POLITECNICO
MILANO 1863

DIPARTIMENTO DI MECCANICA
mecc PhD

Giovanni Lugaresi

Automated Generation and Exploitation of Discrete Event Simulation Models for Decision Making in Manufacturing

Supervisor: Prof. Andrea MATTA
Tutor: Prof. Giorgio COLOMBO

PhD Programme Coordinator: Prof. Daniele ROCCHI

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Ph.D. XXXIII Cycle (Industry of the Future)

CONTENTS

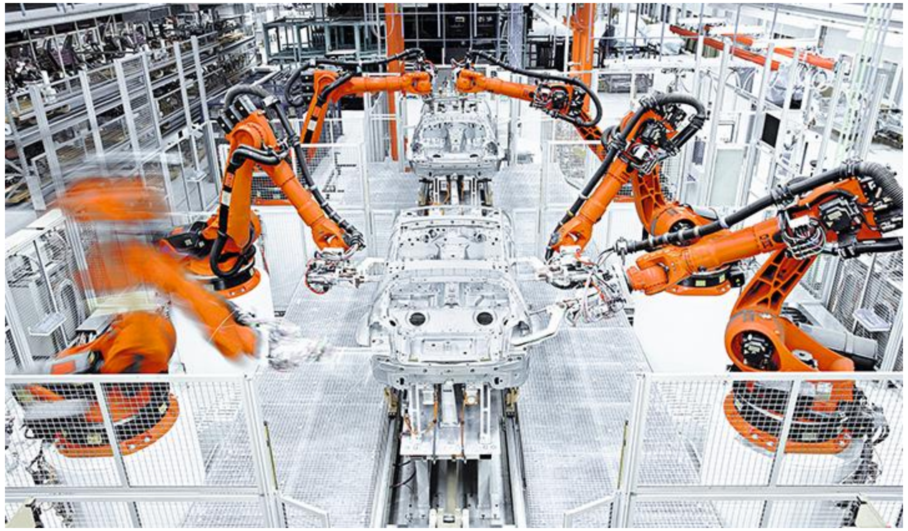
CONTENTS

Introduction

INDUSTRIAL RELEVANCE

CHALLENGES

- **Unpredictable market demand**
- **Complexity**
- **Pressures on cost reduction**
- **High-level of automation**

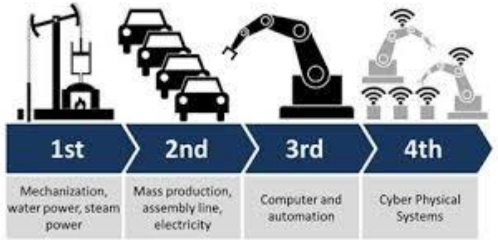


- **Failures impact**
- **Harder control**
- **Longer lead times**
- …

DIGITAL SUPPORT TOOLS
FOR PRODUCTION PLANNING AND CONTROL

OPPORTUNITIES

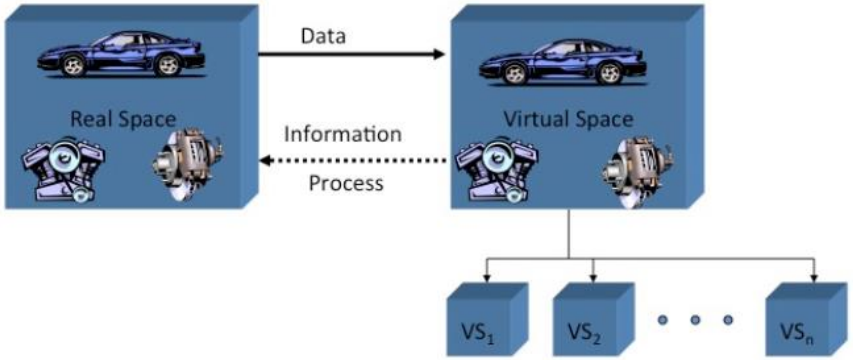
- ✓ **Collecting information** with high frequency
- ✓ Understanding **emerging behaviors**
- ✓ Evaluating alternative **scenarios**
- ✓ Affordable **data analytics**



INDUSTRIAL RELEVANCE

DIGITAL TWIN

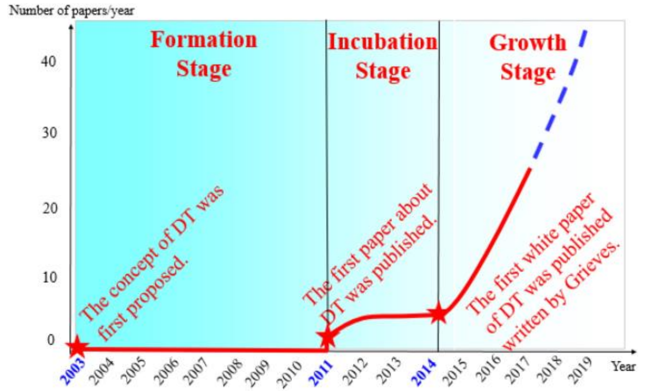
*"It is based on the idea that a **digital informational construct** about a physical system could be created as an **entity on its own**. This digital information would be a "twin" of the information that was embedded within the physical system itself and be **linked** with that physical system through the **entire lifecycle** of the system.."*



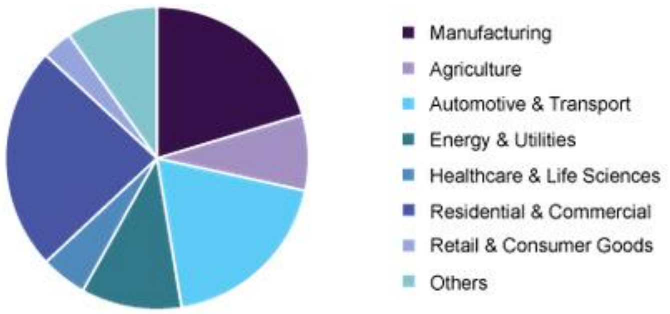
Grieves, Michael. "Origins of the digital twin concept." *Florida Institute of Technology* (2016).

INDUSTRIAL RELEVANCE

DIGITAL TWIN



source: Tao, Fei, et al. "Digital twin in industry: State-of-the-art." *IEEE Transactions on Industrial Informatics* 15.4 (2018): 2405-2415.



source: Digital Twin Market Size, Share & Trends Analysis Report By End-use (Automotive & Transport, Retail & Consumer Goods, Agriculture, Manufacturing, Energy & Utilities), By Region, And Segment Forecasts, 2021 – 2028. Grand View Research.

75%

of organizations that have implemented IoT Already Use Digital Twins or Plan to Within a Year

13%

of organizations that have Implemented IoT claim to already use Digital Twins

"by 2022, over

66%

of companies that have implemented IoT will have deployed at least one digital twin in production"

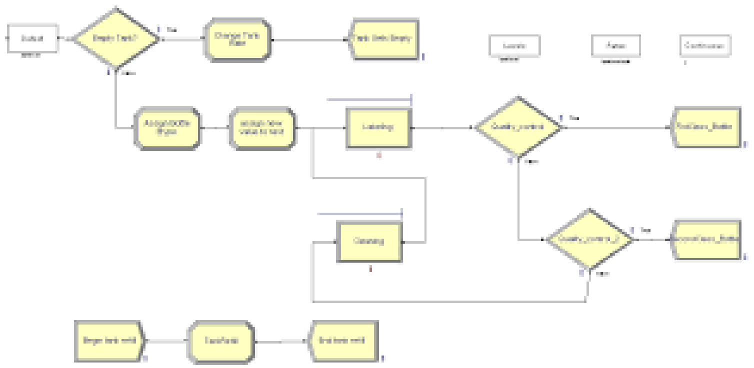
[Benoit Lheureux, Research vice president at Gartner]

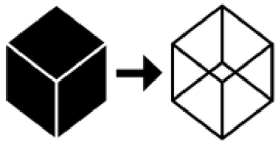
source: Gartner study of IoT implementation conducted July 2018 through August 2018.

REAL-TIME SIMULATION

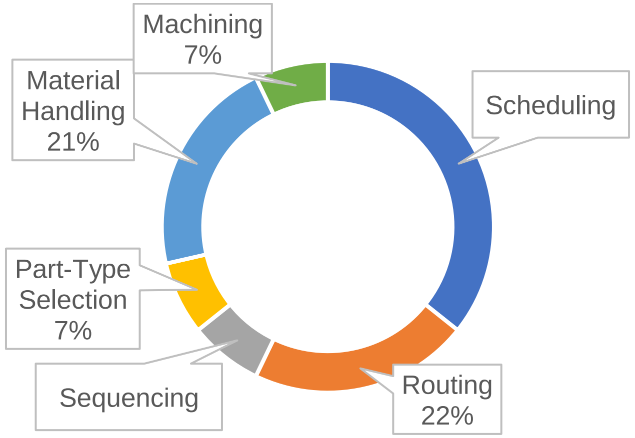
DISCRETE EVENT SIMULATION

- ✓ ***digital informational construct***
- ✓ ***entity on its own****.*
- ✓ ***linked*** *with the physical system*
- ✓ *active in the* ***entire lifecycle*** *of the system*





DIGITAL TWIN FOR PRODUCTION PLANNING AND CONTROL

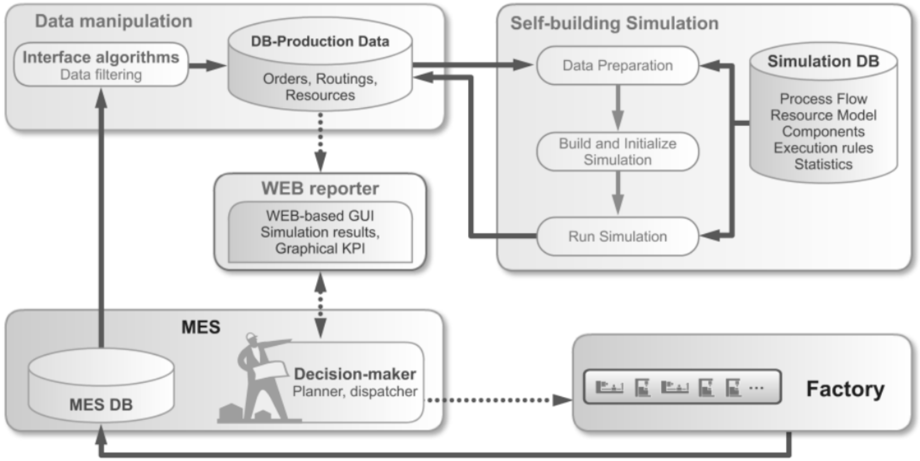


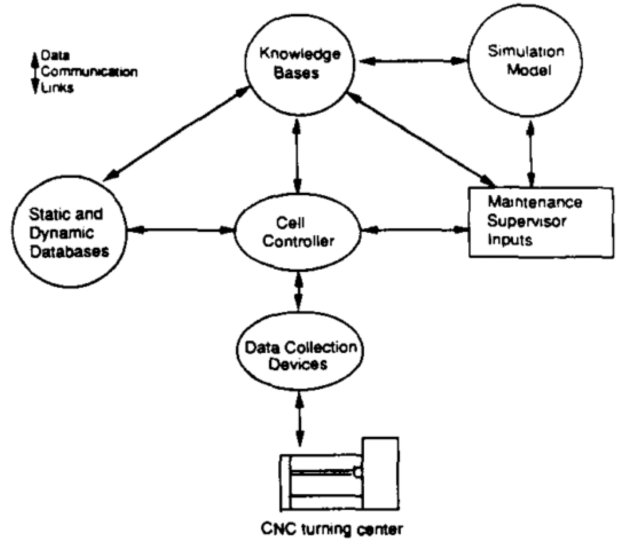
2018→ Short initial survey: 100+ papers

Lugaresi, Giovanni, and Andrea Matta. "Real-time simulation in manufacturing systems: Challenges and research directions." *2018 Winter Simulation Conference (WSC)*. IEEE, 2018.

REAL-TIME SIMULATION

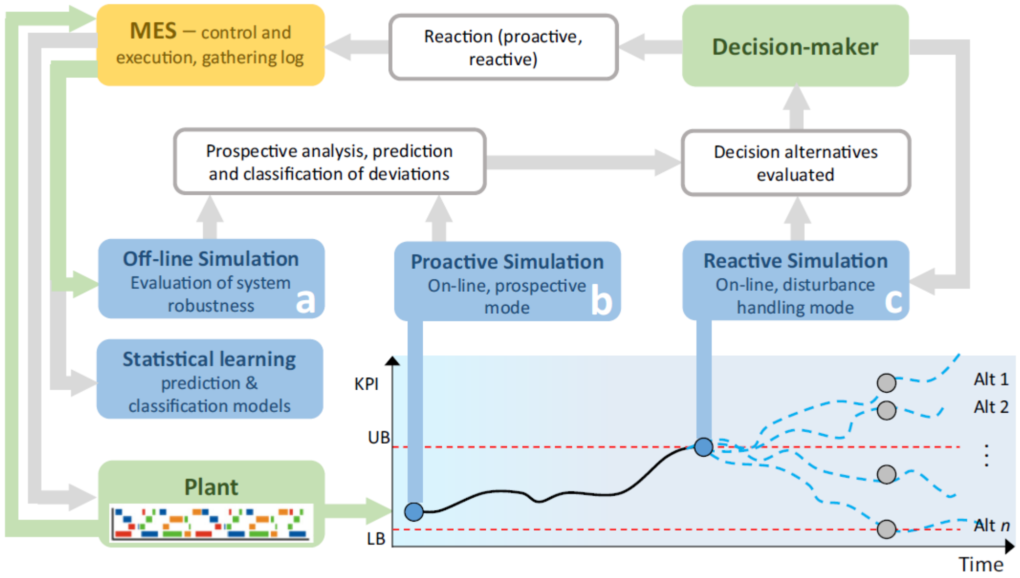
1990 TIME TODAY





Kádár, B., et al. "Co-analysing situations and production control rules in a large-scale manufacturing environment." *Proc. of the 44th CIRP conference on manufacturing systems*. 2011.

Monostori, László, et al. "Cyber-physical systems in manufacturing." *Cirp Annals* 65.2 (2016): 621-641.



Manivannan, S., and Jerry Banks. "Towards a real-time knowledge-based simulation system for diagnosing machine tool failure." Proceedings of IEEE Winter Simulation Conference, 1990.

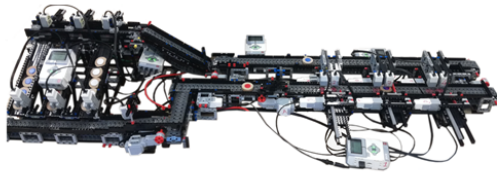
REAL-TIME SIMULATION

RESEARCH TOPIC	WHY IS IT IMPORTANT
Data Management	• The existing approaches do not consider the real-time issues arising from big streams of data coming towards a centralized unit. • Interfaces between different sources have to be defined. • Data and standards (e.g., IEC 61499) are a central topic in I4.0-related research.
Adaptability PHD FOCUS	• Finding the simulation model that best fits the data (alignment). • The simulator will be subject to very frequent changes. • RTS models may never reach the steady state. • The performance measures may have to be computed in the warm-up phase.
Model Generation (e.g., generation from a data log)	• In certain situations, a simulator might not even exist and has to be created.
Online Validation	• RTS loops require it to be done **online**. • Transient phases become critical; it is not possible to use **aggregate KPIs** for validation.
Reactiveness (i.e. Fast-answering capabilities)	• Their development can further unlock **new application scenarios** for RTS. • Recent research shows that it is possible to make use of multiple sub-models of the system to **increase the accuracy** of the model in predicting KPIs.

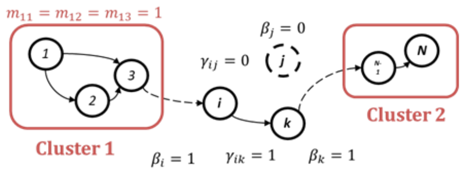
Lugaresi, Giovanni, and Andrea Matta. "Real-time simulation in manufacturing systems: Challenges and research directions." *2018 Winter Simulation Conference (WSC)*. IEEE, 2018.

THESIS CONTENTS

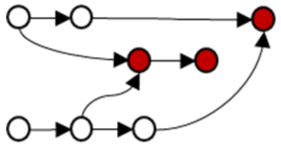
Contents of digitally-assisted production	Challenges	Thesis Contents
Real-time Simulation: Data Handling, Synchronization, Model Validation, Initialization, Model Generation, Proactive Policies	Testing online decision making approaches in a realistic environment	**Testing Platform based on lab-scale models of common manufacturing systems**
Model Generation: System Discovery, Model Tuning, Policy Discovery, Data Integration, Model Conversion, Execution	Model adaptation toward the proper level of detail	**A model tuning method that allows users to adjust the model granularity**
Complex Manufacturing Systems: Disassembly, Assembly, Job shops, Flow shops	Generation of a complete and accurate model	**An approach for graph-model completion in case of assembly operations**



Testing Platform based on lab-scale models of common manufacturing systems



A model tuning method that allows users to adjust the model granularity



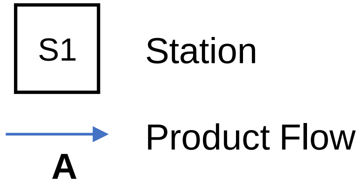
An approach for graph-model completion in case of assembly operations

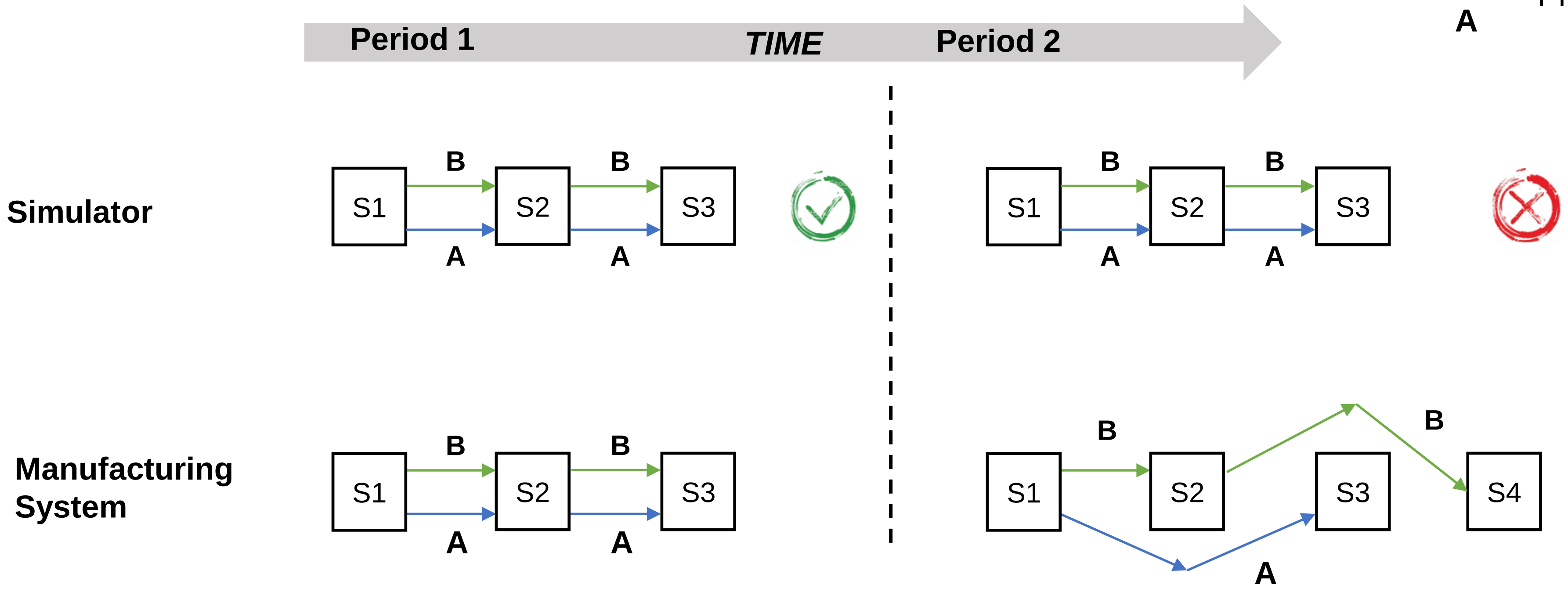
FOCUS OF THIS PRESENTATION

Automated Model Generation

PROBLEM INTRODUCTION

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

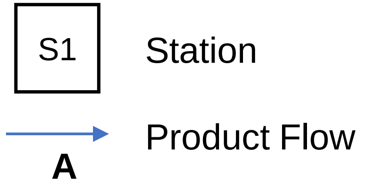


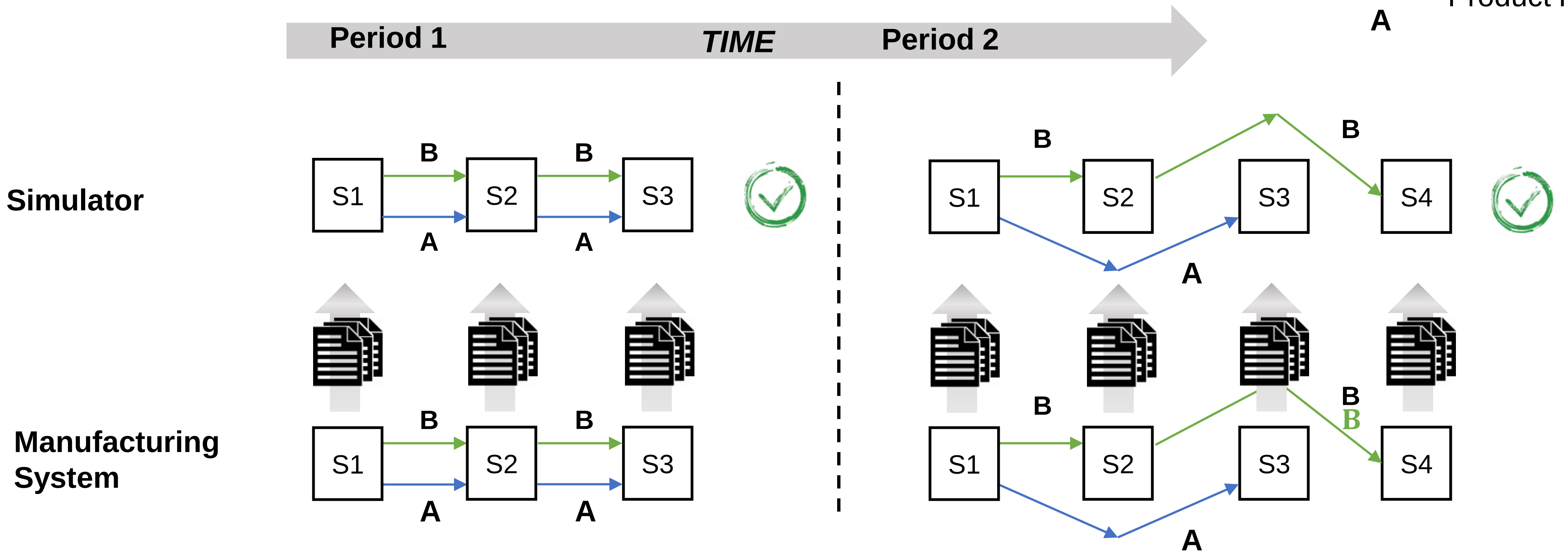


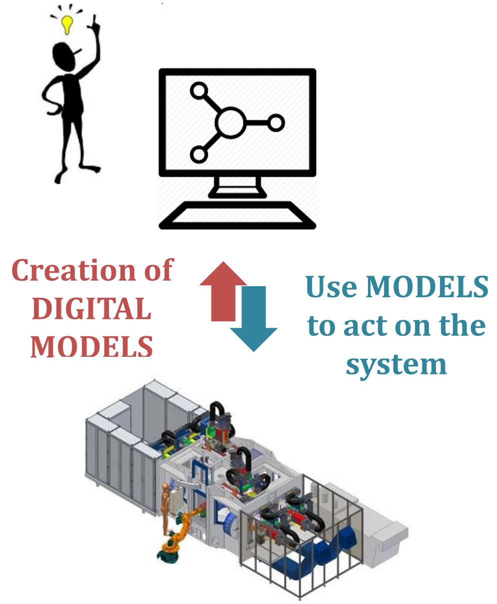
Manufacturing systems change frequently due to external drivers (e.g. demand, price uncertainty).
Hence, **current simulation techniques are poor** as tools for **short-term decision making**.

PROBLEM INTRODUCTION

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



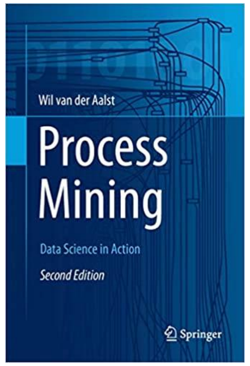




By exploiting the data produced by the parts and resources, it is possible to achieve higher reactivity in the simulation model building phase.

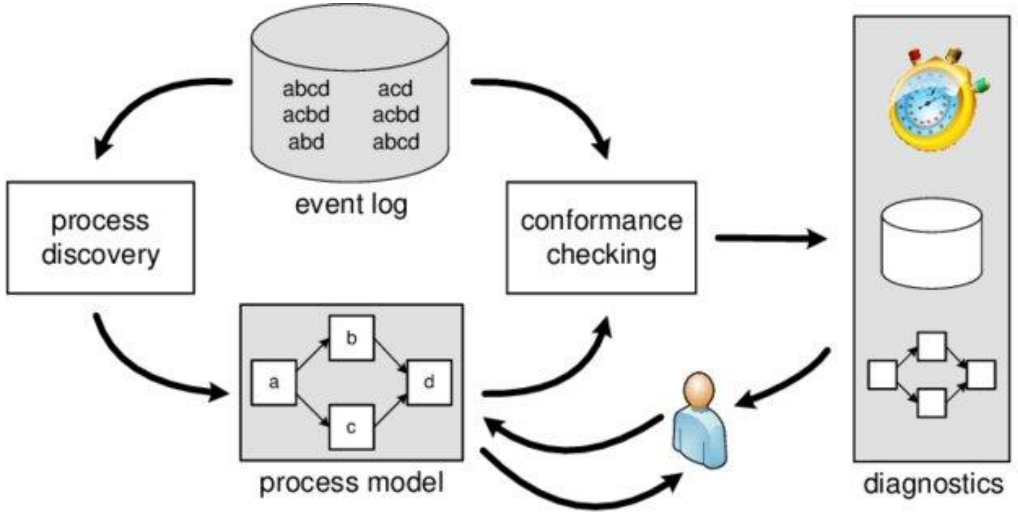
PROBLEM INTRODUCTION

PROCESS MINING



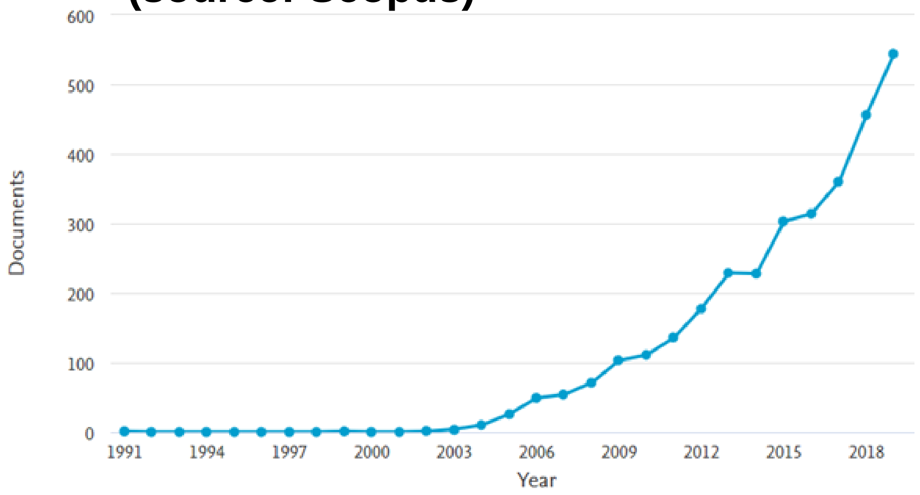
a novel discipline that is concerned with deriving useful insights from operational process execution logs:

- **Process discovery**: the automated recognition of a process model from what observed in the execution log.
- **Conformance checking:** analysis of the relation between the intended behavior of a process and the execution logs.
- **Enhancement**: techniques that take as input an event log and an existing model and produce as output an enhanced model.



Aalst, Wil. (2012). Distributed Process Discovery and Conformance Checking.

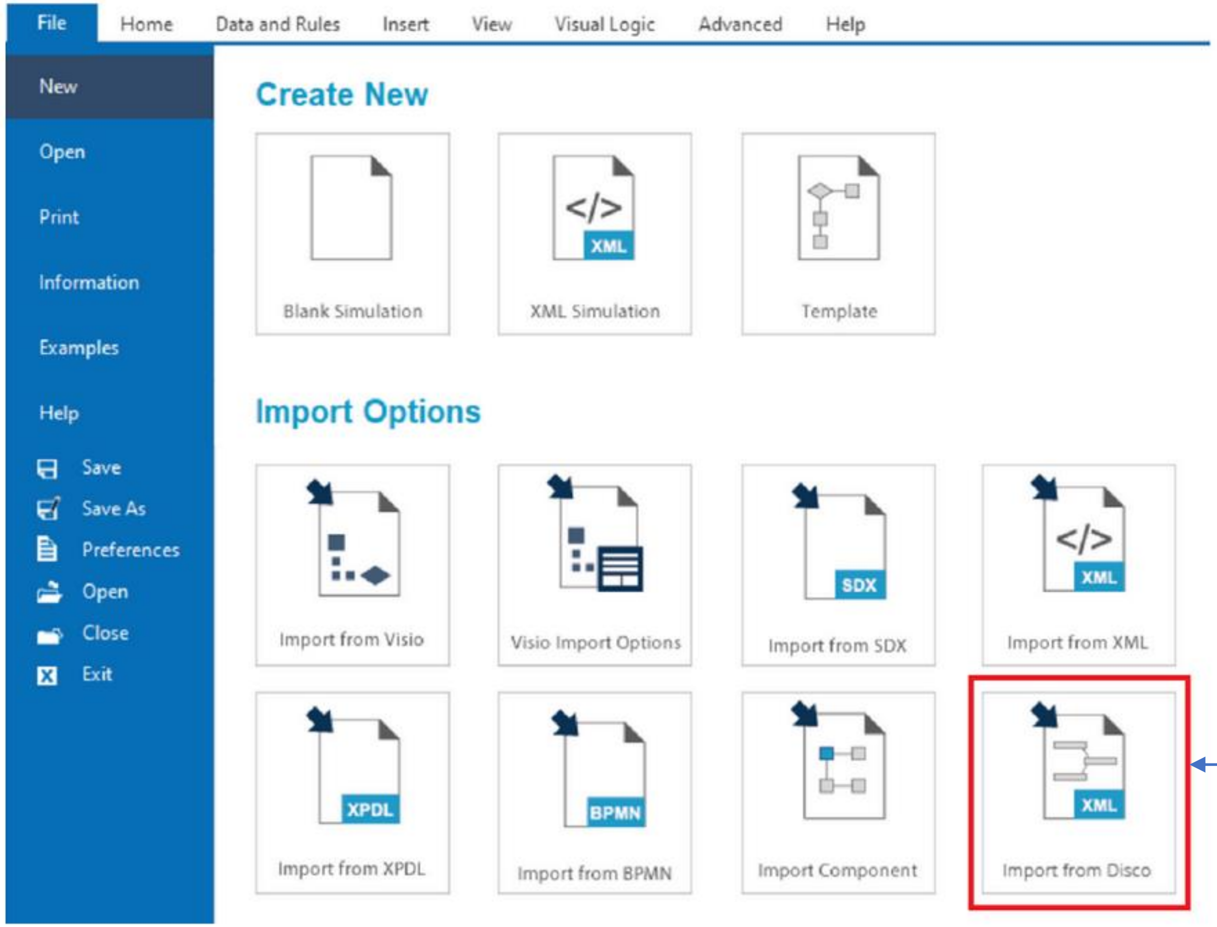
Publications on process mining (source: Scopus)

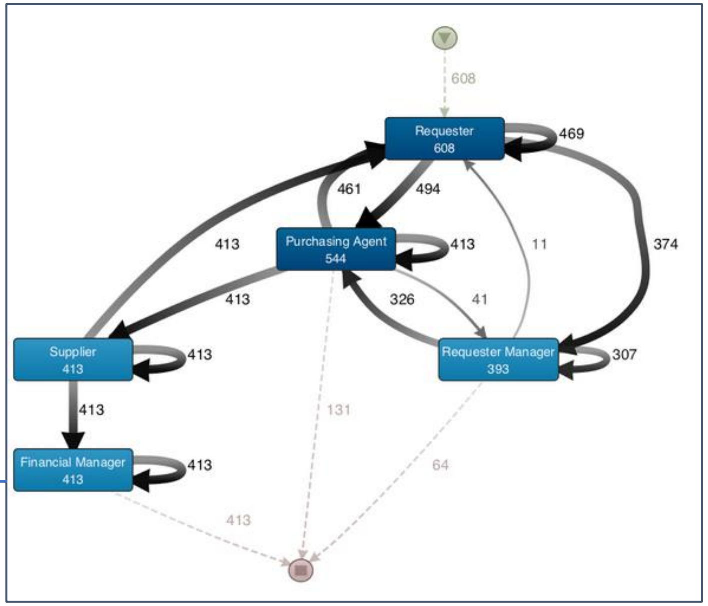


PROBLEM INTRODUCTION

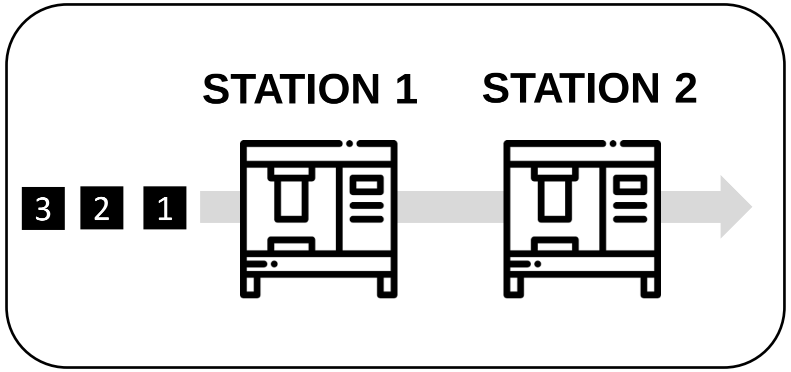
- Since process mining generates models, it has been soon connected with the **generation of discrete event simulation models.**
- Some software packages allow to **import process mining results** to construct a model.

SIMUL8
+
Disco
by Fluxicon





MODEL GENERATION BASICS



MANUFACTURING SYSTEM

EVENT LOG:

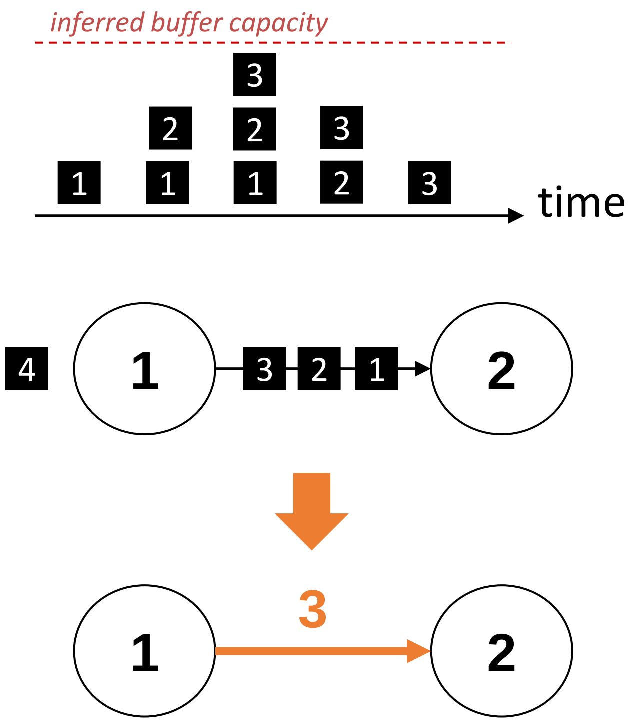
Timestamp [s]	ID	Activity
1	1	S1
2	1	S2
2	2	S1
3	2	S2
4	3	S1
…	…	…

TRACES: 1 {S1, S2}
2 {S1, S2} …

ACTIVITY RELATIONSHIPS:
"Station 2 follows Station 1", …

PARAMETERS (SYSTEM PROPERTIES)

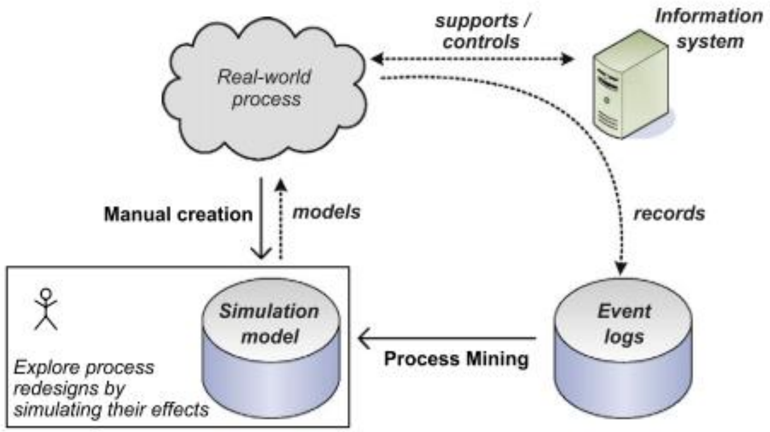
EXAMPLE: CAPACITY



SCIENTIFIC RELEVANCE

Applications of Process Mining in manufacturing (selected):

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.

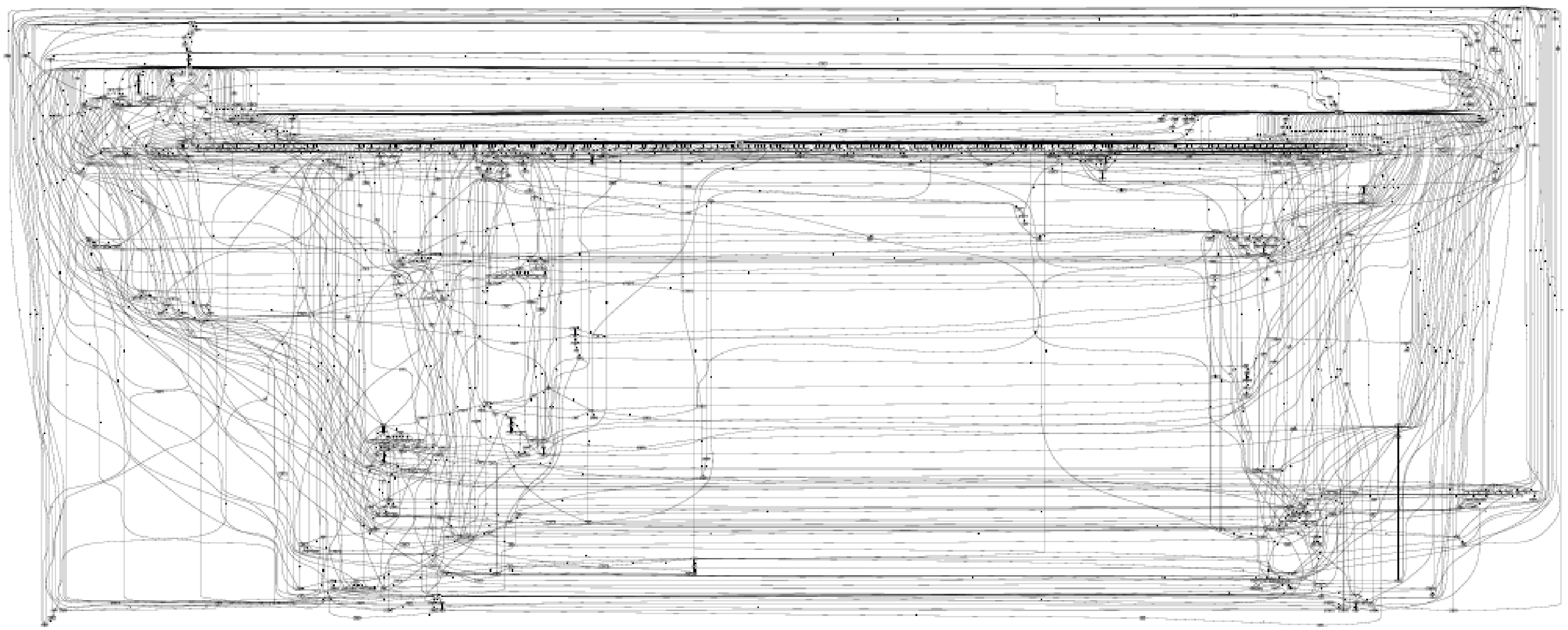
SCOPUS: 0 results for the query: "*process mining"* AND *"manufacturing"* AND *"discrete event simulation*" (15/06/2021)

SCIENTIFIC RELEVANCE

Limitations of current approaches:

Industry produces a very large volume of data, more sensors means more data points. The result can be a graph of very little practical use.

Such problem is known as the *spaghetti model* effect:



Example of a *spaghetti* model.
Source: Van Der Aalst, Wil. "Data science in action." *Process mining*. Springer, Berlin, Heidelberg, 2016. 3-23.

SCIENTIFIC RELEVANCE

MODEL TUNING

1,2 → 3,4 → 5,6

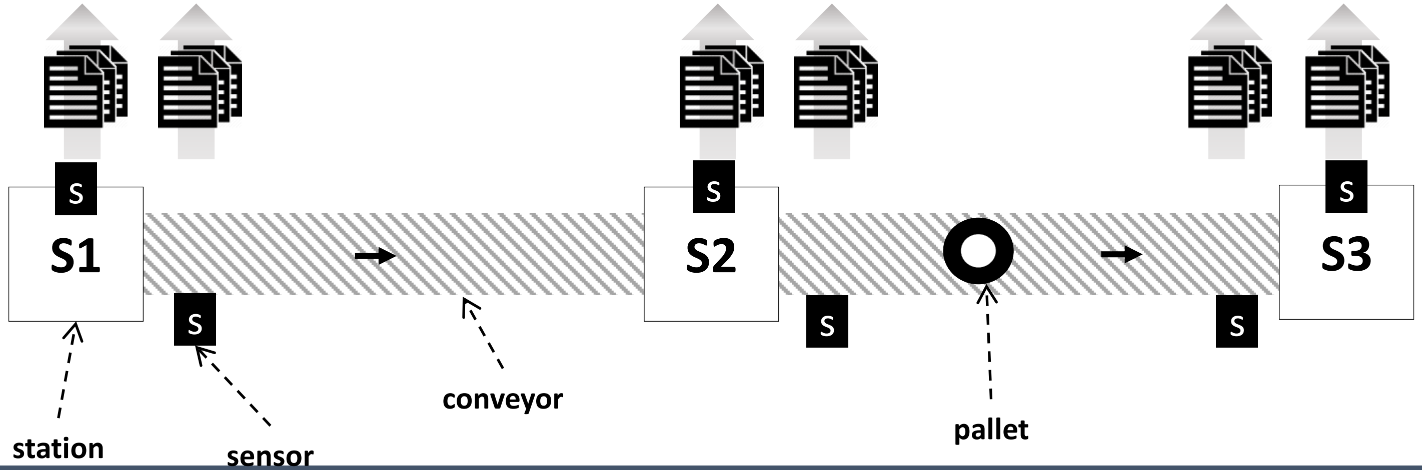
MODEL GENERATION
(Traditional Process Mining)

1 → 2 → 3 → 4 → 5 → 6

Part ID	Timestamp	Sensor (activity)
2	2020-[illegible]7:40	S1
2	2020-[illegible]7:44	S2
2	2020-11-[illegible]:37:47	S3
2	2020-11-23 16:37:51	S4
3	2020-11-23 16:37:52	S1
3	2020-11-23 16:37:54	S2
2	2020-11-23 16:37:57	S5
2	20[illegible]1-23 16[illegible]	S6
4	20[illegible]1-23 16:[illegible]0	S1
4	2020-11-23 16:38:02	S2
3	2020-11-23 16:38:06	S3
3	2020-11-23 16:38:06	S4
3	2020-11-23 16:38:08	S5

EVENT LOG

MANUF. SYSTEM



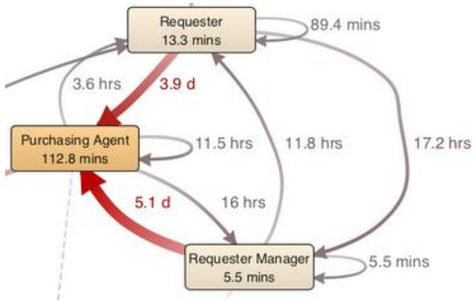
SCIENTIFIC RELEVANCE

Limitations of current approaches for model tuning:

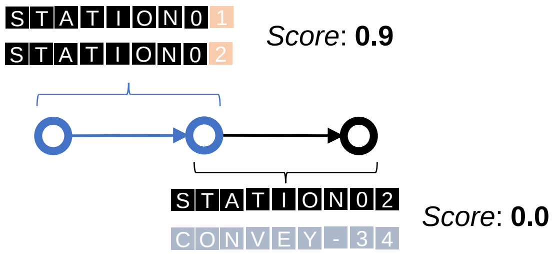
Method	Advantages	Disadvantages
“Traditional” Process Mining (alpha algorithm, heuristic mining) [1]	• Complete graph is easier to understand for users	• Almost all adjustments are manual • Forces a selection of nodes
Fuzzy Mining [2]	• Correlation Measures among activities • Simplified graph version can be obtained in a short time	• Forces to choose a metric for clustering • Ineffective on some types of graphs
Trace Clustering [3]	• Selection of graphs with a lower complexity	• Clusters with a high importance might be excluded • Separate views for all

Our approach aims to:
Fully automated
Multiple metrics can be defined and used
No information loss

HEURISTIC MINING:



FUZZY MINING:

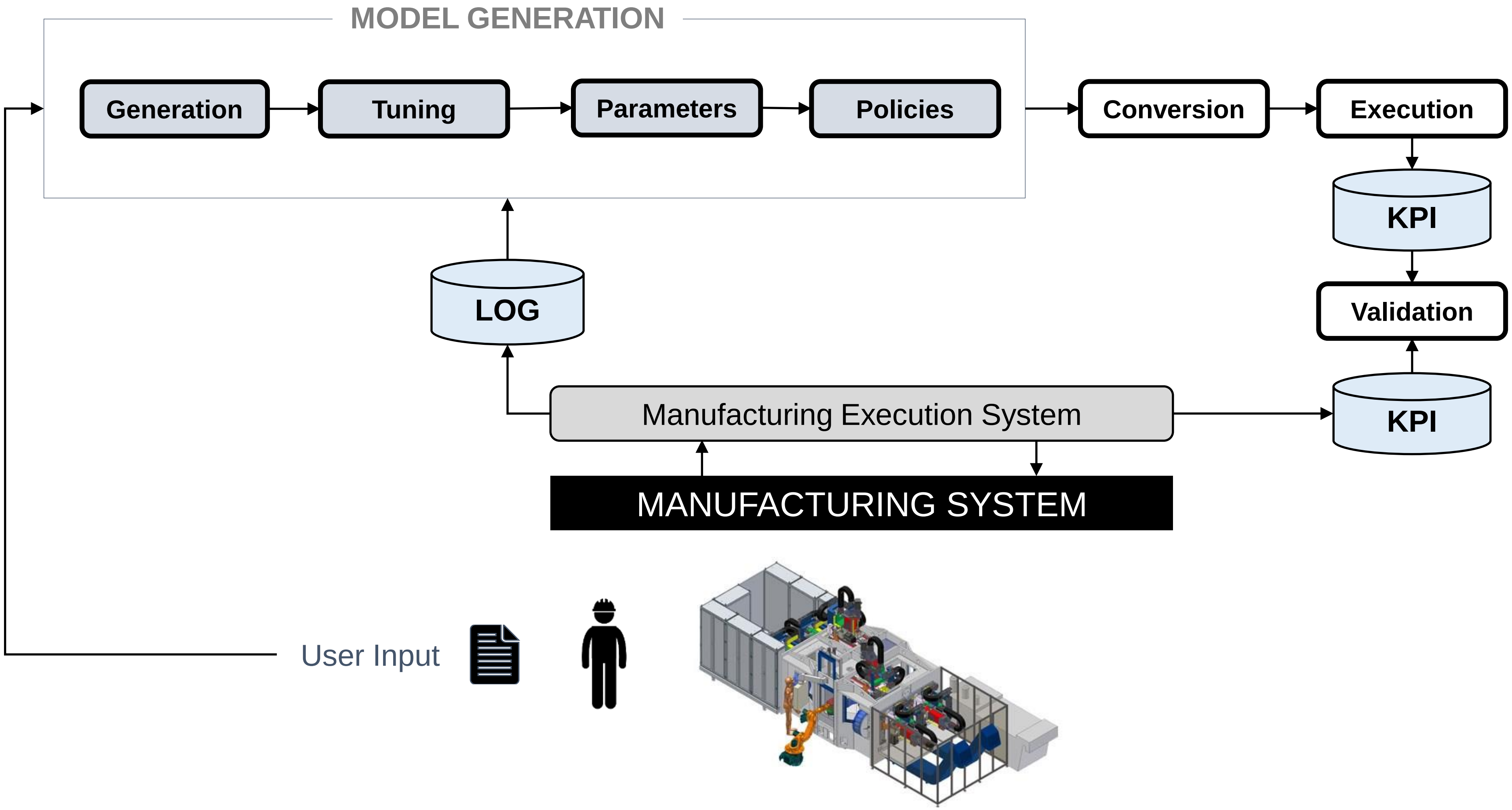


TRACE CLUSTERING:

Case ID	A	B	C	D	E	F	G	H	I
	Activity Profile								
1	1	1	0	1	1	1	1	0	1
2	1	1	1	1	1	0	1	0	1
3	1	1	0	1	1	1	1	0	1
4	1	1	1	1	0	0	0	1	1
5	1	1	1	1	1	0	1	1	0
6	1	1	0	1	0	0	0	1	1

[1] Weijters, A. J. M. M., Wil MP van Der Aalst, and AK Alves De Medeiros. "Process mining with the heuristics miner-algorithm." Technische Universiteit Eindhoven, Tech. Rep. WP 166 (2006): 1-34.
[2] 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.
[3] Song, Minseok, Christian W. Günther, and Wil MP Van der Aalst. "Trace clustering in process mining." International conference on business process management. Springer, Berlin, Heidelberg, 2008.

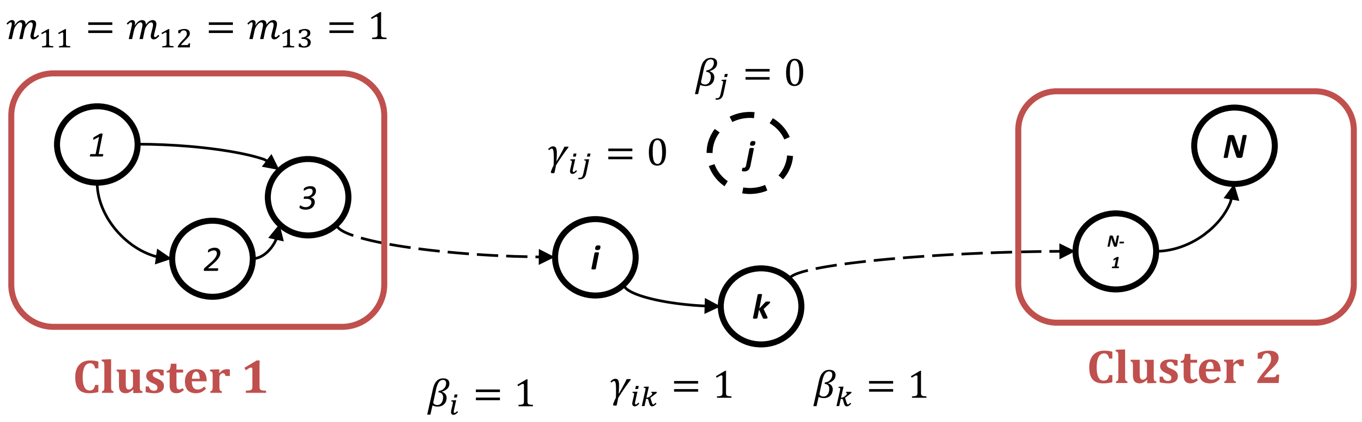
OVERVIEW


MODEL GENERATION
Generation
Tuning
Parameters
Policies
Conversion
Execution
KPI
Validation
KPI
LOG
Manufacturing Execution System
MANUFACTURING SYSTEM
User Input

MODEL TUNING METHODOLOGY

INPUT DATA	
S_N^{max}	Nodes complexity threshold
S_A^{max}	Arcs complexity threshold
X_{jk}	Connection matrix between activities j and k.
k_{max}	Maximum number of iterations allowed.
ζ	1 = self-loops allowed, 0 otherwise
v_{in}, v_{out}	Maximum input/output arcs from a node

DECISION VARIABLES	
β	Boolean vector such that $\beta_i = 1$ if the *i*-th activity is considered for the inclusion in the network, $\beta_i = 0$ otherwise; it represents the list of activities that are used in the network.
Γ	Boolean matrix representing the activity, its elements are $\gamma_{ij} = 1$ if event type I is followed by event type *j*.
M	Boolean matrix. The values represent the clusteting. Hence, m_{ik} equals 1 if the *i*-th cluster includes the *k*-th activity.

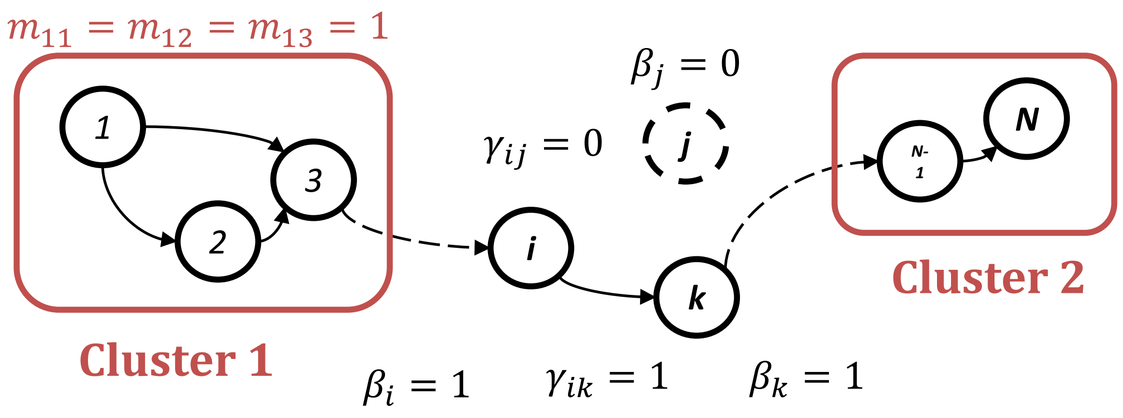


MODEL TUNING METHODOLOGY

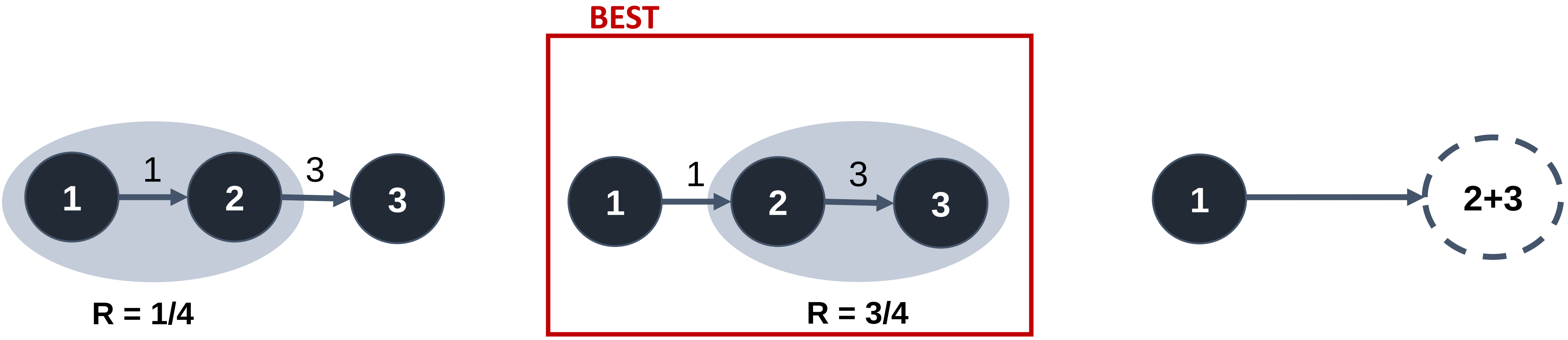
OBJECTIVE: Tune the model toward a reasonable size.

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

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



$S_N^{max} = 2$



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

MODEL TUNING METHODOLOGY

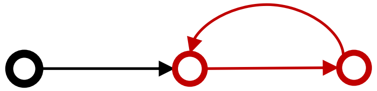
R1: CAPACITY

$$R_1(\Omega) = r_1^{(A)} \frac{\sum_{a\in\mathbb{A}} c_a}{\sum_{a\in\mathbb{A}_0} c_a} + r_1^{(N)} \frac{\sum_{n\in\mathbb{N}} \kappa_n}{\sum_{n\in\mathbb{N}_0} \kappa_n}$$

R2: CONTEMPORARY EVENTS (BATCHING)

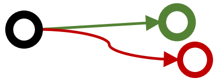
$$R_2(\Omega) = \frac{r_2^{(A)}}{|\mathbb{A}|} \sum_{a\in\mathbb{A}} \left(1 - \frac{e_a}{f_a}\right) + \frac{r_2^{(N)}}{|\mathbb{N}|} \sum_{n\in\mathbb{N}} \left(1 - \frac{\xi_n}{\phi_n}\right)$$

R3: LOOPS



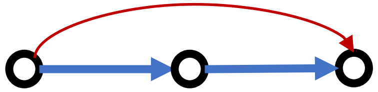
$$R_3(\Omega) = \frac{1}{|\mathbb{A}|} \sum_{n\in\mathbb{N}} \sum_{m\in\mathbb{N}} \gamma_{nm} \iota_{nm}$$

R4: ROUTING



$$R_4(\Omega) = r_4^{(in)} \sum_{n\in\mathbb{N}} \sum_{x\in\mathbb{S}_n} \gamma_{nx} + r_4^{(out)} \sum_{n\in\mathbb{N}} \sum_{l\in\mathbb{P}_n} \gamma_{ln}$$

R5: FREQUENCY



$$R_5(\Omega) = r_5^{(A)} \frac{\sum_{a\in\mathbb{A}} f_a}{\sum_{a\in\mathbb{A}_0} f_a} + r_5^{(N)} \frac{\sum_{n\in\mathbb{N}} \phi_n}{\sum_{n\in\mathbb{N}_0} \phi_n}$$

TOTAL SCORE OF MODEL Ω:

$$\Phi(\Omega) = \sum_i w_i R_i(\Omega)$$

NODES j ∈ ℕ:
- K_n : Capacity
- ϕ_n : Frequency
- ξ_n : Contemporary Activities

ARCS $a_i \in \mathbb{A}$:
- c_a : Capacity
- f_a : Frequency
- e_a: Contemporary Activities

MODEL Ω:
- γ_{ij} : node-arcs matrix
- ι_{ij} : Loops
- w_i: weight of i-th score

MODEL TUNING METHODOLOGY

CONSTRAINTS

OBJECTIVE FUNCTION

$$\max_{\Omega} \quad \Phi(\Omega)$$

Maximum Complexity

$$s.t. \quad \sum_i \beta_i \leq S_N^{max}$$

$$\sum_{ij} \gamma_{ij} \leq S_A^{max}$$

Clustering

$$\gamma_{ij} \leq \mathbf{MXM}^T \qquad \forall i,j$$

$$\sum_i m_{ik} \leq 1 \qquad \forall k$$

Flow Constraints

$$\gamma_{ij} \leq \beta_i \qquad \forall i,j$$

$$\gamma_{ij} \leq \beta_j \qquad \forall i,j$$

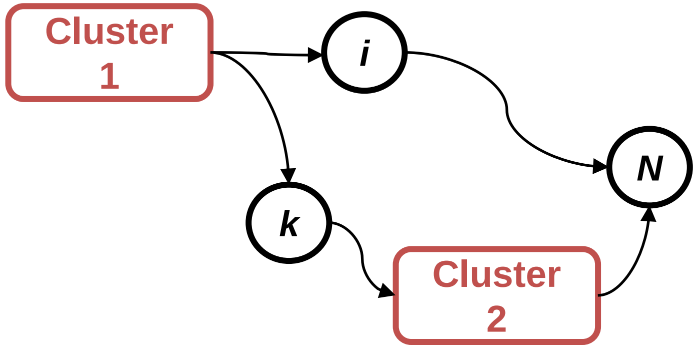
$$\gamma_{ii} \leq \zeta \qquad \forall i$$

$$\sum_i \gamma_{ij} \leq \nu_{in} \qquad \forall j$$

$$\sum_j \gamma_{ij} \leq \nu_{out} \qquad \forall i$$

$$\beta_i, \gamma_{ij}, M_{ik} \in \{0,1\} \qquad \forall i,j,k$$

→ **Solution: Ω^*, model that maximizes the "adequacy" score.**

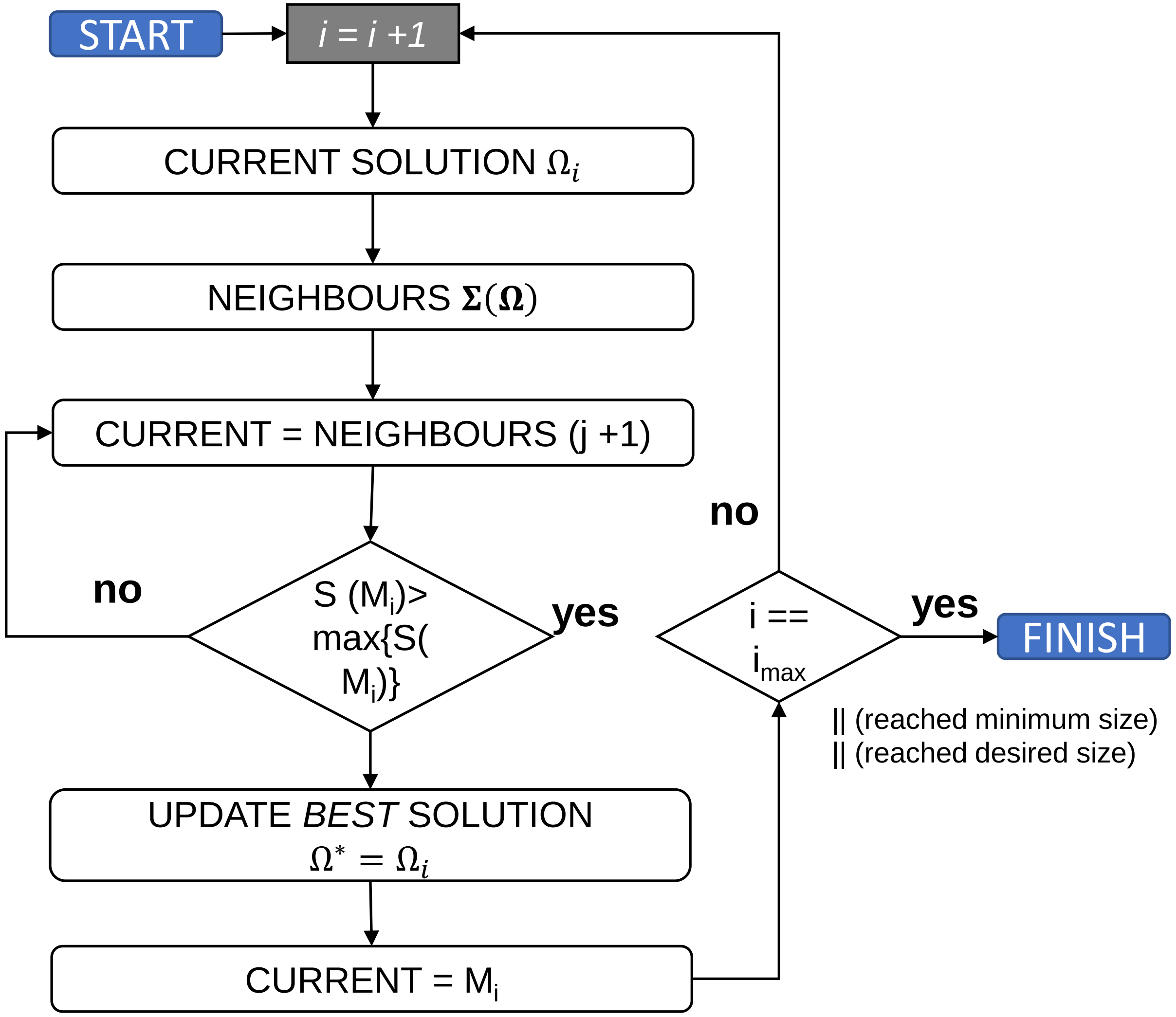


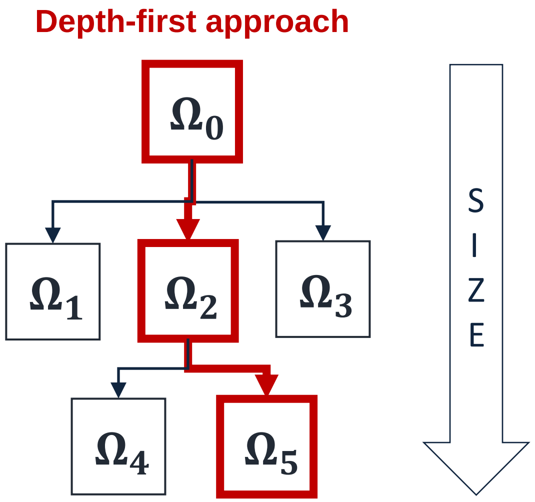
→ MODEL SOLVED THROUGH A DEPTH-FIRST LOCAL SEARCH ALGORITHM

MODEL TUNING: SOLUTION METHOD

LOCAL SEARCH

Heuristic



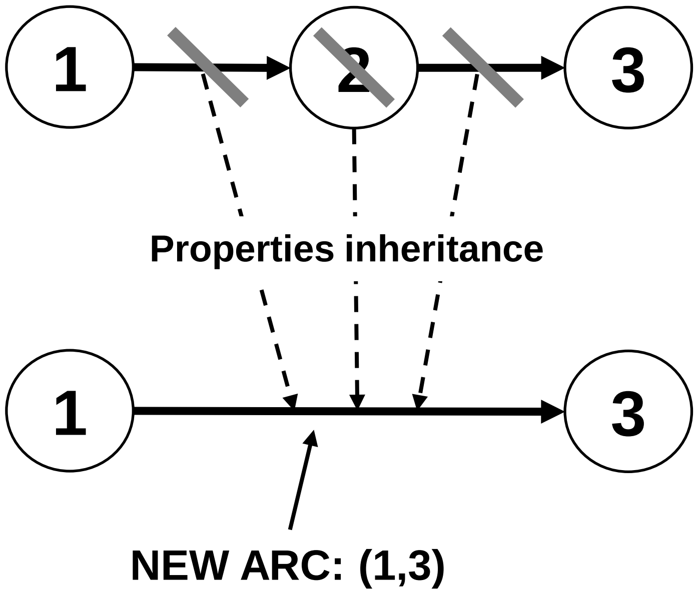


MODEL TUNING: SOLUTION METHOD

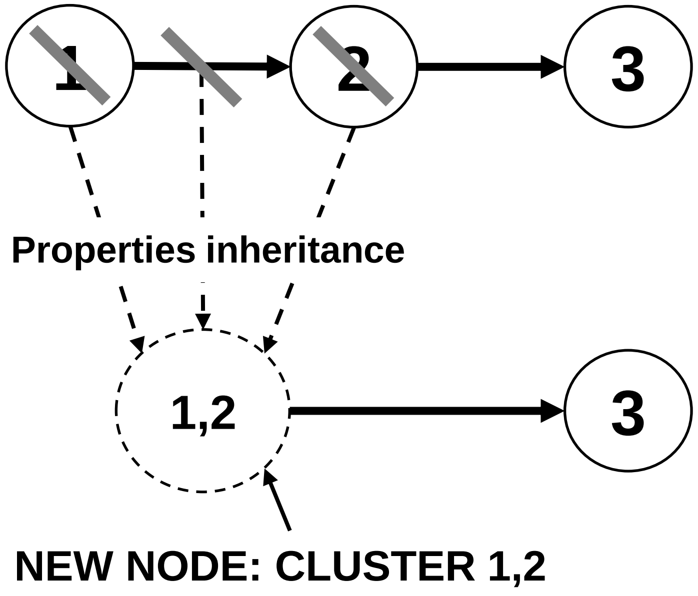
NEIGHBORS GENERATION

Modes

REDUCTION



AGGREGATION



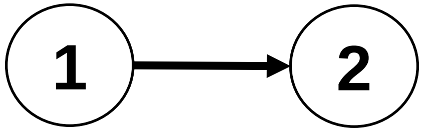
PROPERTIES

NODES j ∈ ℕ
- Cn_j : Capacity
- f_j : Frequency
- ξ_j^N : Contemporary Activities
- [*other*]

ARCS a_i ∈ 𝔸
- Ca_i : Capacity
- f_i : Frequency
- ξ_j^A: Contemporary Activities
- [*other*]

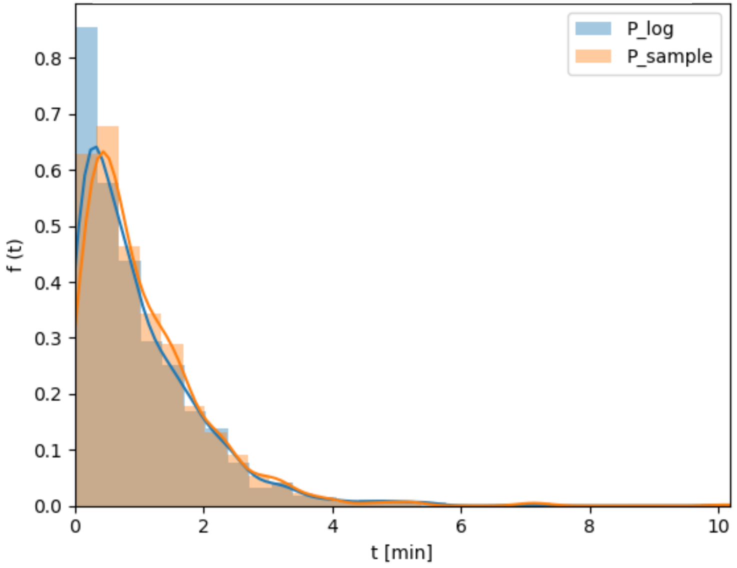
PARAMETERS AND POLICIES

Parameters such as processing times are estimated with a **Kernel Density Estimation** (Gaussian).

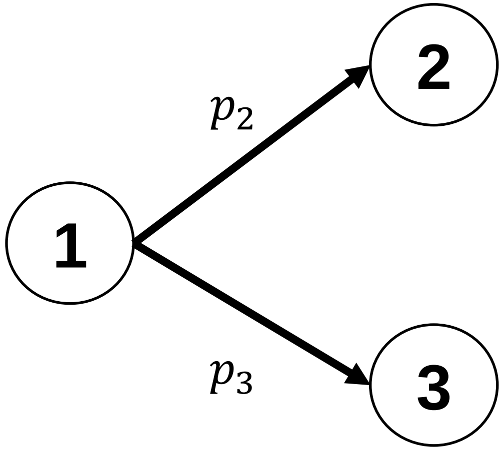


$t_1 \sim \hat{F}_1?$ $t_2 \sim \hat{F}_2?$

$$\hat{f}(x) = \sum_{observations} K\left(\frac{x - observation}{bandwidth}\right)$$



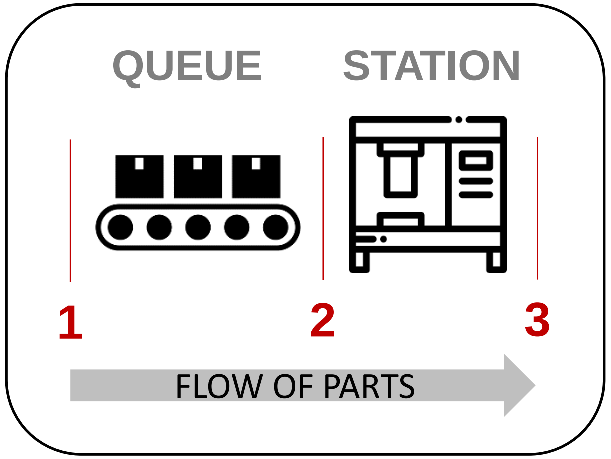
Policies are inferred from the flow of parts (frequency). More complex rules (e.g., Machine Learning) can be applied.



$$\hat{p}_2 = \frac{f_2}{f_2 + f_3}$$

$$\hat{p}_3 = 1 - \hat{p}_2$$

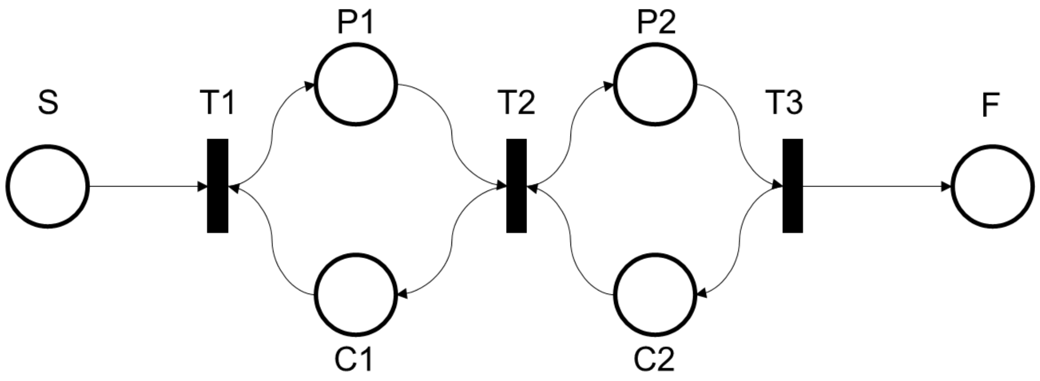
MODEL CONVERSION



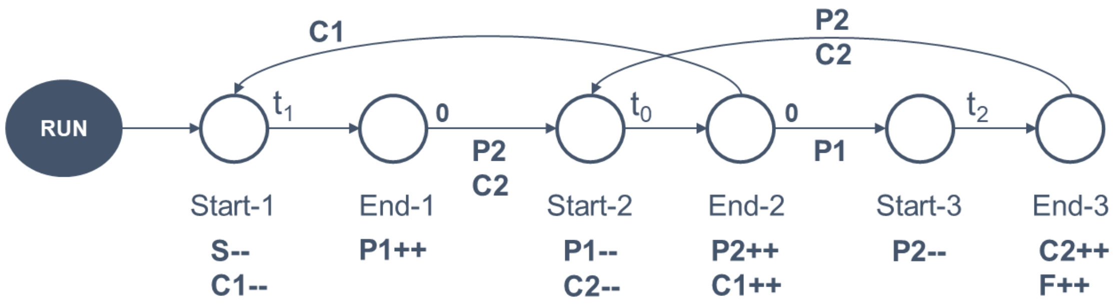
MANUFACTURING SYSTEM

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

Petri Net Model



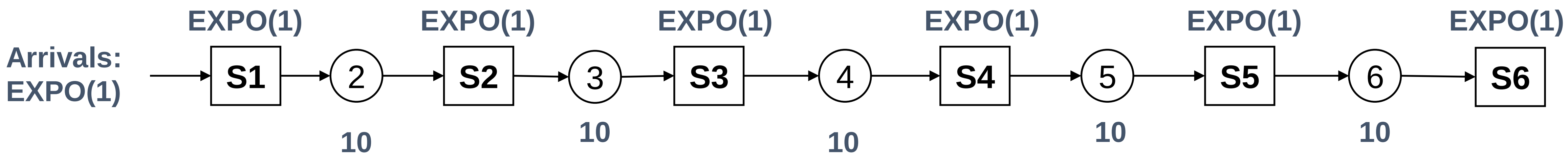
Event Relationship Graph*



*** further reduction may be applied**

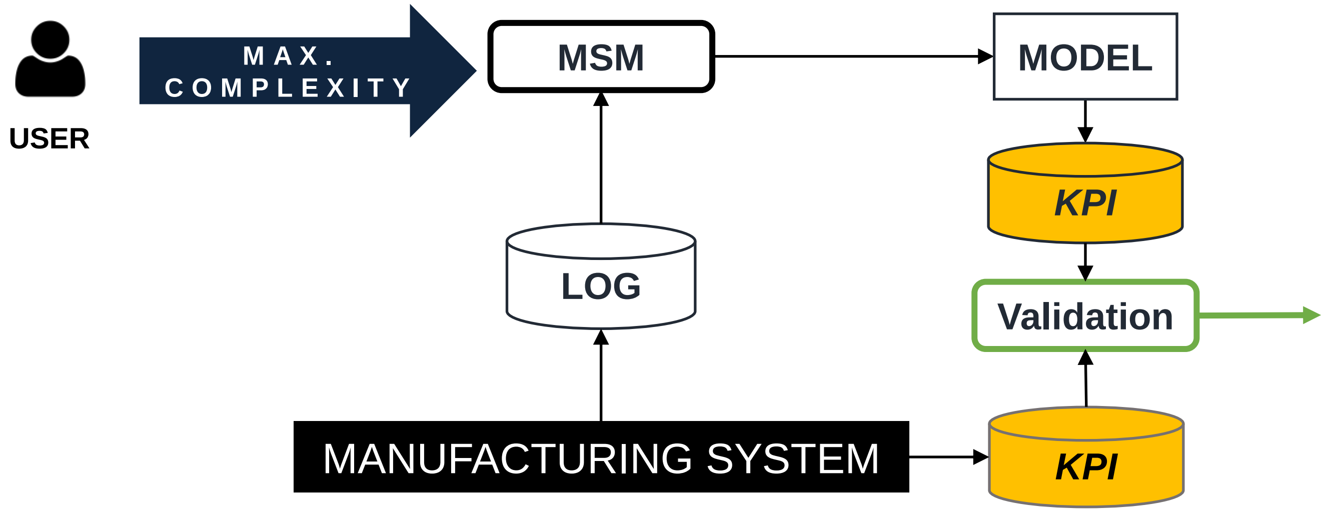
*Schruben, Lee, and Enver Yucesan. "Transforming Petri nets into event graph models." *Proceedings of Winter Simulation Conference*. IEEE, 1994.

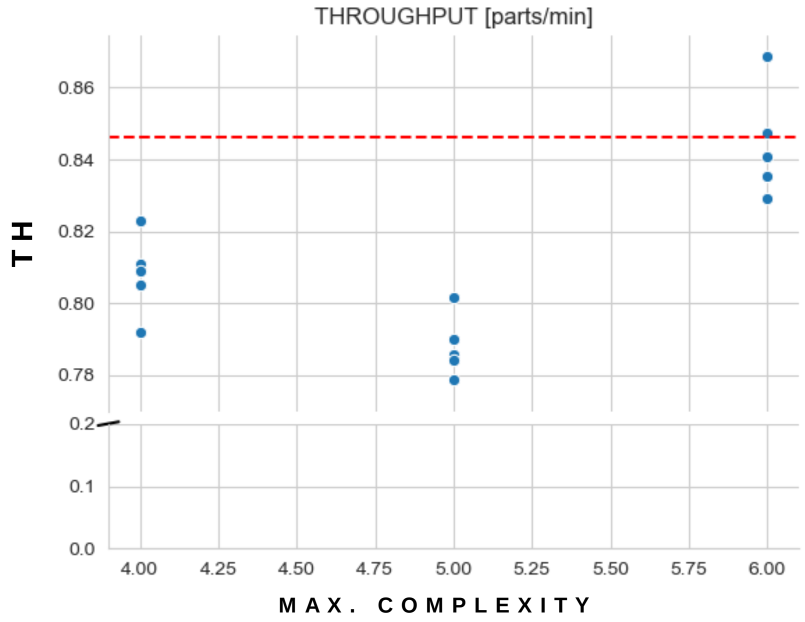
VALIDATION: SIMULATED FLOW LINE



PERFORMANCE COMPARISON:

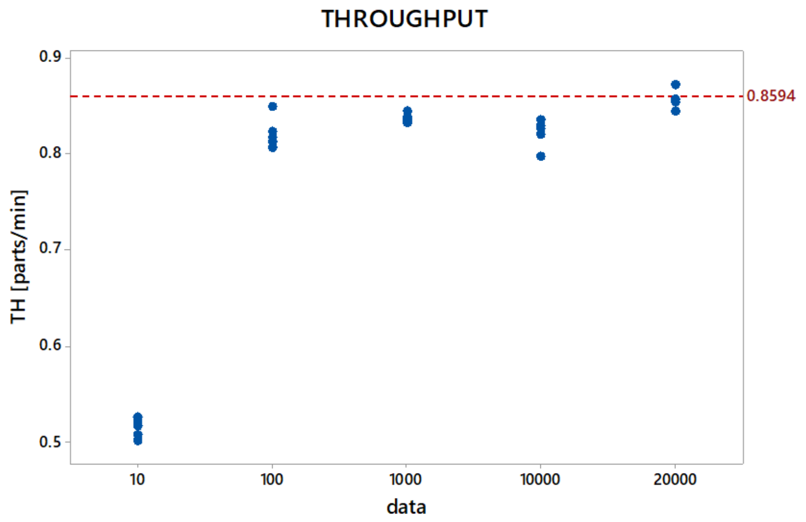
AV. ERROR = *4.7 %*
MAX ERROR = *11.8 %*

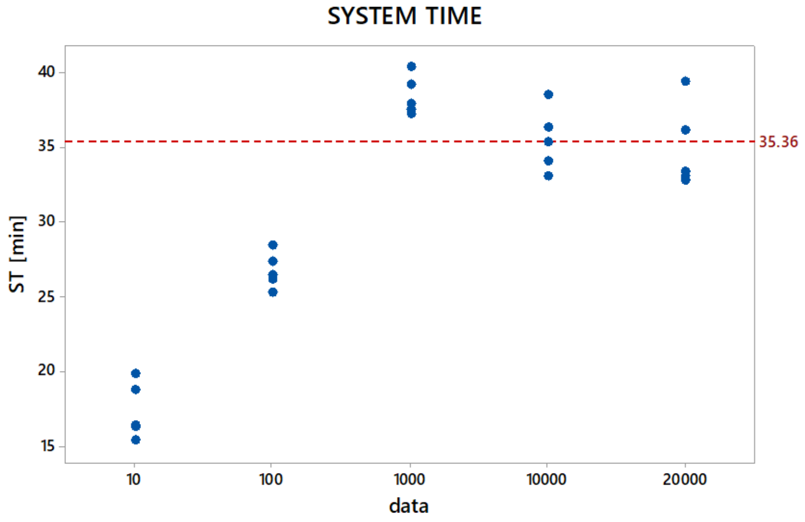


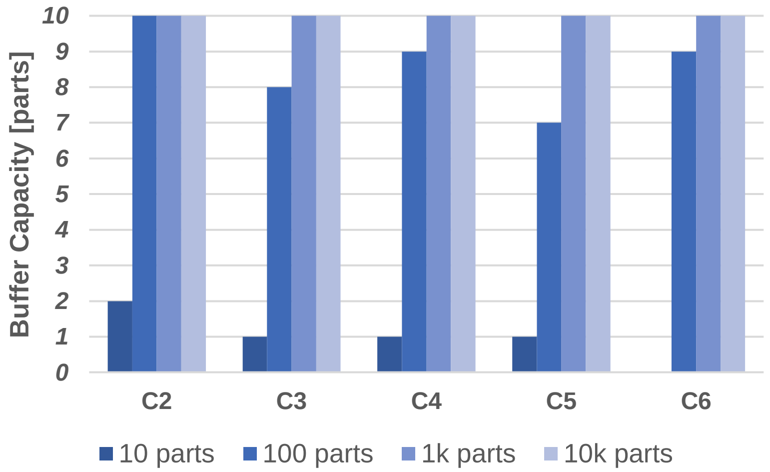


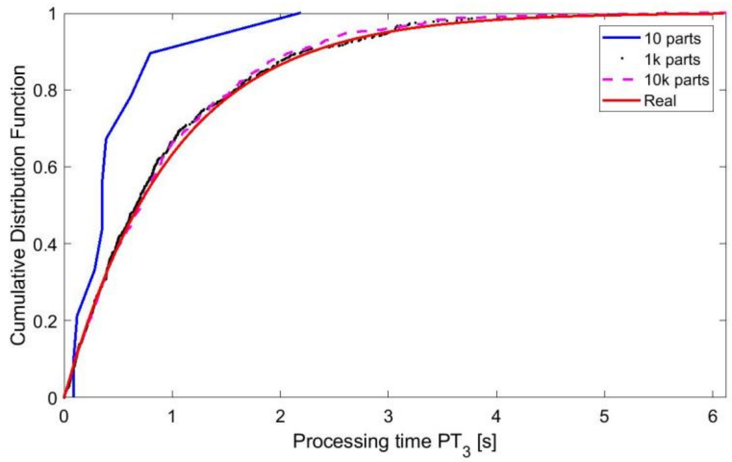
NOTICE: Validation can also be applied online! (Online Model Adaptation)

VALIDATION: SIMULATED FLOW LINE

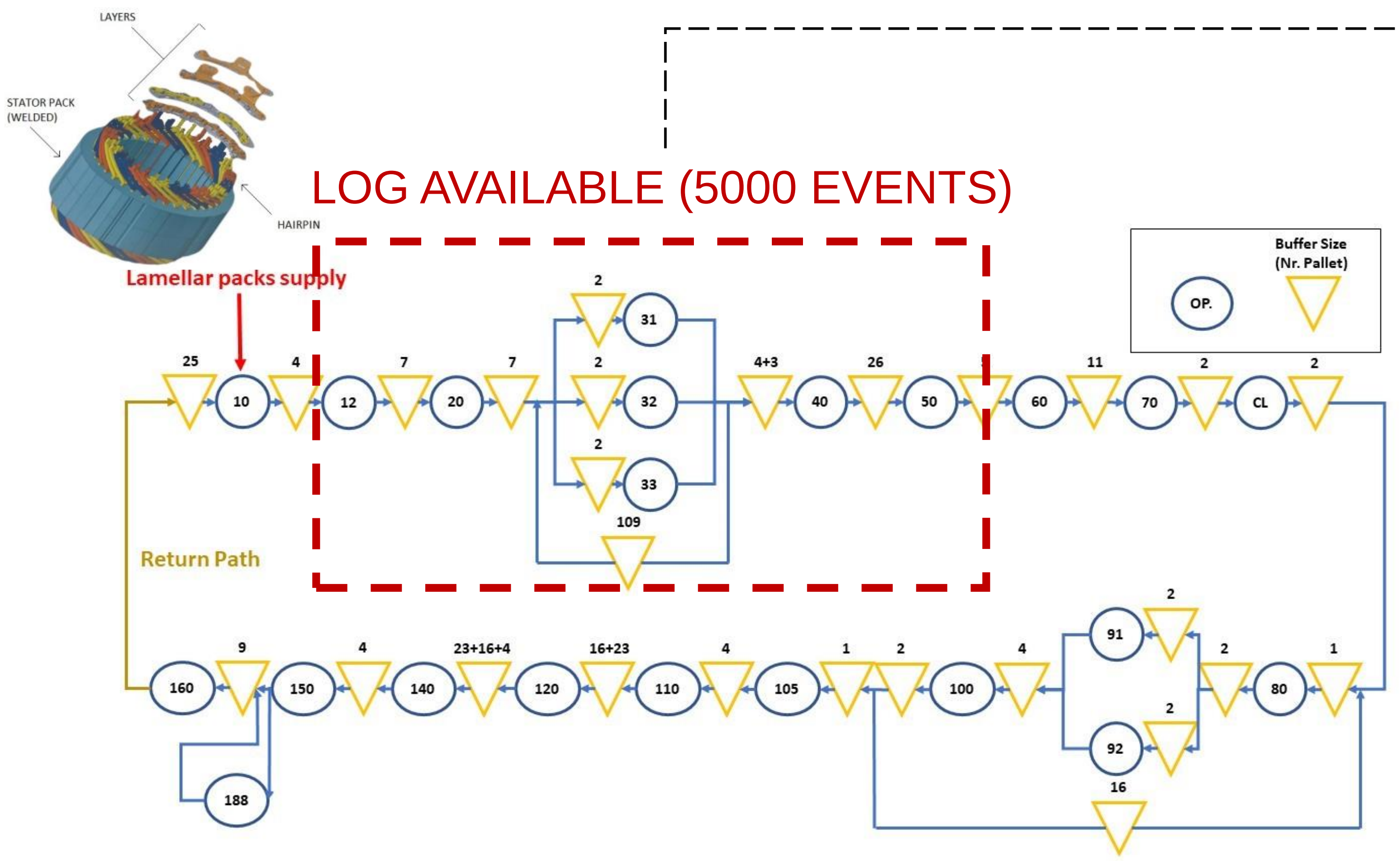




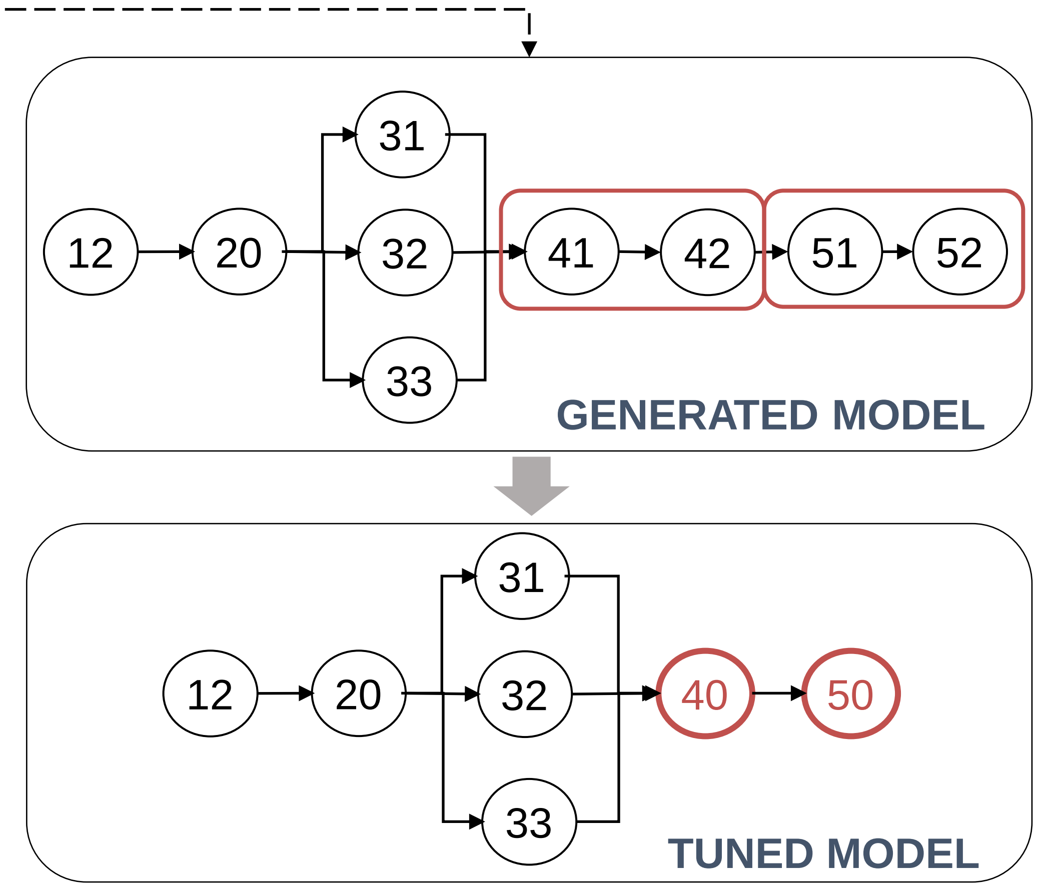




VALIDATION: REAL PRODUCTION LINE



MANUFACTURING SYSTEM (MARELLI EV STATOR LINE)



DIGITAL MODEL (IN LESS THAN 30 s)

LIMITATIONS AND FUTURE DEVELOPMENTS

LIMITATIONS

- Current work is limited by the **hypothesis of single IDs**
  → Cannot use MSM in assembly/disassemly applications → EXTENSION FOR ASSEMBLY
- **Limited information** in the log translates in less descriptive models (e.g. reliability models)
- **Log-preprocessing is still necessary** (e.g., events with same timestamp are critical and are removed)
- Different system types might require ad-hoc parameter setting

FUTURE DEVELOPMENTS

- Investigate the **value of prior information**
- Arrival times estimation: comparison with other PM techniques
- Investigate Simulation-Optimization applications
- Definition of ad-hoc convertion rules toward ERGs, model tuning on ERGs [1].
- Investigation of **smarter inheritance rules** for nodes aggregation
- Understand the behavior with very large logs

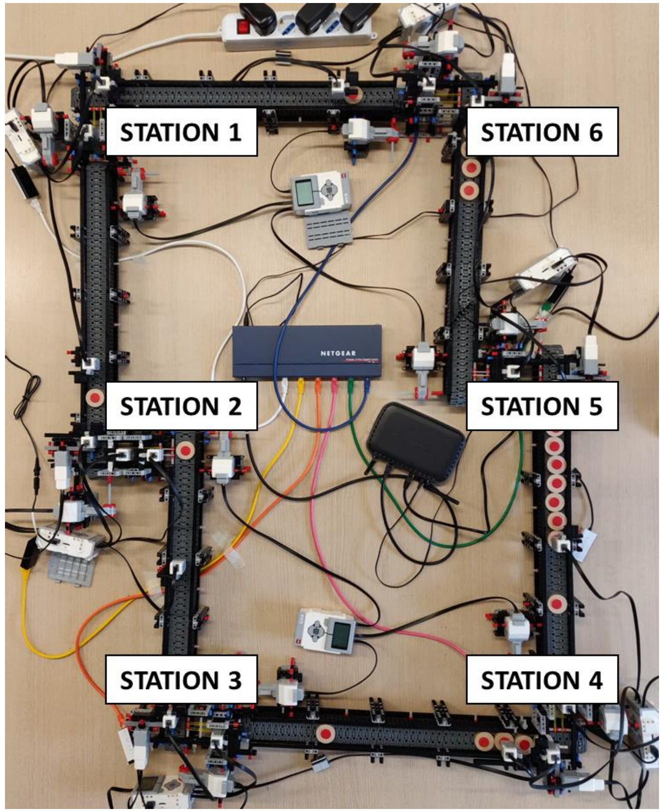
[1] Enver Yücesan and Lee Schruben. Structural and behavioral equivalence of simulation models. ACM Transactions on Modeling and Computer Simulation (TOMACS), 2(1):82–103, 1992.

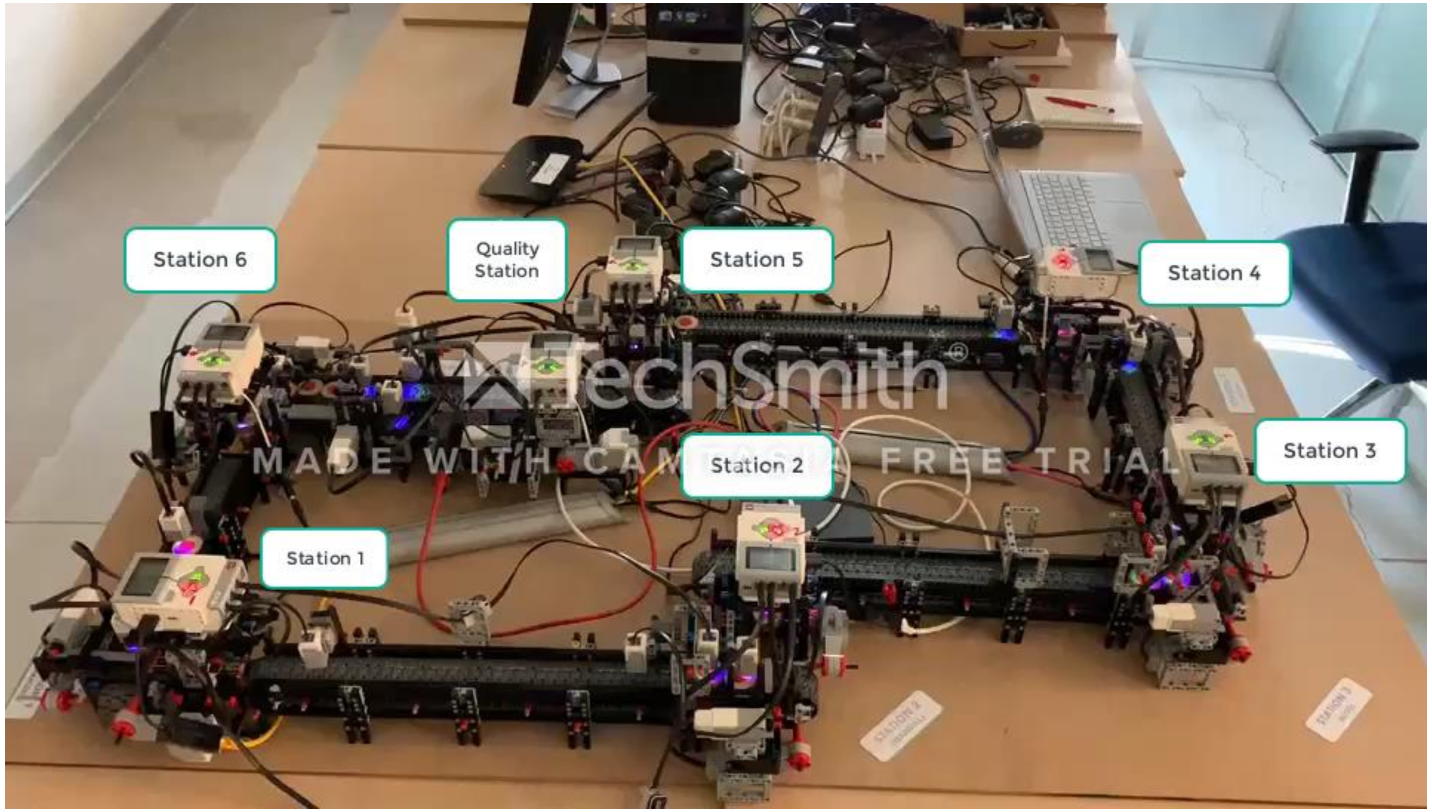
Testing Platform: Lab-scale models of manufacturing systems

LAB-SCALE MODELS AS TESTING PLATFORM

New 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 are controlled by LEGO ® EV3® intelligent bricks.
- Each station has sensors for entrance checking, processing, blocking.
- Wooden circles tagged with red plates represent pallets/parts.

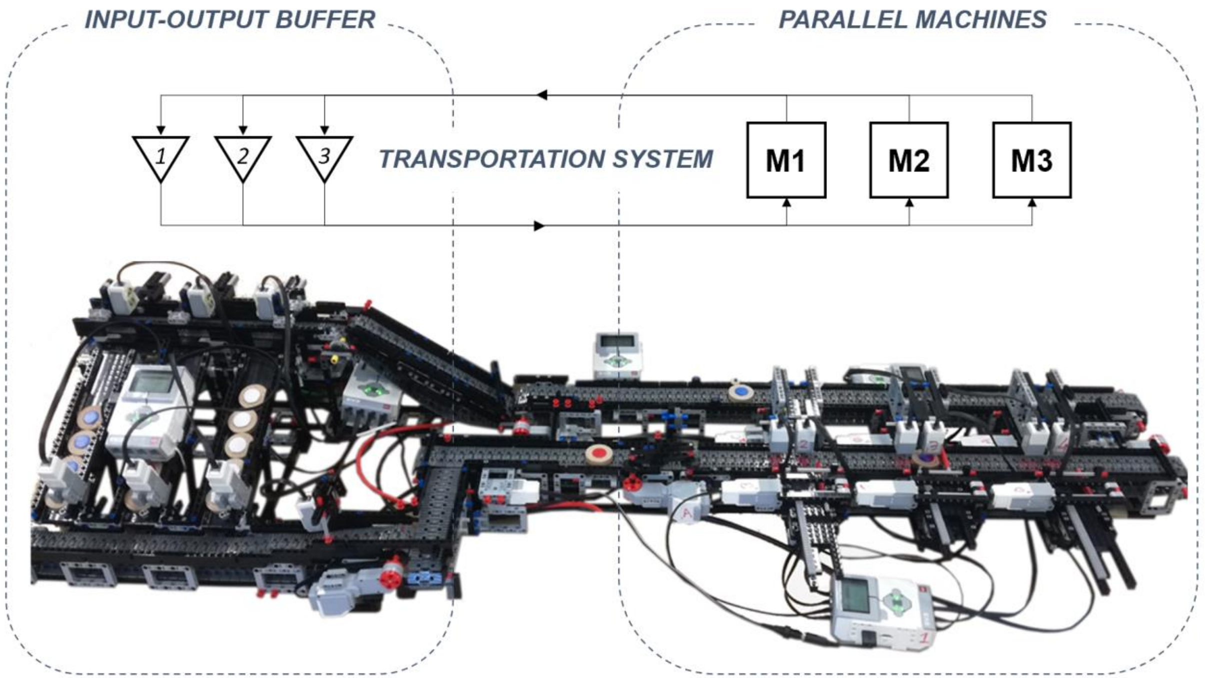




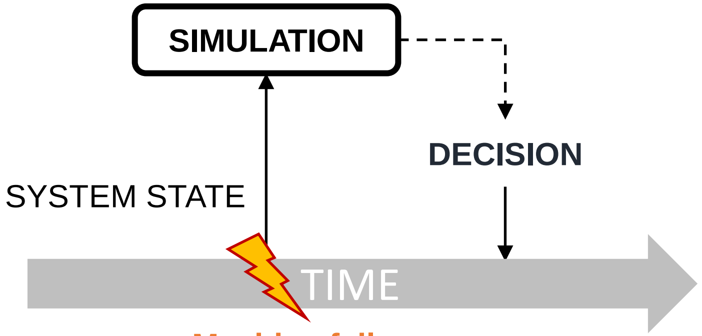
LAB-SCALE MODELS AS TESTING PLATFORM

TEST OF REAL-TIME SIMULATION

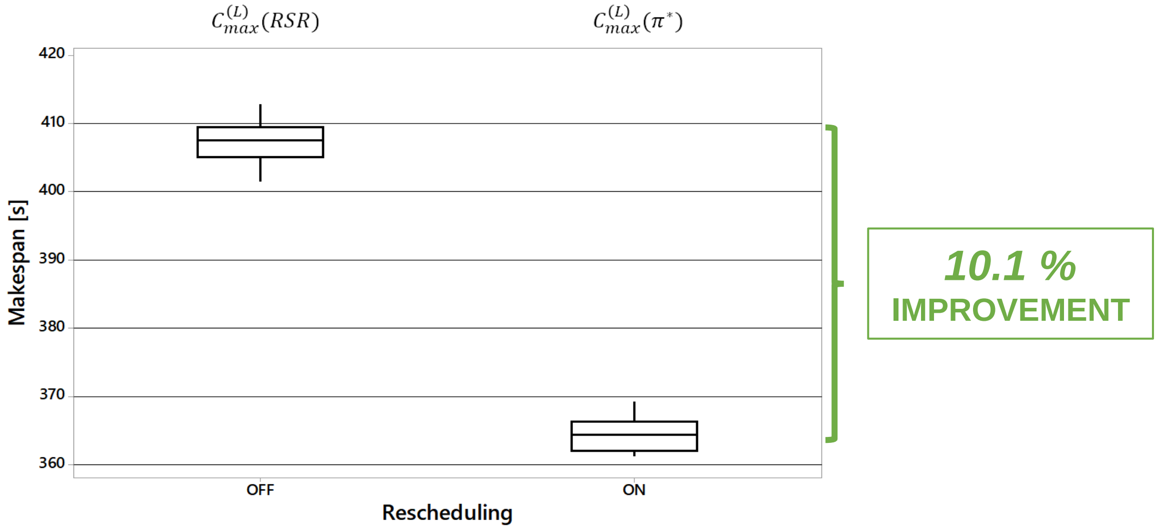
Simulation model to simulate and evaluate an **optimal re-scheduling plan** using re-planning rules from the recent literature (Arnaout, 2014).



(alternative scheduling policies)



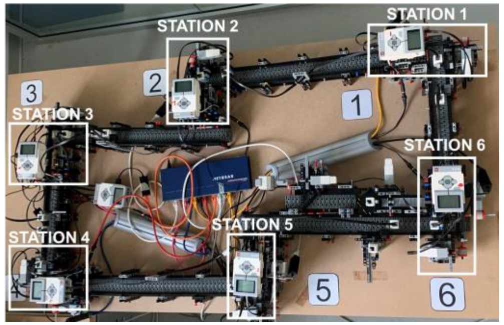
- **Machine failure**
- **Demand change**
- **Unplanned maintenance**



LAB-SCALE MODELS AS TESTING PLATFORM

TEST OF ONLINE MODEL GENERATION

Physical Model



TIME

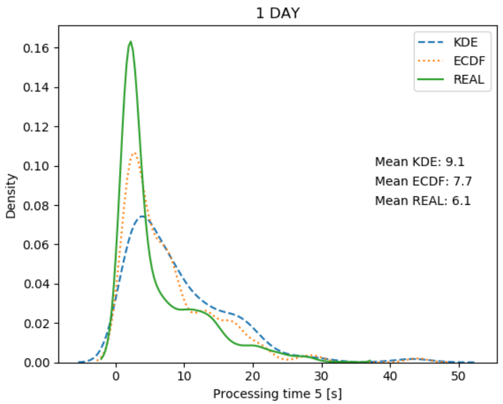
Log portion

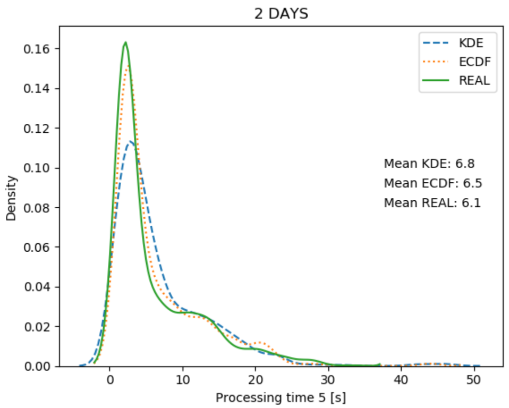
Timestamp	Part-ID	Activity-ID
2020-11-23T16:37:40Z	1	S1
2020-11-23T16:37:44Z	1	S2
2020-11-23T16:37:47Z	2	S1
2020-11-23T16:37:51Z	2	S2
2020-11-23T16:37:52Z	3	S1
...	...	...

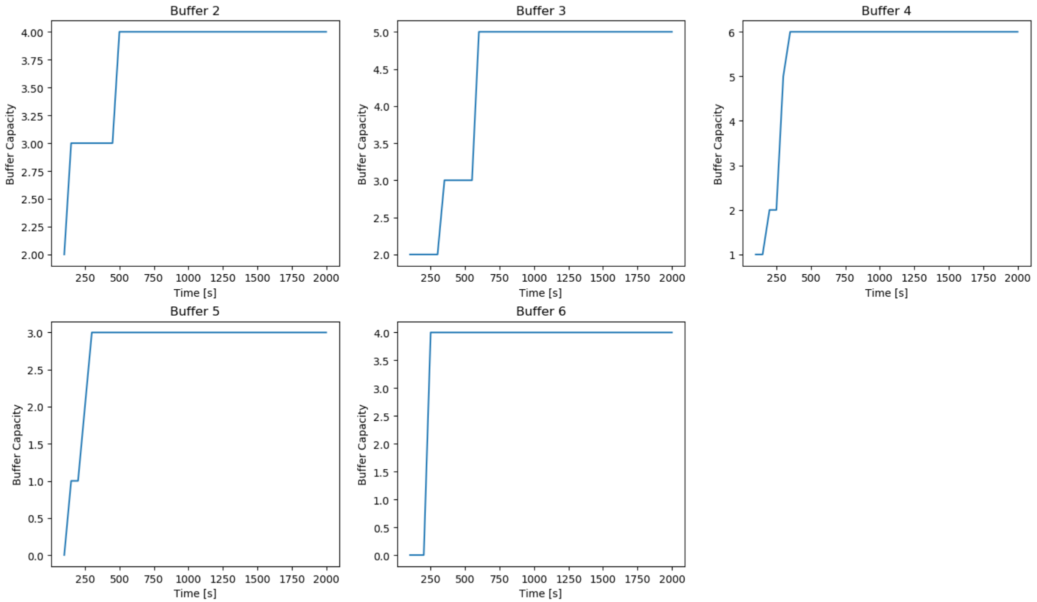
MODEL GENERATION

MODEL GENERATION

- ✓ *Model Structure*
- ✓ *Buffer Capacities*
- ✓ *Processing Times*







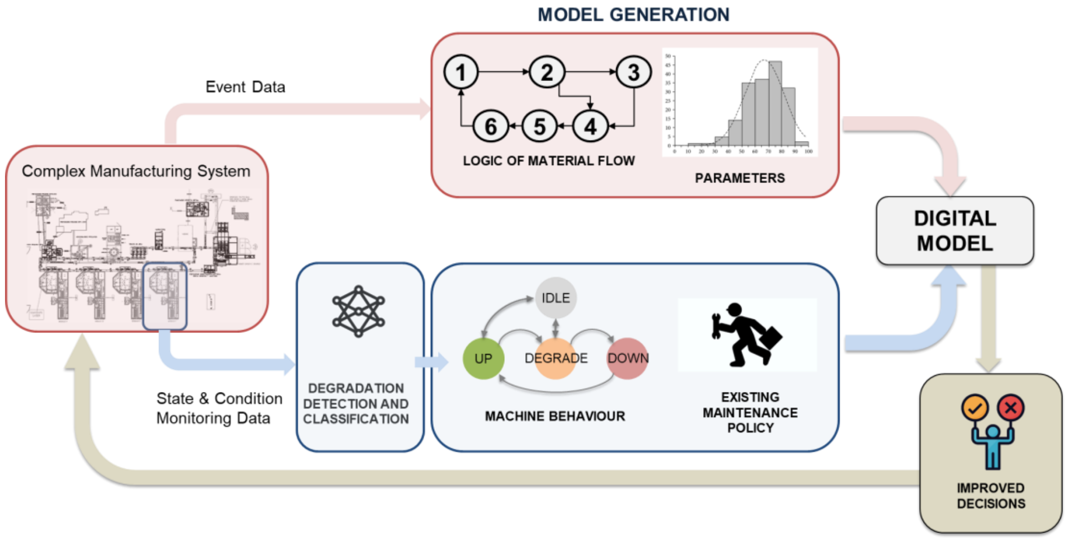
Lugaresi, Giovanni, and Andrea Matta. "Automated Digital Twins Generation for Manufacturing Systems: a Case Study." INCOM Conference 2021, Budapest, Hungary.

Conclusions

CONCLUSIONS

FUTURE DEVELOPMENTS

- Development of **joint mining approaches** → discovery of features of the system (e.g., maintenance policies)
- Using process mining to **enhance performance estimation** → support for approaches that need a model to estimate performance under specific scenarios.
- Extension of **model conversion techniques** → connectors to software tools
- Collaboration with **interested industrial partners** to test the appraches within realistic settings (e.g., MES integration).
- Development of **online validation tecnhiques** to «*close the loop*» in real-time.



IMPACT

- Real-time Simulation as **online decision-support tool**
- Digital Manufacturing: closer to **real applications of *digital twins***
- **New ways to test** softwares and PPC technologies (lab-scale devices)

Other Activities in Doctoral Curriculum

JOURNAL PAPERS

1. **Giovanni Lugaresi**, Andrea Matta. *Automated manufacturing system discovery and digital twin generation.* Published on Journal of Manufacturing systems.
2. **Giovanni Lugaresi**, Vincenzo Alba, Andrea Matta. *Real-time Simulation for Manufacturing Systems: a Framework Based on a Lab-scale Environment for Testing Production Planning and Control Research*. Published on Journal of Manufacturing systems.
3. **Giovanni Lugaresi**, Andrea Matta. *Automated simulation model generation for production systems with assembly operations*. In submission to International Journal of Production Research.

Other research activity: robust optimization

1. **G. Lugaresi,** E. Lanzarone, N. Frigerio, A. Matta; “A cardinality-constrained robust Part Type Selection model". Work-in-progress.

2. **G. Lugaresi,** E. Lanzarone, N. Frigerio, A. Matta; “A robust cardinality-constrained model to address the machine loading problem“. Published on Robotics and Computer-Integrated Manufacturing.

CONFERENCE PAPERS

1. **G. Lugaresi** and A. Matta. "A Remote Laboratory Experience in Teaching Discrete Event Simulation Modeling for Manufacturing Applications". 11th Conference on Learning Factories, 2021.
2. **G. Lugaresi** and A. Matta. "Discovery and digital model generation for manufacturing systems with assembly operations". Proceedings of the CASE 2021 conference.
3. **G. Lugaresi** and A. Matta. «Automated Digital Twins Generation for Manufacturing Systems: a Case Study". 17th IFAC Symposium on Information Control Problems in Manufacturing, 2021.
4. **G. Lugaresi** and A. Matta. "Generation and Tuning of Discrete Event Simulation Models for Manufacturing Applications". Proceedings of the 2020 Winter Simulation Conference.
5. **G. Lugaresi**, V. Alba, and A. Matta. "An Internet of Things Architecture for Lab-scale Prototypes of Real-Time Simulation." Proceedings of the CASE 2020 conference.
6. **G. Lugaresi,** N. Frigerio, and A. Matta. "A New Learning Factory Experience Exploiting LEGO For Teaching Manufacturing Systems Integration." Procedia Manufacturing 45 (2020): 271-276.
7. **G. Lugaresi**, D. Travaglini, and A. Matta. "A LEGO® manufacturing system as demonstrator for a real-time simulation proof of concept." 2019 Winter Simulation Conference (WSC). IEEE, 2019
8. **G. Lugaresi**, et al. "Active learning experience in simulation class using a LEGO®-based manufacturing system." 2019 Winter Simulation Conference (WSC). IEEE, 2019.
9. **G. Lugaresi**, M. Zanotti, D. Tarasconi, A. Matta. *Manufacturing Systems Mining: Generation of Real-time Discrete Event Simulation Models.* 2019 IEEE International Conference on Systems, Man, and Cybernetics (SMC).
10. **G. Lugaresi,** Gianluca Aglio, Federico Folgheraiter, Andrea Matta. *Real-time Validation of Digital Models for Manufacturing Systems: a novel Signal-processing-based Approach*. 2019 IEEE 15th International Conference on Automation Science and Engineering.
11. **G. Lugaresi**, A. Matta; *Real-time Simulation In Manufacturing Systems: Challenges And Research Directions*; Proceedings of the 2018 Winter Simulation Conference.

TEACHING ACTIVITIES

- **Teaching Assistant** for the course “Tecnologia Meccanica e Qualità” [Industrial Engineering]: **2 academic years** 2019-2020, 2020-2021.
- **Teaching Assistant** for the course “Intergrated Manufacturing Systems” [Mechanical Engineering]: **3 academic years** 2018-2019, 2019-2020, 2020-2021.
- **Tutor** for the course “Tecnologia Meccanica e Qualità” [Ingegneria Gestionale]. **2 academic years**: 2017-2018, 2018-2019.
- **Teaching Assistant** for the *Passion in Action* course “LEGO® FACTORY”. **2 editions**: Fall 2018, Spring 2019.
- **Co-Supervisor of 12 M.Sc. students for 9 master theses**:
    1. Davide Travaglini. *Manufacturing system based on LEGO®-robotics: development of physical and digital models* (2018).
    2. Marco Zanotti, Diego Tarasconi. *Process mining for manufacturing systems discovery* (2018).
    3. Federico Folgheraiter, Gianluca Aglio. *Real-time validation of discrete event simulation models in a real-time framework: statistical techniques and harmonic analysis approach* (2018).
    4. Vincenzo Valerio Alba. An *IoT Architecture for Real-Time Simulation applications* (2019).
    5. Luca Spada. *Study and application of a dynamic condition-based maintenance policy* (2020).
    6. Jacopo Barbieri. *Development of an Industry 4.0 supply-chain integrated scheduling* (2020).
    7. Sofia Gangemi, Giulia Gazzoni. *Simulation-based Digital Twin Application in a highly automated Manufacturing Stystem* (2021).
    8. Edoardo Passarin. *Development and Implementation of Automated Online Model Generation Techniques* (2021).
    9. Francesco Verucchi. *Development of a Real-time Synchonized Discrete Event Simulation Model for Manufacturing Applications* (2021)

STUDY PLAN

	Dept.	A.Y./sem.	Grade	Date	ECTS
Research Management Prof. Urgo, Prof. Tolio	DMECC	2018/II	A (30)	2018	5
Engineering Complex Systems with Big data and IOT Prof. Pernici	PHD	2018/II	A (30)	2018	5
Industrial Skills Prof. Biscari	PHD	2018/II	B (29)	2018	5
Python per il calcolo scientifico *Prof. Miglio*	DIMA	2018/II	A (30)	2021	5
Statistics in the big data era Prof. Panagiotis	DMECC	2019/I	B (29)	2019	5
Other courses					
Production Systems Control (DEIB) Prof. Ferrarini					
Autonomous Agents and Multi-agent Systems (DEIB) Prof. Amigoni					
Applied Statistics (DIMA) Prof. Secchi					

Requirements for MeccPhD: 20 ECTS

OTHER RESEARCH ACTIVITIES

Projects:

1. "FactoryBricks: Smart Learning @Home for the Management of Connected Factories" funded by EIT-Manufacturing (European Union, 2020). Role: project coordination.
2. "FISVAL: Filiera Integrata e Sostenibile per la produzione di VALvole smart", funded by Regione Lombardia (2020-2021). Role: WP1 lead: development of scheduling algorithm.
3. "Development of lab-scale models of manufacturing systems" funded by Sme.UP (2018). Role: project coordination.
4. "Analysis of alternative layouts for the assembly of the GDI injector IHP10E" funded by Magneti Marelli (2018). Role: collaborator.
5. "RECAM: Rapid Reconfiguration of Flexible Production Systems through Capability based Adaptation, Auto configuration and Integrated tools for Production Planning", EUFP7 FOF, H2020 GRANT AGR. 680759 (2017-2018). Role: collaborator.

   Related Publications:

   1. M. Colledani, A. Yemane, **G. Lugaresi**, G. Borzi, D. Callegaro. *A software platform for supporting the design and reconfiguration of versatile assembly systems.* 51st CIRP Conference on Manufacturing Systems (CIRP CMS 2018).
   2. M. Colledani, A. Yemane , **G. Lugaresi** , N. Frigerio, G. Borzi , A. Bassi , D. Callegaro. *A Decision Support Methodology for the Design of Reconfigurable Assembly Systems.* 16th IFAC Symposium on Information Control Problems in Manufacturing.
6. "Analysis of alternative layouts for the assembly of 81 and 85kw throttle body" funded by Magneti Marelli (2017). Role: collaborator.

Research Periods Abroad:

- NO PERIODS ABROAD, DUE TO COVID-19 PANDEMIC.

Q&A

Selected References

G. Lugaresi and A. Matta. *Real-time simulation in manufacturing systems: Challenges and research directions.* 2018 Winter Simulation Conference (WSC), 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.

W. V. der Aalst. *Process Mining - Data Science in Action.* Springer, second edition ed., 2016.

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.

Monostori, László, et al. "Cyber-physical systems in manufacturing." Cirp Annals 65.2 (2016): 621-641.

Q&A

Big thanks to all the people who supported me in this adventure!