A LEGO® MANUFACTURING SYSTEM AS DEMONSTRATOR FOR A REAL-TIME SIMULATION PROOF OF CONCEPT

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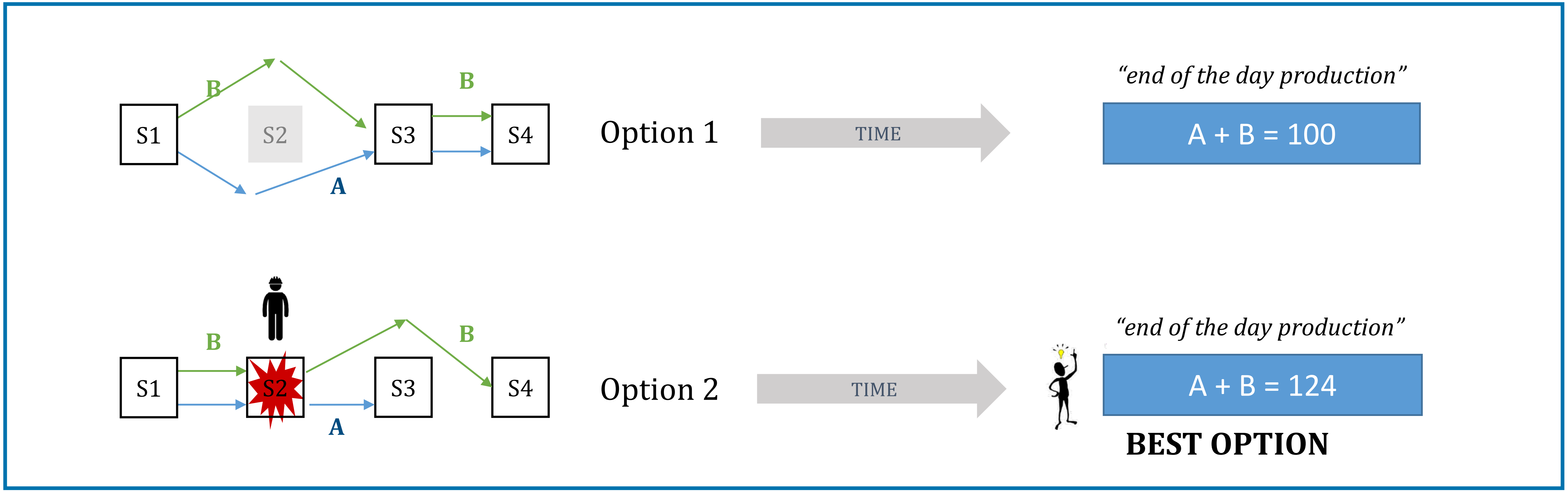
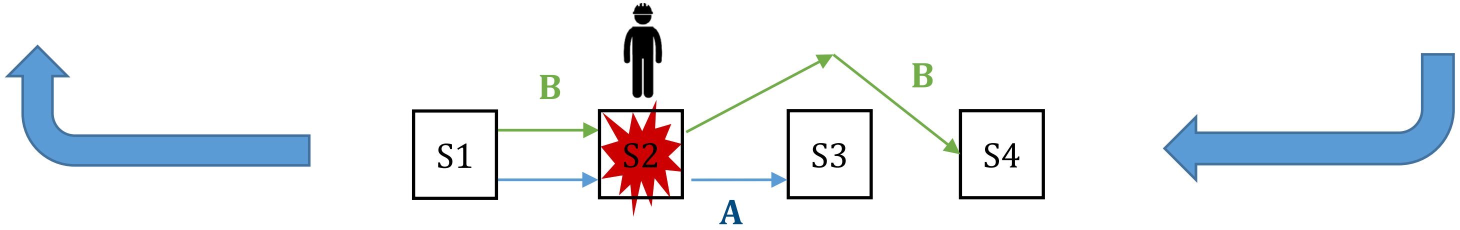
Highlights

- Prove the applicability of a Real-Time Simulation (RTS) framework.
- Exchange current-status data from a LEGO® Manufacturing System
- Alternative simulation models are used to decide the next moves.
- Results show that the framework can effectively be used to find better production policies.

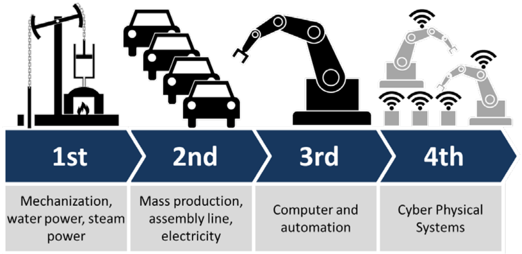
1. Problem Introduction

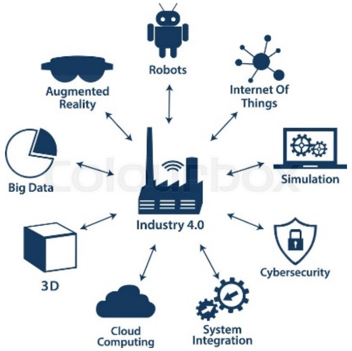
Simulation-Optimization

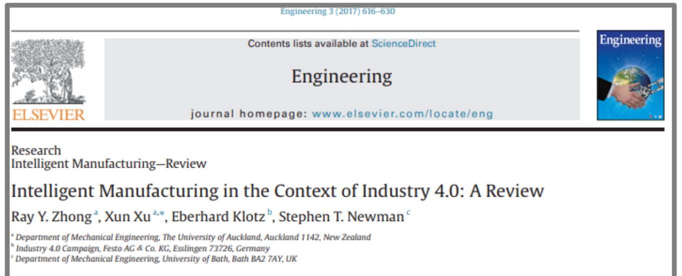




1. Industrial Scenario



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ELSEVIER

Research
Intelligent Manufacturing—Review

Intelligent Manufacturing in the Context of Industry 4.0: A Review

Ray Y. Zhong[a], Xun Xu[a,*], Eberhard Klotz[b], Stephen T. Newman[c]

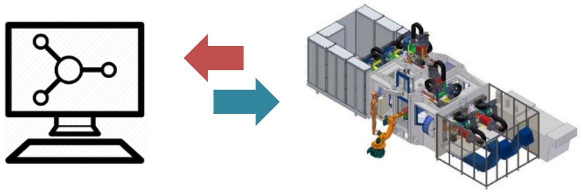
[a] Department of Mechanical Engineering, The University of Auckland, Auckland 1142, New Zealand
[b] Industry 4.0 Campaign, Festo AG & Co. KG, Esslingen 73726, Germany
[c] Department of Mechanical Engineering, University of Bath, Bath BA2 7AY, UK

«[…] Typical resources are converted into intelligent objects so that they are **able to sense, act, and behave within a smart environment**. In order to fully understand intelligent manufacturing in the context of Industry 4.0.»

New Application Scenarios

- Collecting information with high frequency
- Understanding emerging behaviors
- Evaluating alternative scenarios
- Affordable Data analytics

Creation/Update of SIMULATORS



Use SIMULATORS to act on the system

Ray Y. Zhong, Xun Xu, Eberhard Klotz, Stephen T. Newman, Intelligent Manufacturing in the Context of Industry 4.0: A Review, Engineering, Volume 3, Issue 5, 2017.
G. Lugaresi, A. Matta; Real-time Simulation In Manufacturing Systems: Challenges And Research Directions; Proceedings of the 2018 Winter Simulation Conference.

2. Contribution

FRAMEWORK RELATED ISSUES

● = *this work*

- ● RTS SW Framework definition
- ● Definition of alternative scenarios
- ● Definition of application test cases

IMPLEMENTATION ISSUES

- Data Collection
- Interfaces between Software Components
- Synchronizazion Digital-Physical Model
- ● Lab-scale testing environment

SIMULATION-RELATED ISSUES

- ● Initialization of alternative models.
- Alignment and Validation
- Accuracy in predicting KPIs

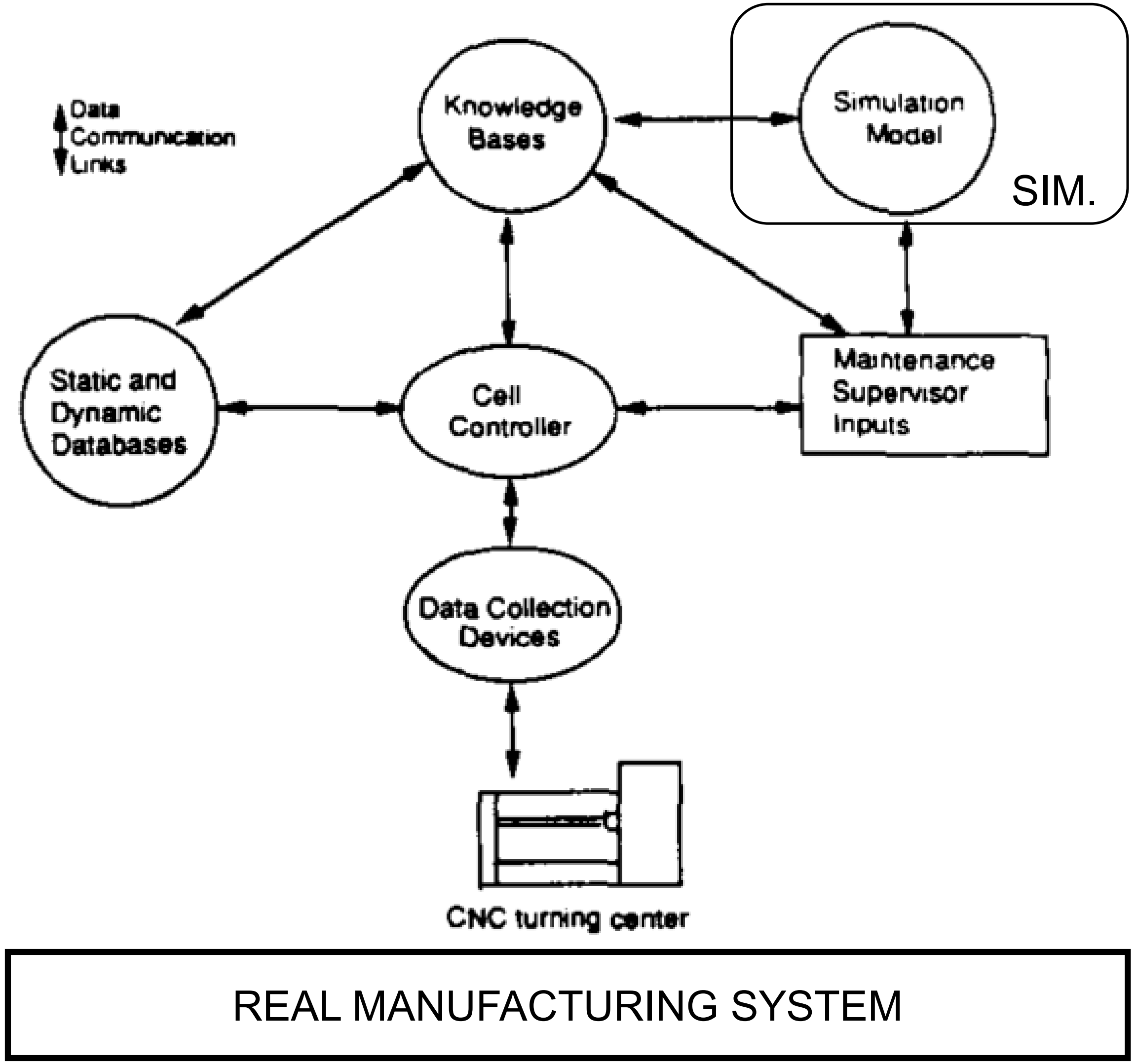
RESEARCH IMPACT

Real-Time Simulation can be exploited for <u>short-term decision-making</u> and <u>online management</u> of production systems.
Short-term performances of manufacturing systems could be significantly improved.

Possibility to <u>test algorithms and policies from the literature</u> (usually compared and validated using simulation models, thus ignoring all the issues regarding data communication and alignment between a physical and a digital system).

Performances of <u>different reaction policies</u> can be compared and applied when unexpected events happen.

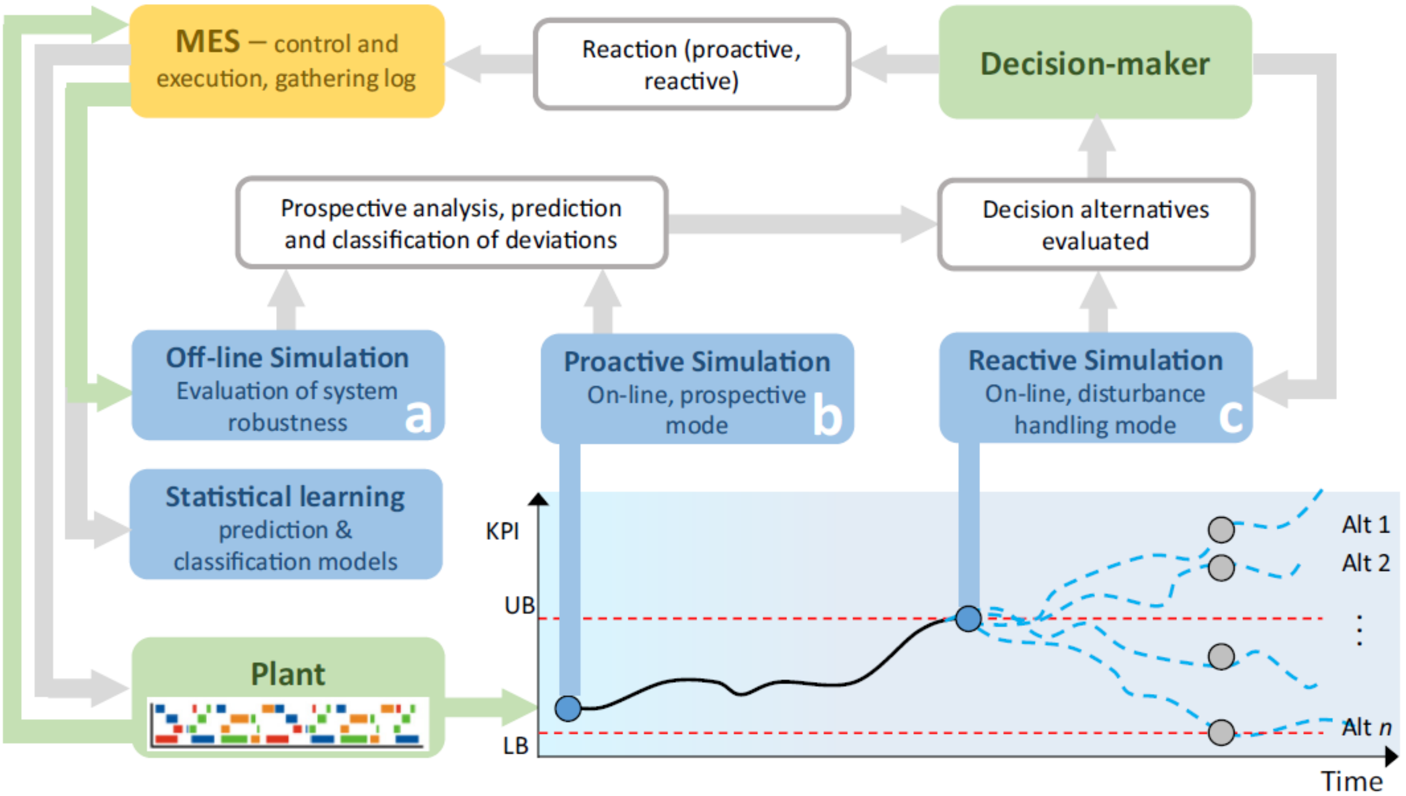
3. State of the Art



Source: Manivannan and Banks (1990)

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.

3. State of the Art

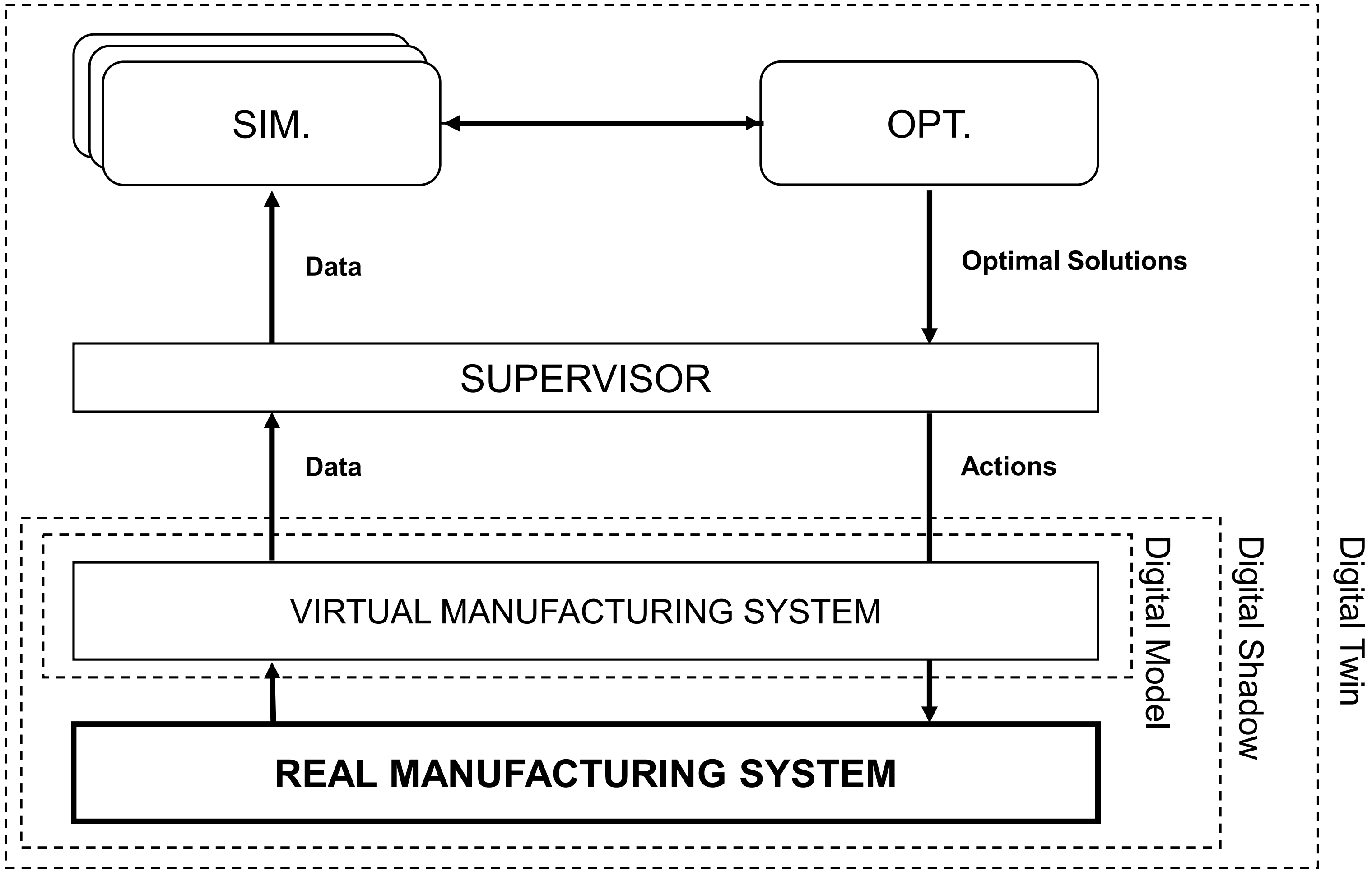


Source: Monostori et al. (2016)

Monostori, L., B. K´ad´ar, T. Bauernhansl, S. Kondoh, S. Kumara, G. Reinhart, O. Sauer, G. Schuh, W. Sihn, and K. Ueda. 2016. “Cyber-physical Systems in Manufacturing”. CIRP Annals 65(2):621–641.

3. Contribution

Real-Time Simulation (RTS) enables a new way of planning and controlling production systems:

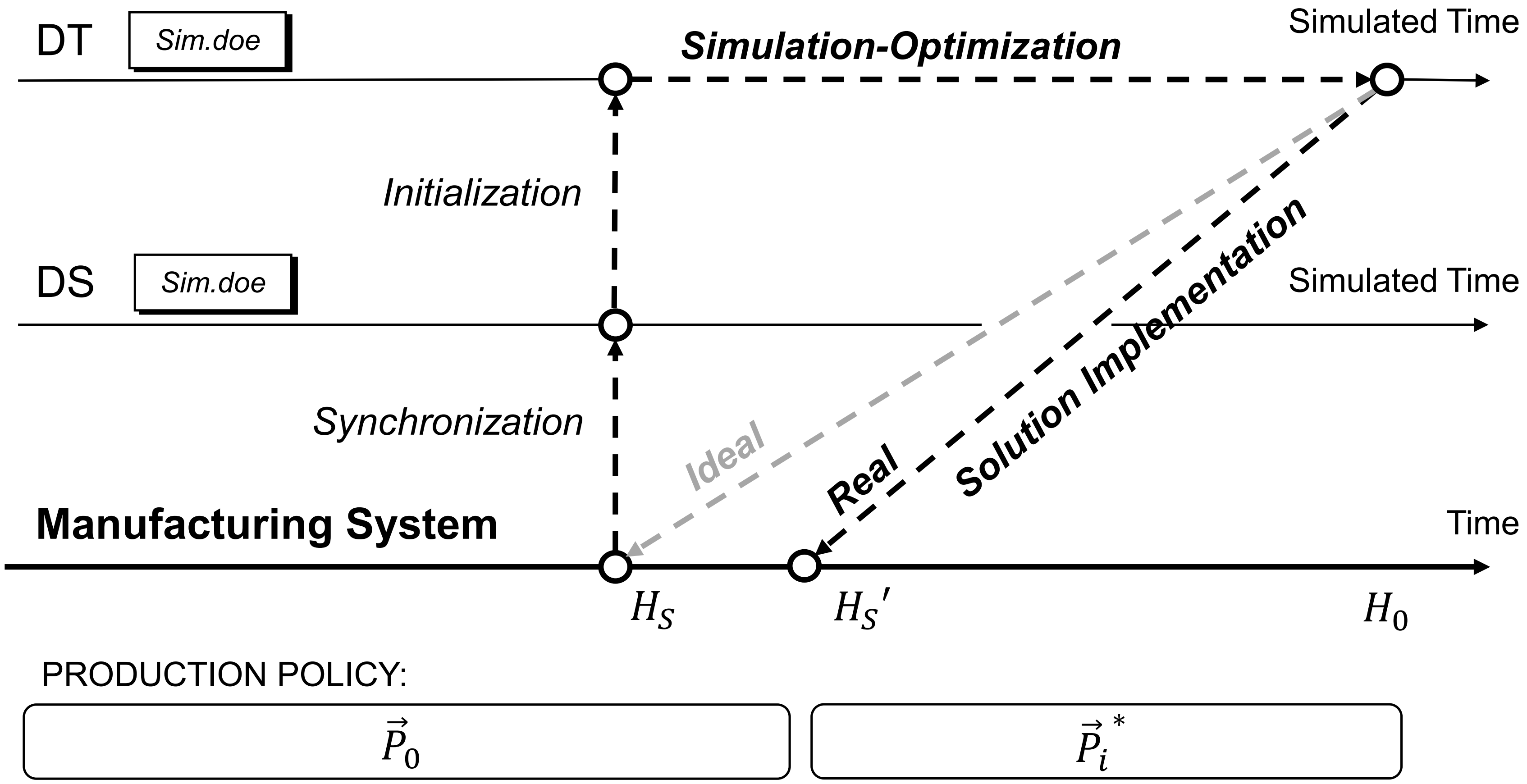


4. RTS Methodology

NOTATION:

Quantity	Meaning
H_0	Time horizon of interest for production.
H_S	Time at which a disruptive event occurs.
$H_S{}'$	Time at which a new identified management policy P_i^* is applied to the system. If the computational time is 0, then $H_S = H_S'$ (ideal case).
$P_i \in \boldsymbol{P}$	$\boldsymbol{P}$ is a finite set of N+1 system management policies: • P_0 is the original policy run on the system. • the remaining N policies define alternative reaction scenarios (decided a priori)
$\boldsymbol{\Theta}$ (P_i)	A generic Key Performance Index (KPI) for the time interval $t \in [H_s, H_0]$. It depends on several parameters, and the policy P_i .
P_i^*	**The solution** corresponds to an optimal system management policy $P_i^* \in \boldsymbol{P}$ which satisfies: $P_i^* = argmax_{\{P_i \in \boldsymbol{P}\}} \{\boldsymbol{\Theta}(P_i)\}$

4. Working Procedure

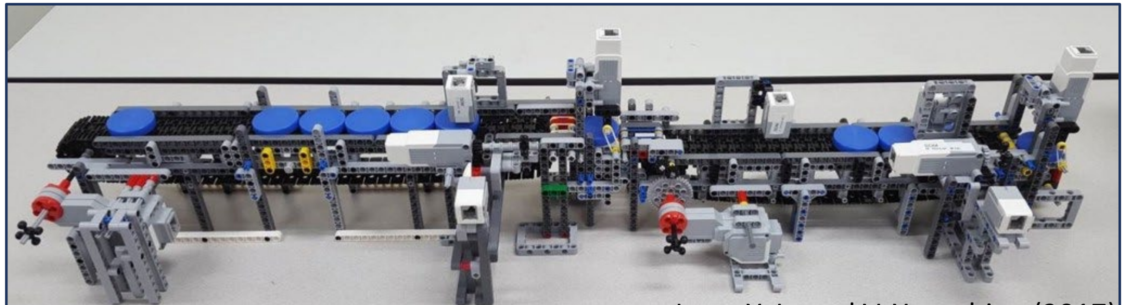


NOTATION REMINDER:

Q.ty	Meaning
H_0	Time horizon.
H_S	Disruptive event occurs
$H_S{}'$	P_i^* is applied to the system.
$P_i \in \boldsymbol{P}$	System management policies.
$\boldsymbol{\Theta}$ (P_i)	Key Performance Index (KPI)
P_i^*	$P_i^* = argmax_{\{P_i \in \boldsymbol{P}\}} \{\boldsymbol{\Theta}(P_i)\}$

LEGO® BASED INDUSTRIAL ENGINEERING EDUCATION:

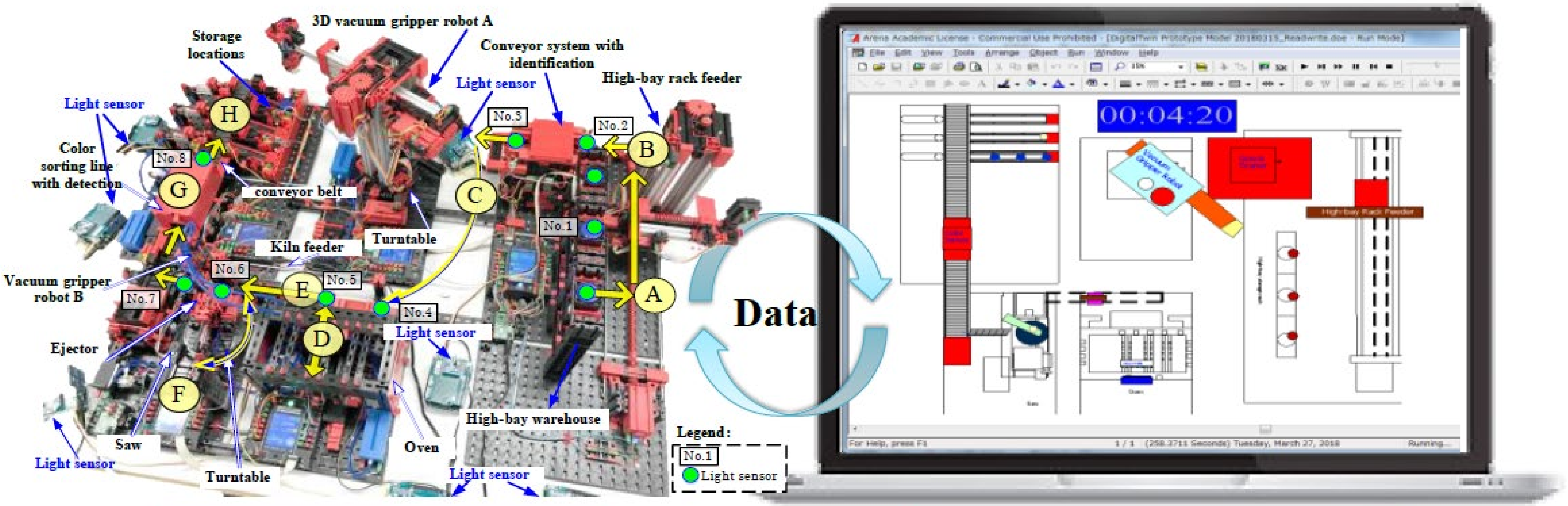
- Sanchez and Bucio (2012) based a course on a manufacturing system realized with LEGO® to teach the principles for controlling discrete event systems to postgraduate
- Syberfeldt (2010) described a practical exercise to teach simulation-optimization to students using a physical LEGO® factory simulating the refinement of raw materials. The main purpose was to make students understanding the benefits of performance evaluation.
- Jang and Yosephine (2017) developed a LEGO® MINDSTORMS® flow line consisting in one feeder and two machines with an intermediate buffer.



source: Jang, Y. J., and V. Yosephine (2017)

Sanchez, A., and J. Bucio. 2012. "Improving the teaching of discrete-event control systems using a LEGO manufacturing prototype". IEEE Transactions on Education 55(3):326–331.
Syberfeldt, A. 2010. "A LEGO factory for teaching simulation-based production optimization". In Industrial Simulation Conference, ISC'2010, June 7-9, 2010, Ramada Plaza Hotel, Budapest, Hungary, 89–94. EUROSIS-ETI.
Jang, Y. J., and V. Yosephine. 2017. "Teaching stochastic systems modeling using lego robotics based manufacturing systems".

5. State of the Art

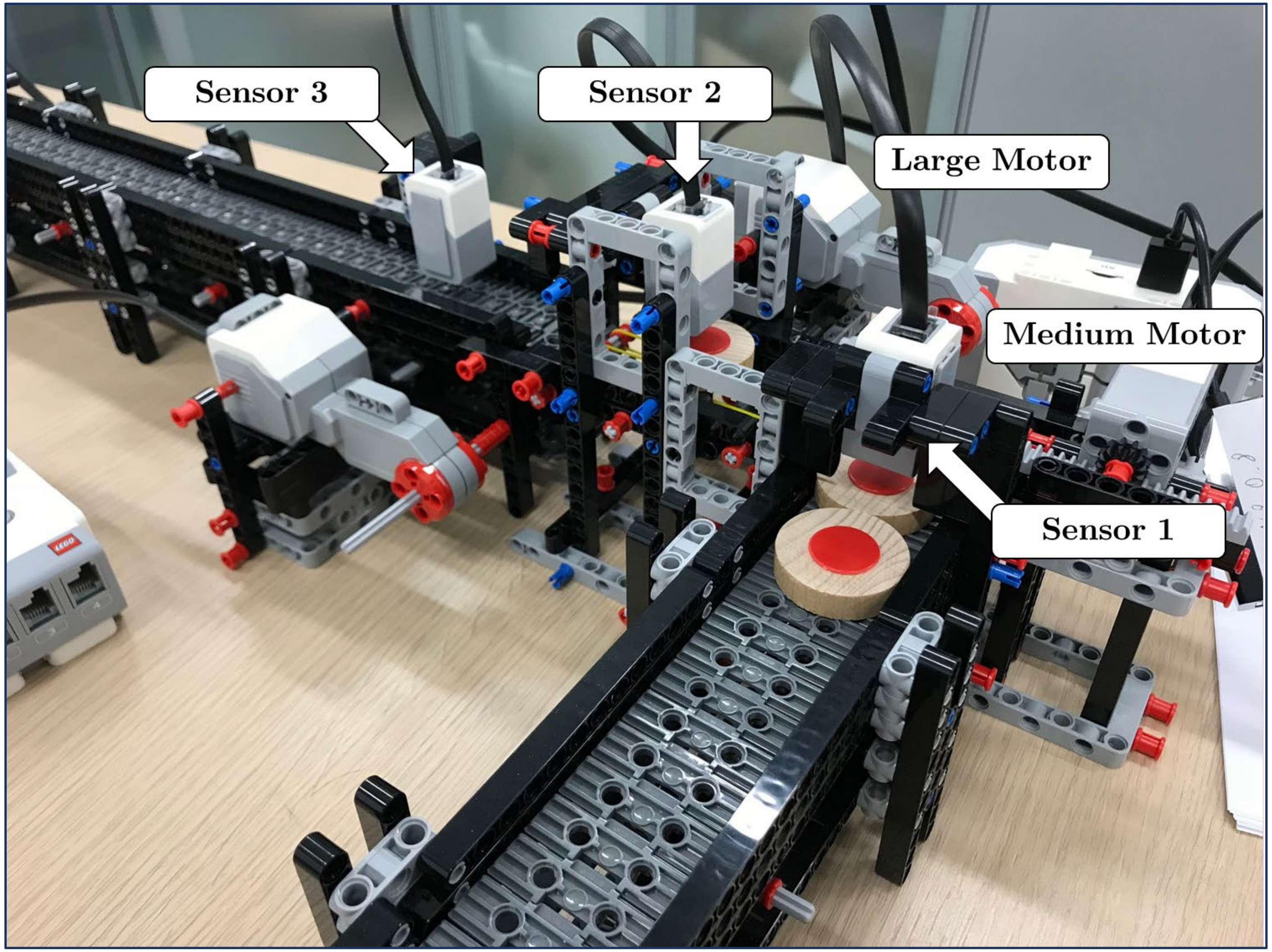


Physical Space

Cyber Space

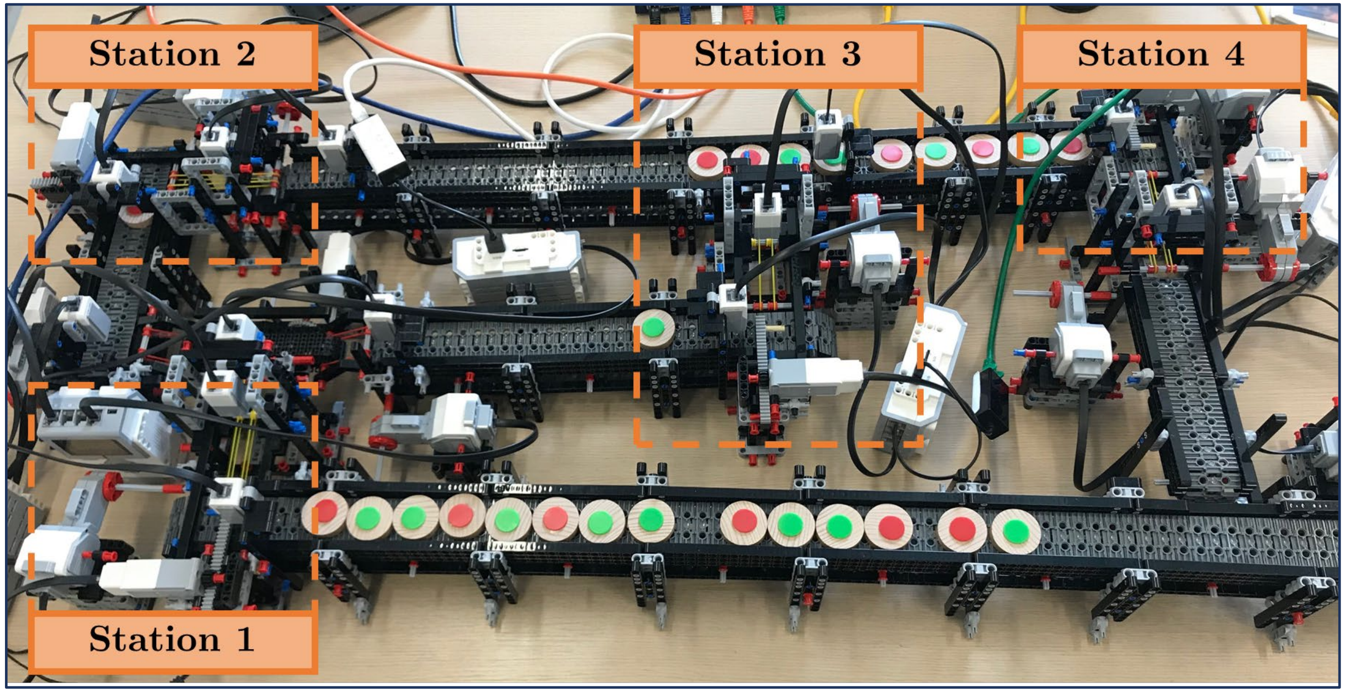
Tan, Y., W. Yang, K. Yoshida, and S. Takakuwa. 2018. “Application of IoT-aided simulation for a cyber-physical system”. In Proceedings of the 2018 Winter Simulation Conference, edited by M. Rabe, A. A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, 4086–4087. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

5. Physical Model

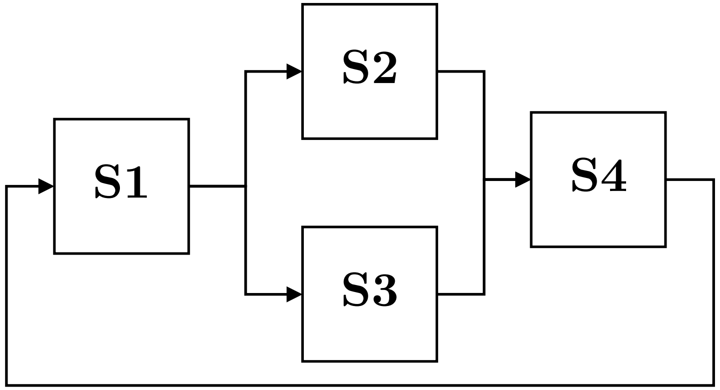


5. Physical Model

Manufacturing System Model



Part-flows Layout

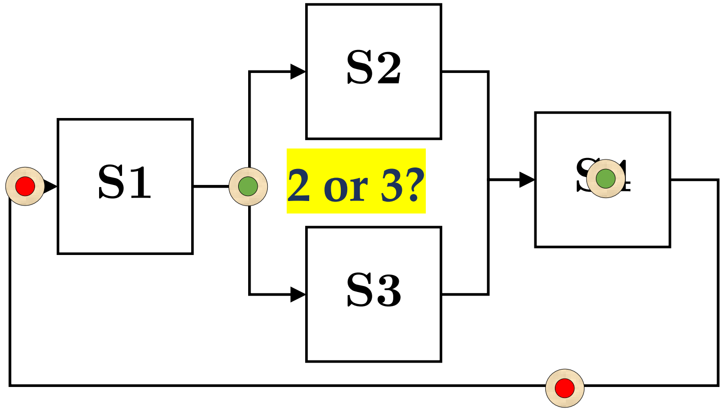


BUFFER	SIZE	STATION	$T_{W,A}$	$T_{W,B}$	SETUP (A to B, B to A)	MAINTENANCE
1	*9*	*1*	$WEIB(10,3)$	$WEIB(12,7)$	-	-
2	*5*	*2*	$WEIB(16,5)$	$WEIB(10,8)$	$(15+f,35)$	-
3	*13*	*3*	$WEIB(18,4)$	$WEIB(25,5)$	$(15,20)$	-
4	*8*	*4*	$WEIB(19,3)$	$WEIB(20,4)$	$(22,18)$	$WEIB(50,10)$*

* once every three pallets of product type B produced.

6. Test Case

SPLITTING POLICY:



Policies (P)	Φ_A	Φ_B
P_0	(2, 1)	(2, 1)
P_1	(1, 2)	(2, 1)
P_2	(2, 1)	(1, 2)
P_3	(1, 7)	(7, 1)
P_4	(1, 5)	(2, 1)

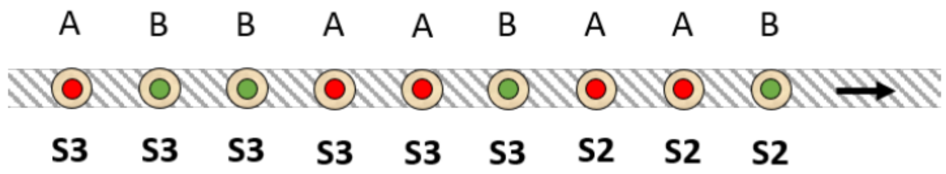
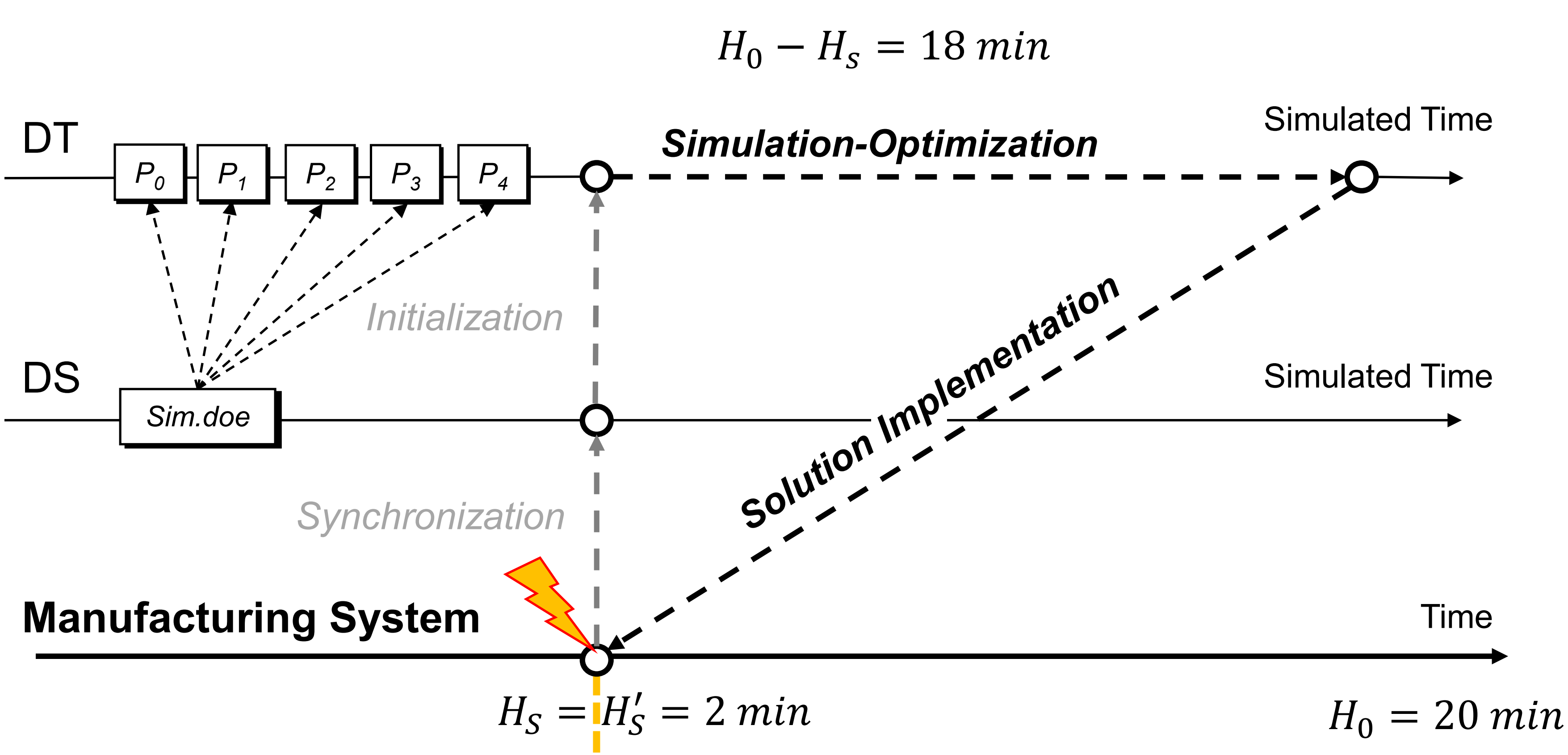


Figure 6: Example of the policy sequence $P_i := \{\Phi_A^{(i)} = (2,3), \Phi_B^{(i)} = (1,3)\}$.

6. Test Case: Disruption Handling



PRODUCTION POLICY:

$\vec{P}_0$ = {(2,1), (2,1)}

$\vec{P}_i$ = {(**x**,**y**), (**j**,**k**)}

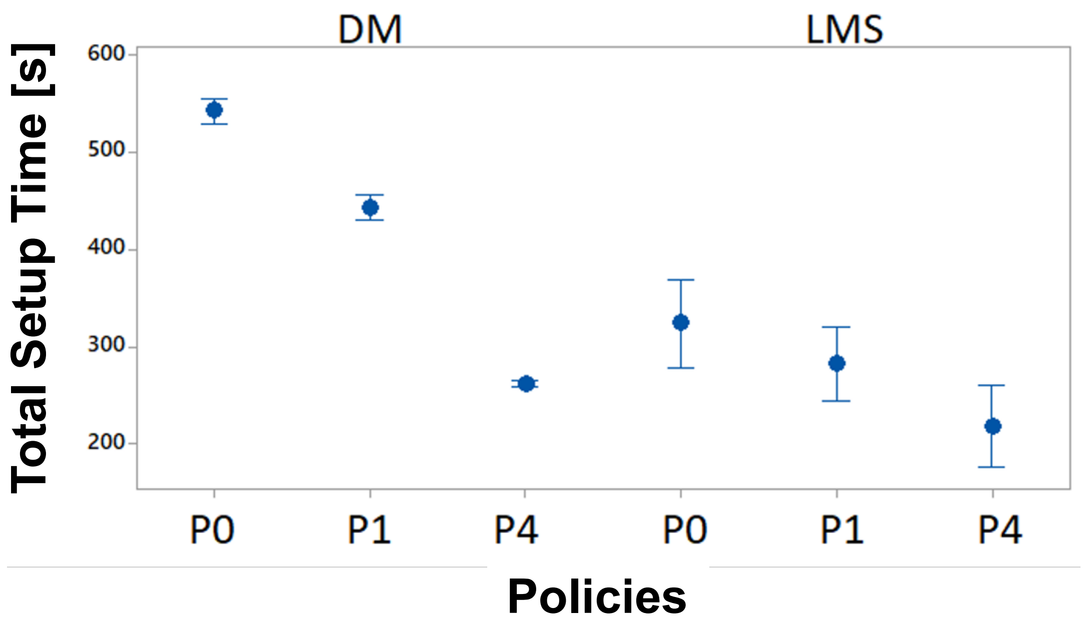
DISRUPTION:
System has to pass from 22 to 37 pallets (+15)

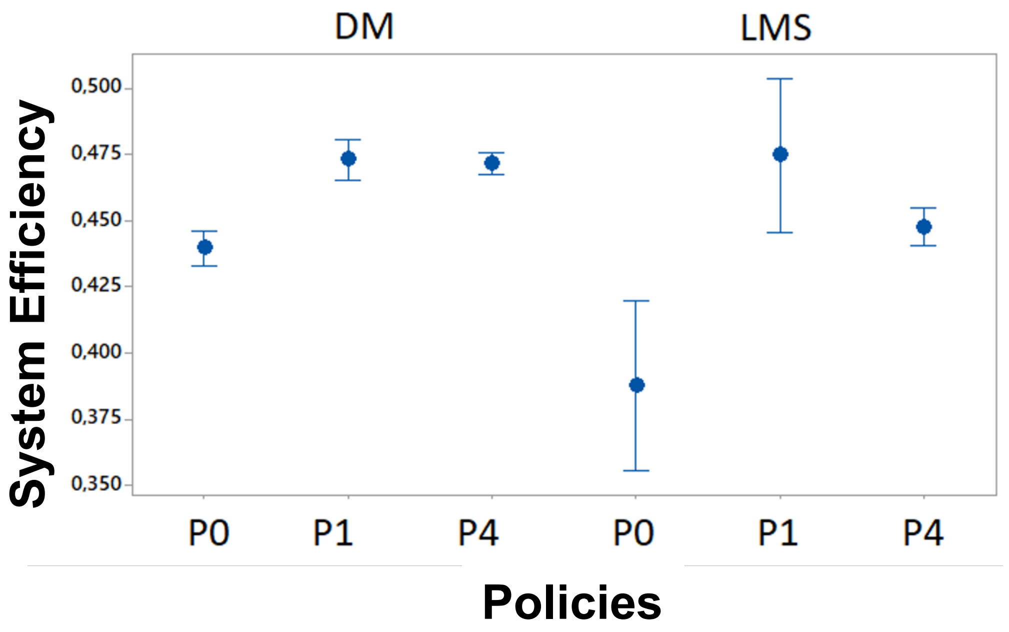
NOTE: In this work, we assume to apply the solution at $H_S = H'_S$

6. Test Case: Numerical Results

Implementation on the System

Policy	Effect on LMS
P_1	Maximizaion of System Efficiency.
P_4	Minimization of total setup times over the time horizon of interest.





6. Test Case: Numerical Results

Implementation on the System

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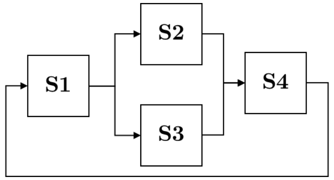
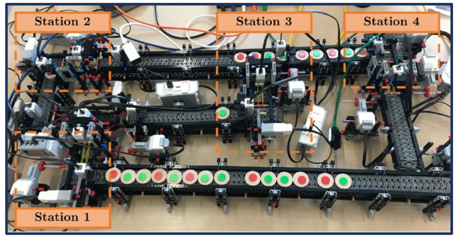




Model	KPI	Comparison	99% Confidence Interval	P-Value
DM	θ	P_0 vs. P_1	[0.0216 , 0.0458]	0.000
		P_0 vs. P_4	[0.0228 , 0.0417]	0.000
	σ_2 [s]	P_0 vs. P_1	[-125.75 , -72.660]	0.000
		P_0 vs. P_4	[-299.96 , -260.95]	0.000
LMS	θ	P_0 vs. P_1	[0.0161 , 0.1584]	0.005
		P_0 vs. P_4	[-0.0010 , 0.1214]	0.011
	σ_2 [s]	P_0 vs. P_1	[-149.90 , 66.200]	0.149
		P_0 vs. P_4	[-201.80 , -9.900]	0.007

DM = Digital Model LMS = Lego® Manufacturing System

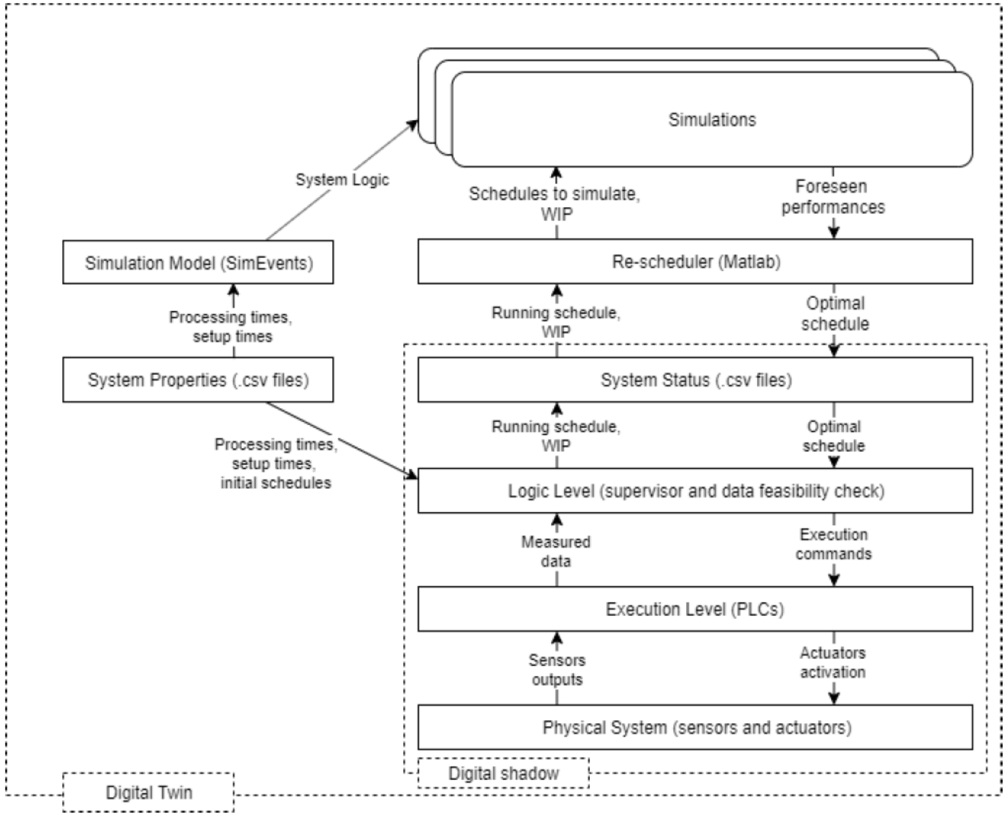
7. Conclusions

Achieved Results

- We proposed an RTS framework and demonstrated its applicability with a test case on a LMS.
- We have accomplished the data exchange and reaction policy identification procedure.

Next Developments

- Improving the decision-making process:
  - Automatic generation of alternative policies (in this work, chosen a-priori)
  - how to optimally choose between a pool of candidates.
- Experimental campaign for evaluating the most influencing factors causing a systematic deviation between the LMS and its DM .
- Tests **without stopping the LMS** (in this work, Hs – Hs' is too big).



RTS Software Architecture (on-going development).

THANK YOU

Suggested References

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