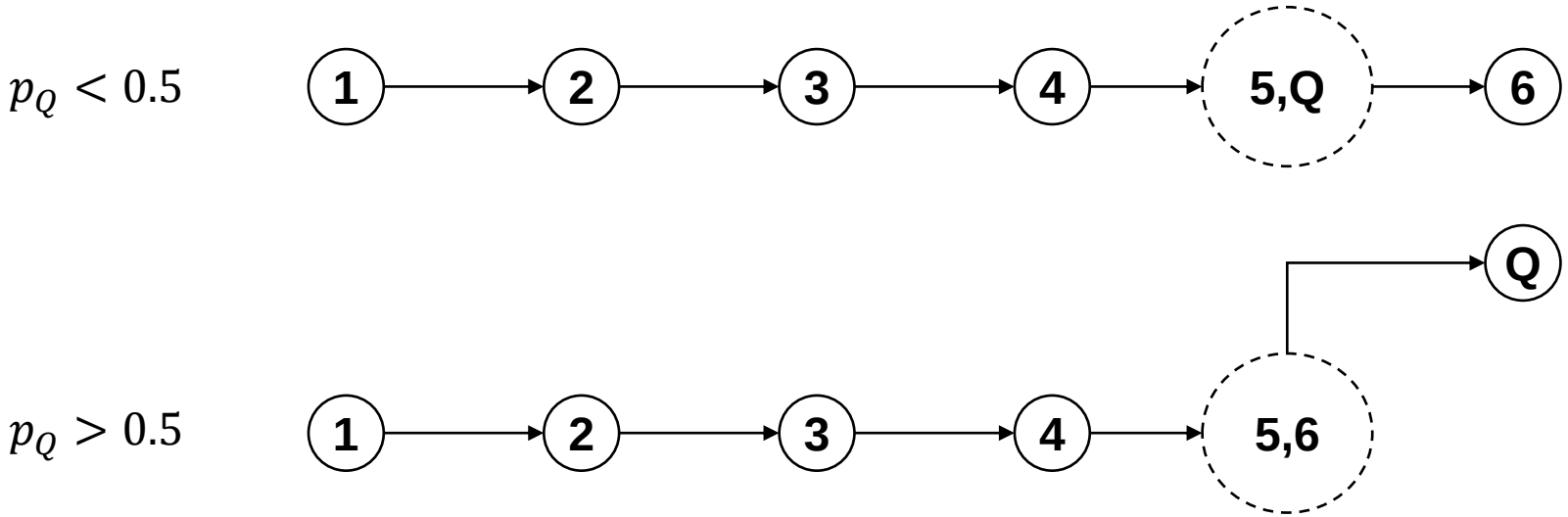
# ILLUSTRATIVE EXAMPLE: FLOW LINE

**MANUFACTURING SYSTEM:**

**Inter arrivals: EXPO(1), Processing times: EXPO(1), Buffers: 10**




**OBTAINED MODELS:**



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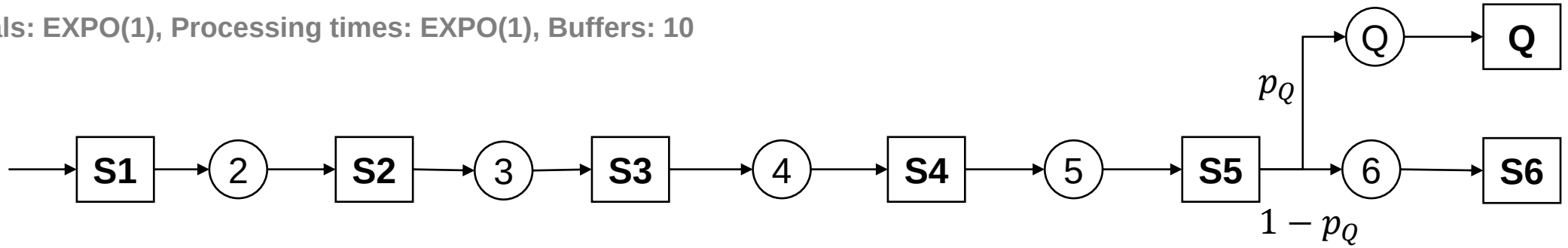
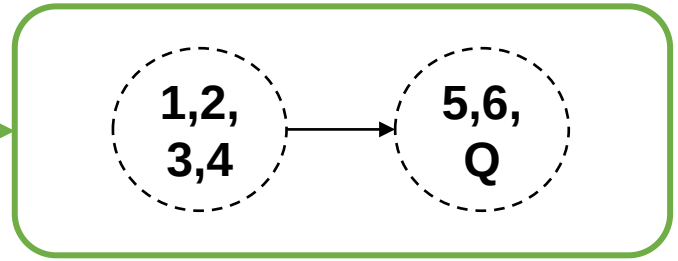


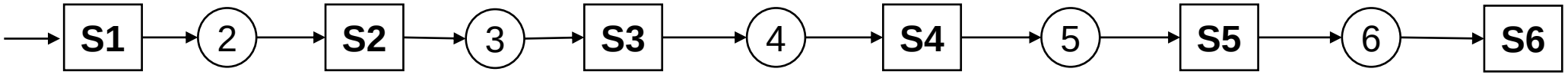

**OBTAINED MODELS:**

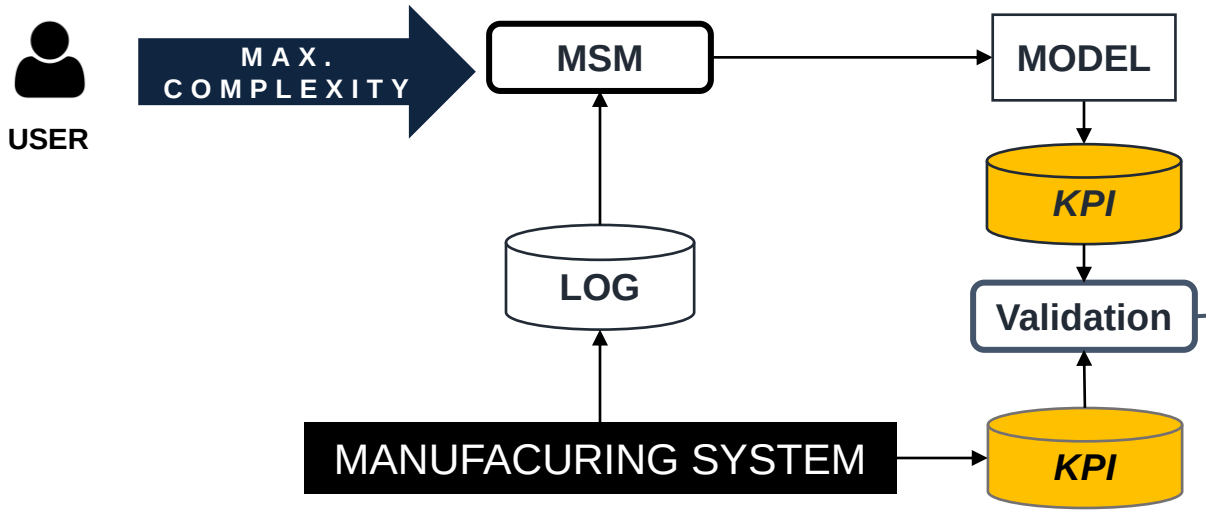
| | Model Nodes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Step** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **Score** |
| **1** | S1 | S2 | S3 | S4 | S5 | S6 | SQ | 0.400 |
| **2** | S1 | S2 | S3 | S4 | (S5, SQ) | S6 | | 0.367 |
| **3** | S1 | S2 | S3 | S4 | (S5, SQ, S6) | | | 0.333 |
| **4** | (S1,S2) | S3 | S4 | (S5, SQ, S6) | | | | 0.300 |
| **5** | (S1,S2,S3) | S4 | (S5, SQ, S6) | | | | | 0.267 |
| **6** | (S1,S2,S3,S4) | (S5, SQ, S6) | | | | | | 0.233 |



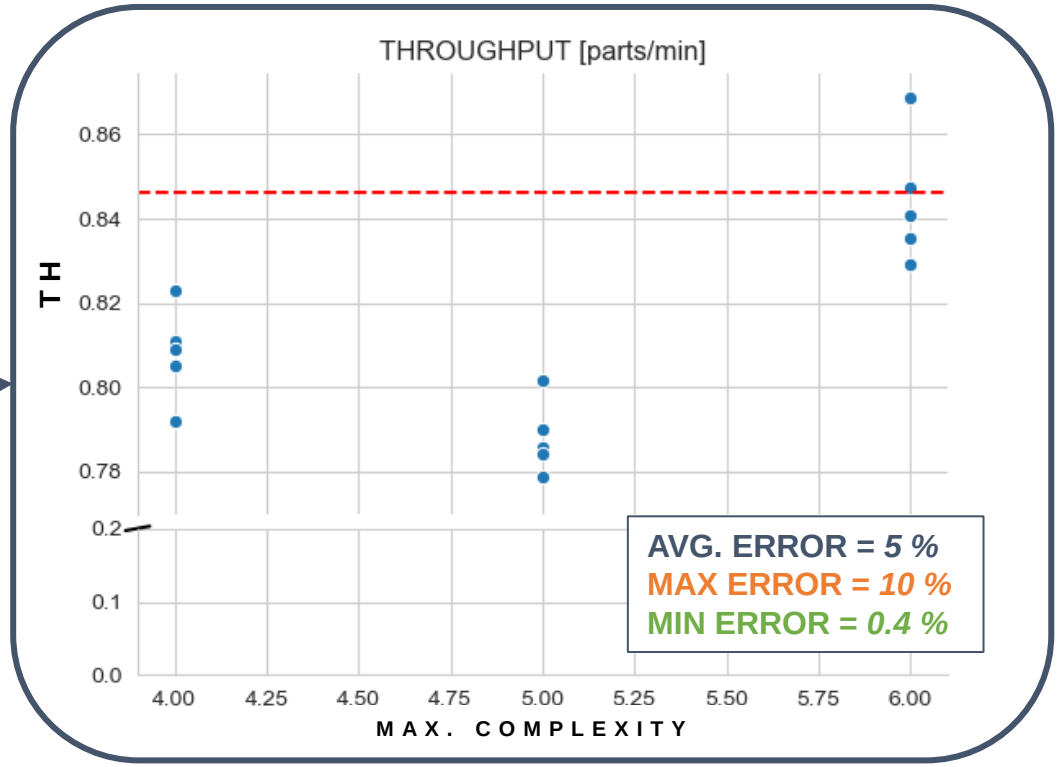
# VALIDATION: SIMULATED FLOW LINE

Inter arrivals: EXPO(1), Processing times: EXPO(1), Buffers: 10



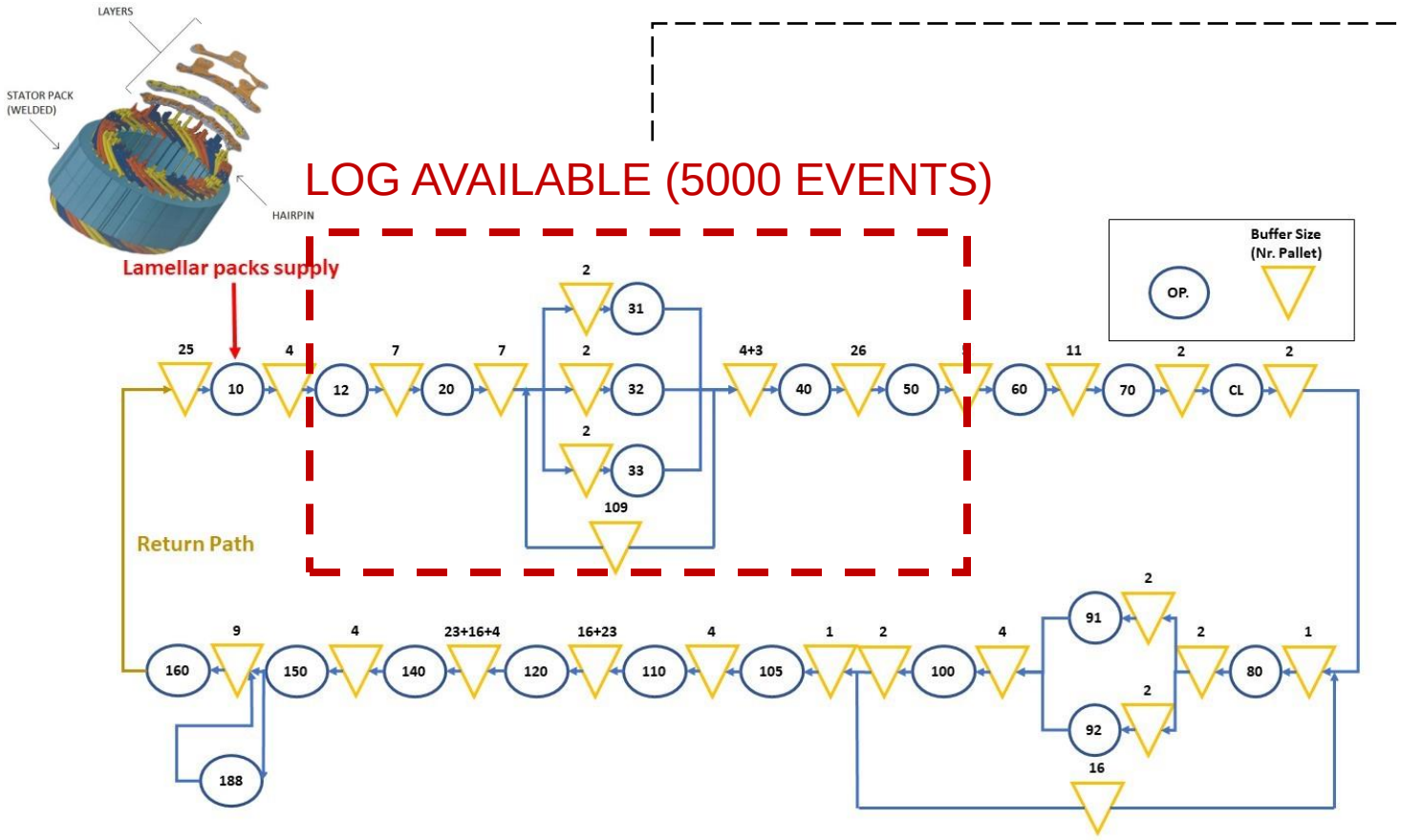



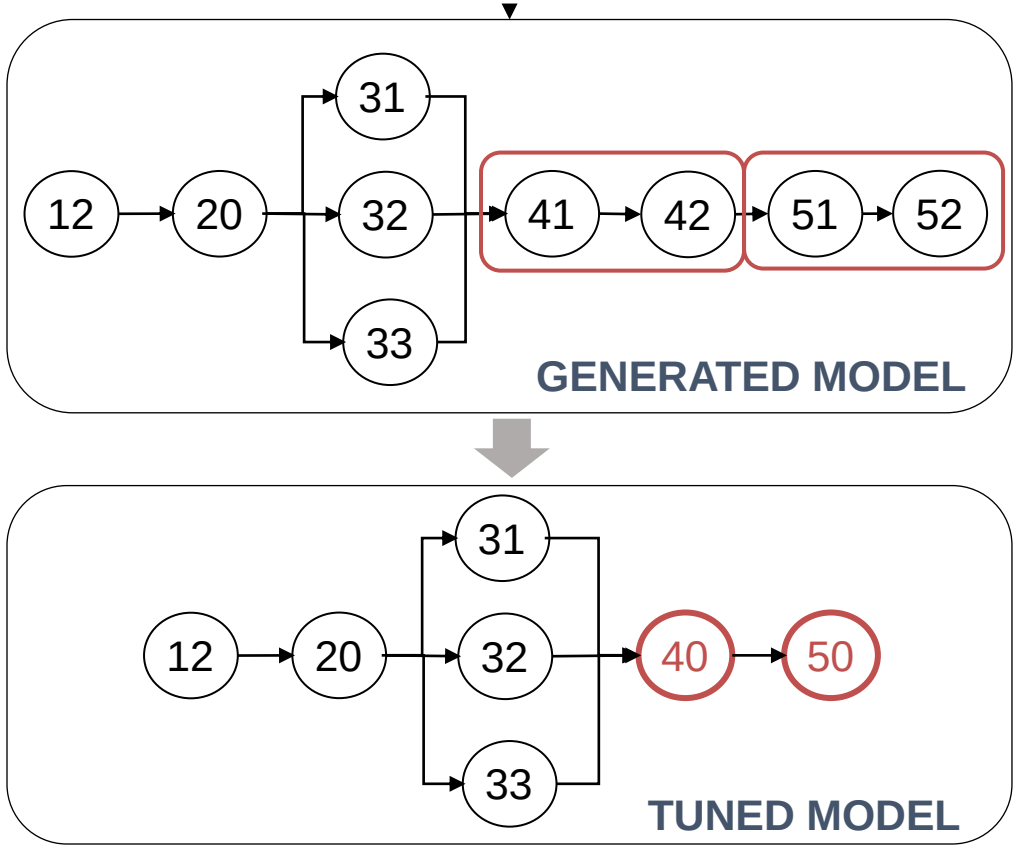

**PERFORMANCE COMPARISON:**




**NOTICE: Validation can also be applied online (Online Model Adaptation)**

# VALIDATION: REAL PRODUCTION LINE




MANUFACURING SYSTEM (EV STATOR LINE)

DIGITAL MODEL (IN LESS THAN 30 s)

# 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
- **Log-preprocessing is still necessary** (e.g., events with same timestamp are removed)

## FUTURE DEVELOPMENTS

- Investigate the **value of prior information**
- Investigate Simulation-Optimization applications
- Investigation of **smarter inheritance rules** for nodes aggregation, improve local search
- Understand the behavior with **very large logs**

# 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.

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**OTHER PUBLICATIONS**