A Digital Process Twin Conceptual Architecture for What-If Process Analysis

2nd International Workshop on Modelling and Implementation of Digital Twins for Complex Systems (MIDas4CS'24)

Ivan Compagnucci[1], Barbara Re[2], Monique Snoeck[3], Estefanía Serral Asensio[3]

[1] Gran Sasso Science Institute, Italy
[2] University of Camerino, Italy
[3] KU Leuven, Belgium

What-if Process Analysis

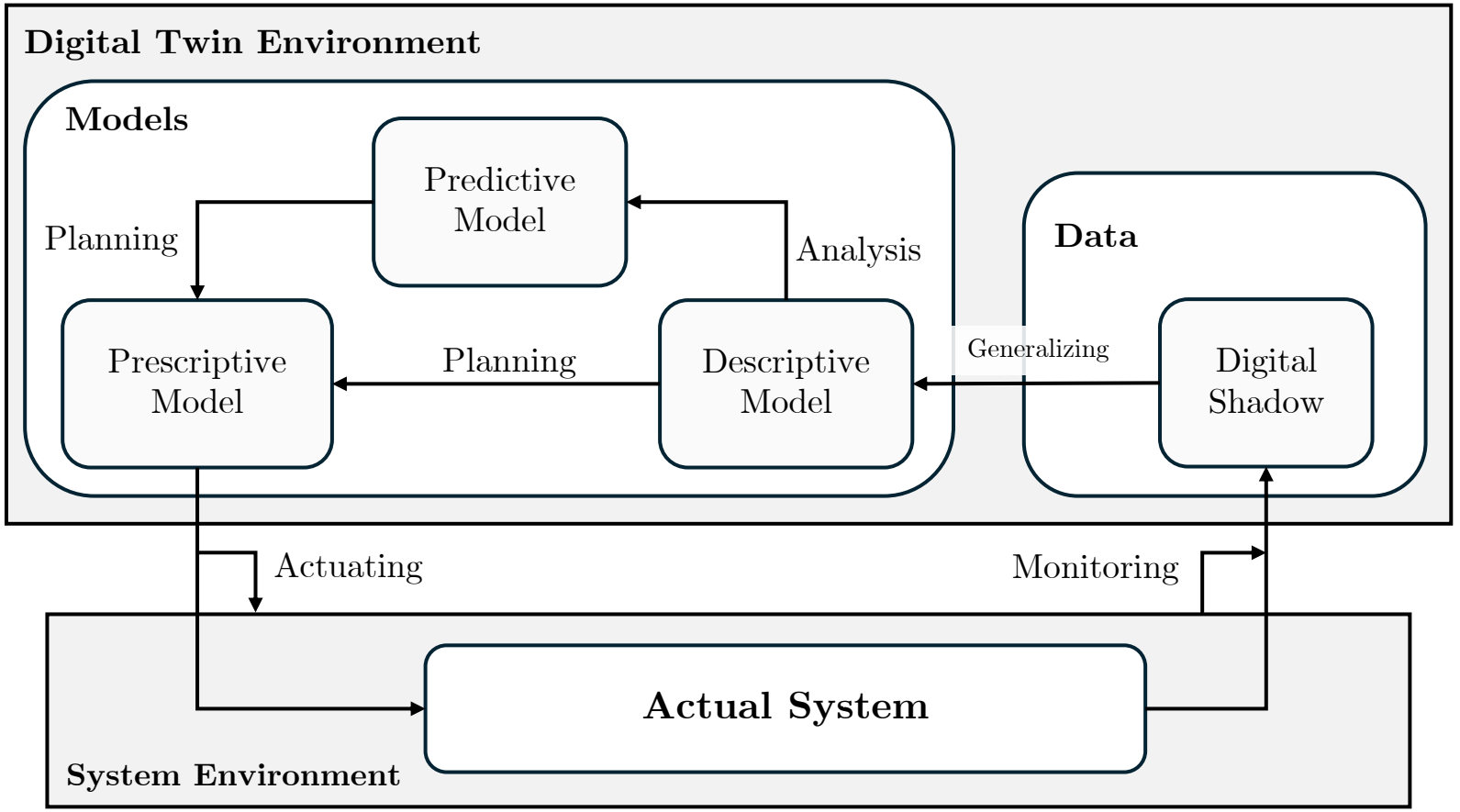
Interventions allow to continuously update and modify business processes to improve their overall performance (i.e., reduce costs, balancing resource utilization, reduce process cycle time)

"How to predict the values that one or more process performance measures will take after a given business ***process intervention****?"*

Goal: Find a way to predict the values of process performance before implementing business process **interventions** in real-world

The Digital Twin Paradigm

A_{DT} = <Actual System, Data, Models>



Eramo, R., Bordeleau, F., Combemale, B., van den Brand, M., Wimmer, M., Wortmann, A.: **Conceptualizing Digital Twins**. IEEE Softw. 39(2), 39–46 (2022)

Digital Process Twin

A **Digital Process Twin** is a digital representation of a real business process, integrated with real-time data and used for simulations, predictions and optimizations

Digital Process Twins provide a new approach to **rethinking and re-engineering** of business processes

1. Enhanced Business Process Model

From **static models** vs Real-time **dynamic models**

2. Process Optimization

Simulations and predictions for proactive optimizations (instead of retrospective analysis)

3. Continuous Feedback Cycle

Continuous feedback loop for **continuous improvement**

ADAPTIVE-TWIN

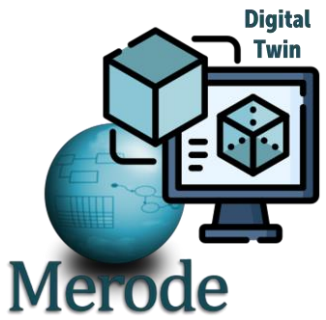
ADAPTIVE-TWIN is a conceptual architecture for implementing Digital Process Twin

The proposed conceptual architecture consist in a **multi-modeling approach** combining a **Domain Model** and the **standard BPMN** into a **data-aware business process modeling**

Goal: virtual implementation and simulation of potential changes in business processes

It was implemented in a tool and evaluated in an inspired-by real-world dispatching of smart containers

Digital Process Twin Conceptual Model



Data-Driven Simulation Process Model (**P1'**)

Digital Process Model Replica (**P1**)

Models

Predictive Model

Planning

Analysis

Prescriptive Model

Planning

Descriptive Model

Data

Generalizing

Digital Shadow

Domain Data Model

Feedback and KPIs Estimation for **P1'**

New! *New!*

Actuating

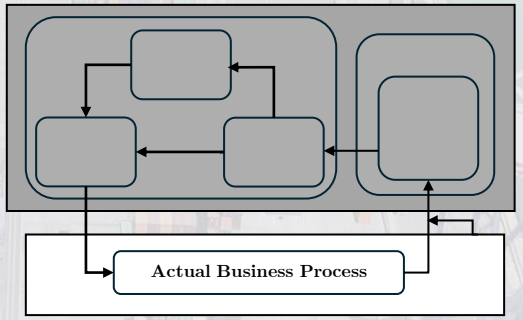
Monitoring

Mining

Actual Business Process

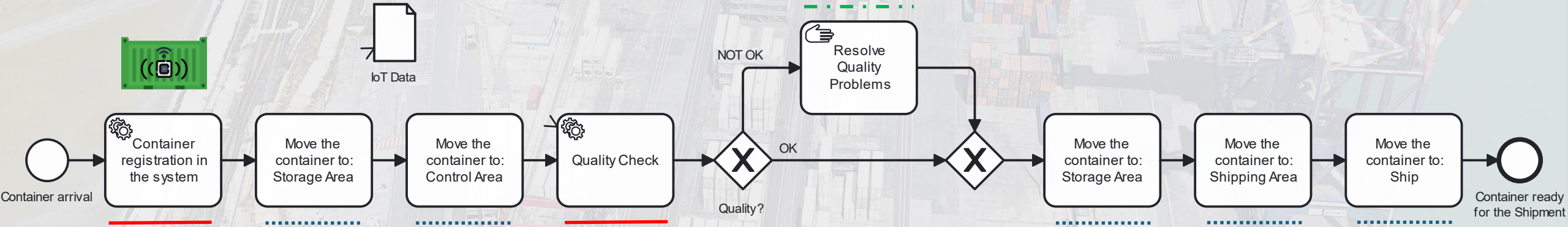
Process-Aware Information System

Actual Business Process: The Container Dispatch



Generated from synthetic event logs

IoT-Enhanced Business Process

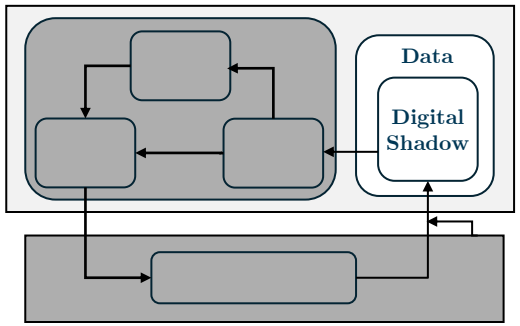


Costs:
Worker 1: 20€/hr – 24/7
Worker 2: 30€/hr – 24/7
Worker 3: 25€/hr – 24/7

Activities Duration:
Moving the Container: 25/35mins – Uniform
System Registration: 5 mins – Fixed
Solving Quality Problems: 1 hour - Fixed

Scenario Specification:
Total N°of Instances: 500 Containers
Instances Arrival Time: 1 Container/hr
Work schedules: 24/7

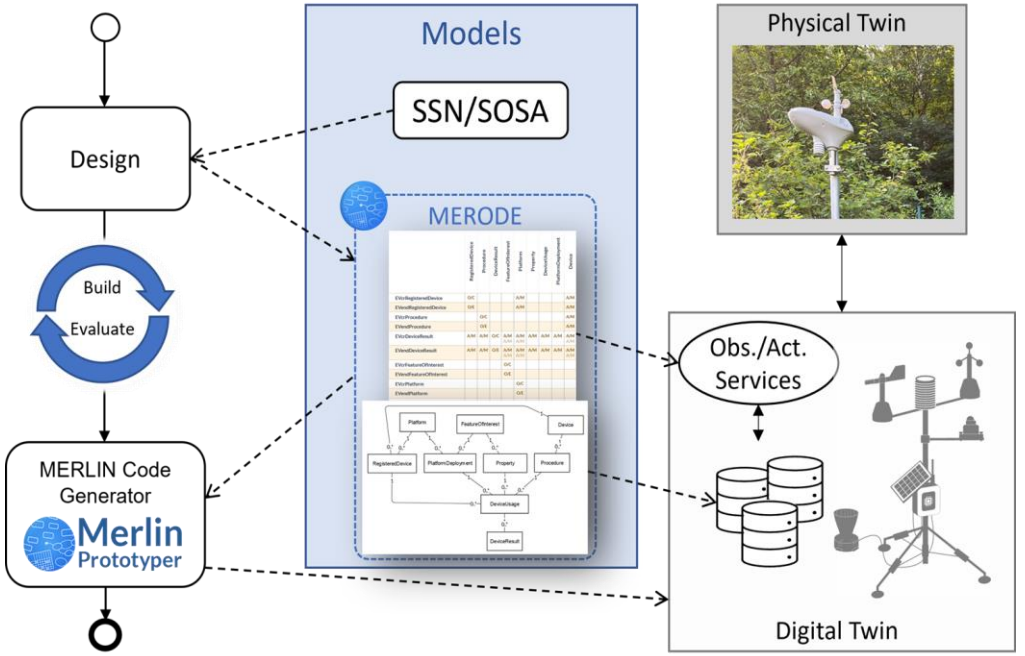
Data: Digital Shadows



Digital Shadows were generated by instantiating a **MERODE Domain Model**

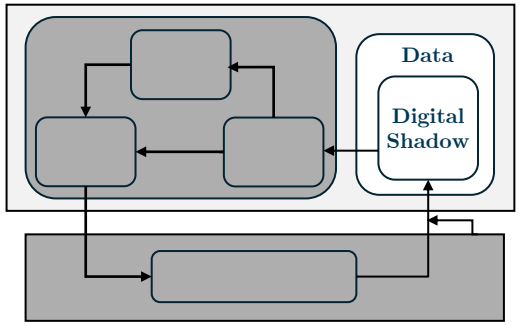
MERODE is a Model-Driven methodology that uses **object-oriented domain modeling to develop Enterprise Information Systems**

A MERODE Domain Model for IoT was derived by mapping classes from the SSN/SOSA IoT ontologies

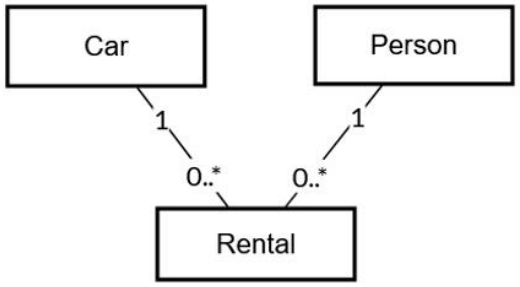


Compagnucci, I., Snoeck, M., Serral E. 2023. **Supporting Digital Twins Systems Integrating the MERODE Approach** (MODELS-C '23), pp. 449–458.

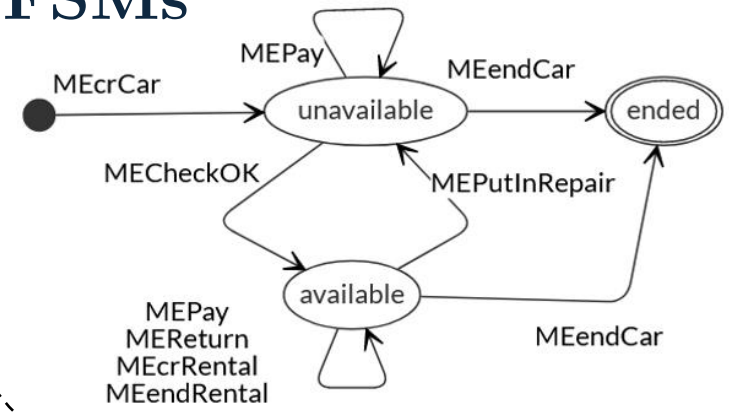
Data: Digital Shadows



EDG



FSMs



OET

	Car	Person	Rental
EVcrCar	O/C		
EVCheckOK	O/M		
EVPutInRepair	O/M		
EVendCar	O/E		
EVcrPerson		O/C	
EVApply		O/M	
EVApprove		O/M	
EVDisapprove		O/M	
EVUpdateInfo		O/M	
EVendPerson		O/E	
EVcrRental	A/M	A/M	O/C
EVPay	A/M	A/M	O/M
EVReturn	A/M	A/M	O/M
EVendRental	A/M	A/M	O/E

The MERODE Domain Model

Existence Dependency Graph (EDG)

Designed to **define business process objects** (classes) and their associations

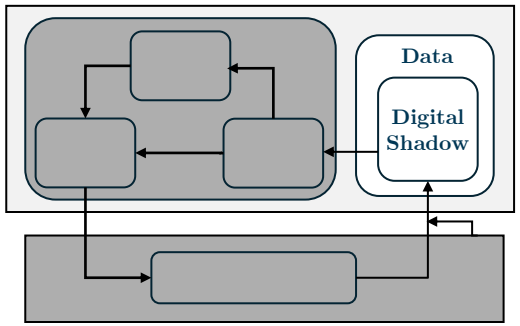
Finite State Machines (FSMs)

Designed to **trigger state changes in multiple business objects** performing business events

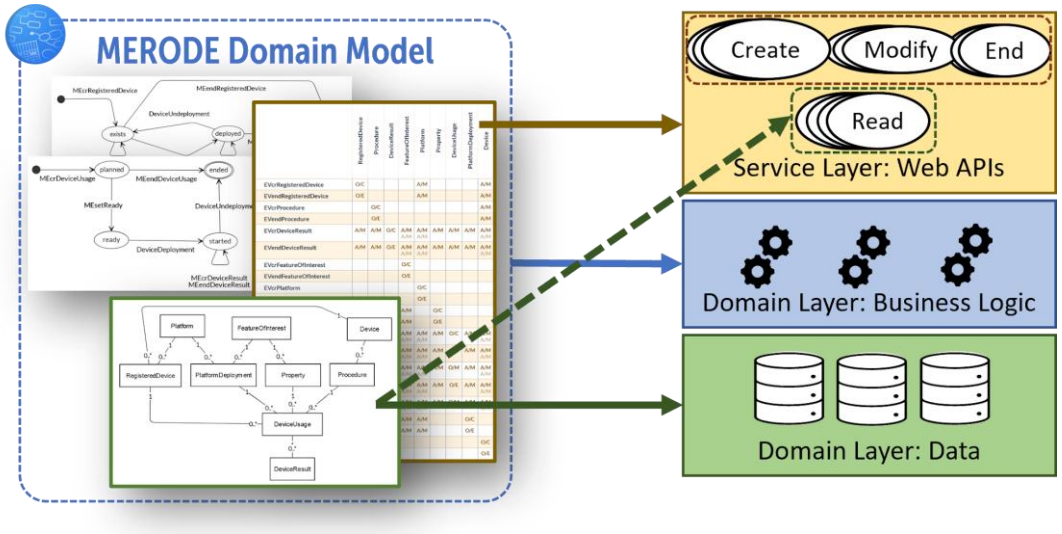
Object Event Table (OET)

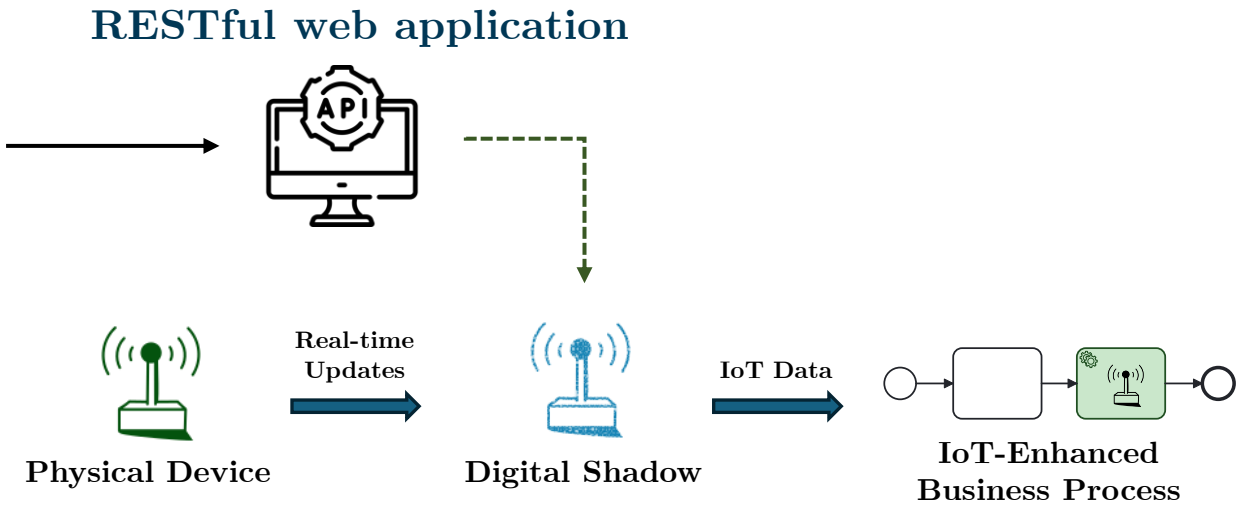
Designed to **map business events to each business objects** indicating state change (C/M/E)

Digital Shadows in Practice

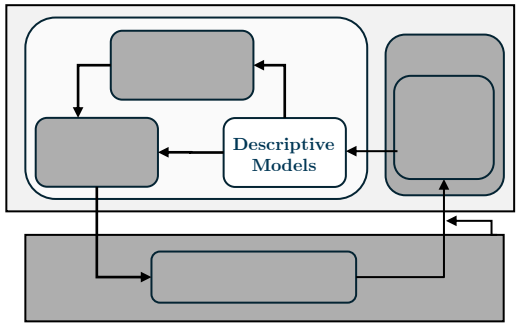


> MERLIN Code Generator has been used to pass from the **MERODE Domain Model to Code** as RESTful web application





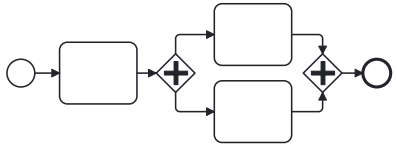
Models: Descriptive Models



The Actual Process (*P1*) correspond to a behavior process model describing the process logic

Process-Aware Information System

Process Mining →

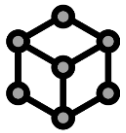


BPMN Model of the Actual Business Process **P1**

Real-time domain process data are handled by Digital Shadows

Real-World Business Object

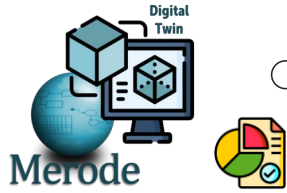
Instantiation →



Digital Shadow of Business Object

+ **Attributes**
+ **Current State**
+ **Possible Actions**

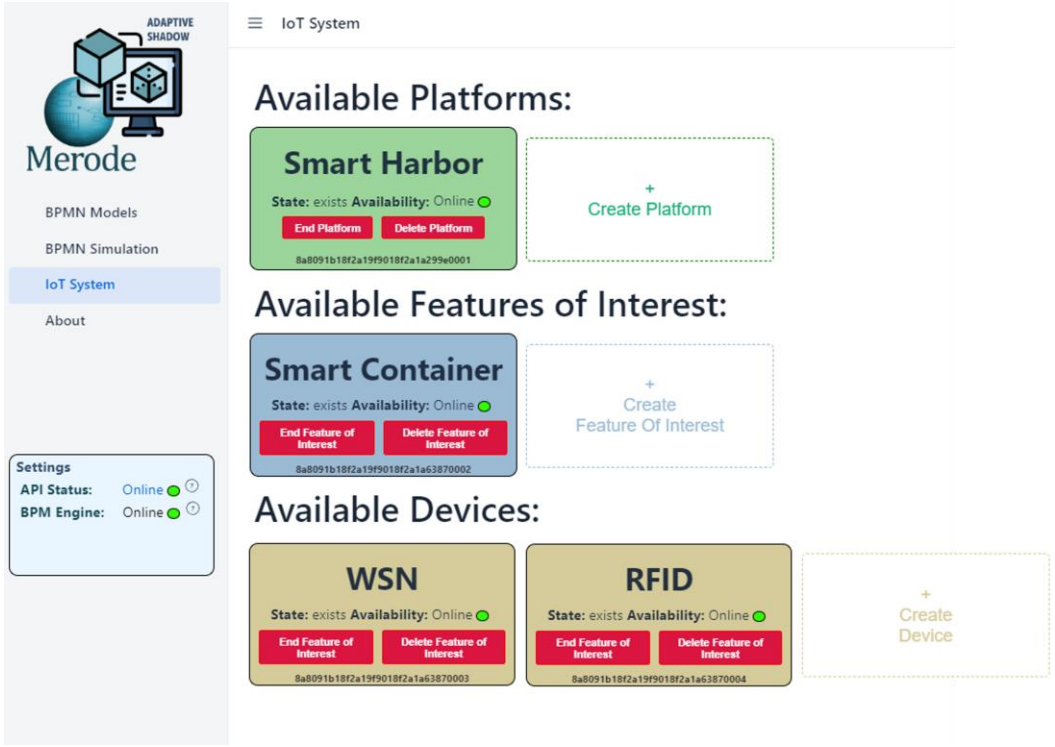
Real-Time Business Objects Data →



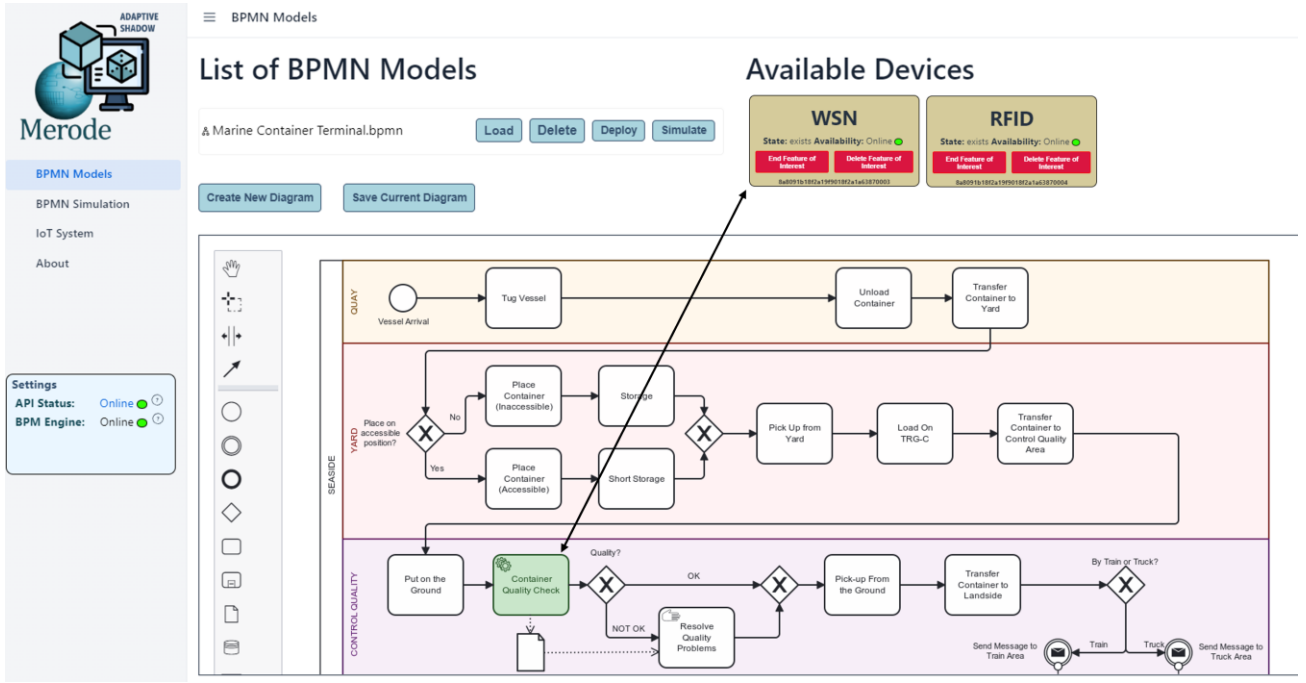
ADAPTIVE-TWIN

Merging Process and Data Perspectives

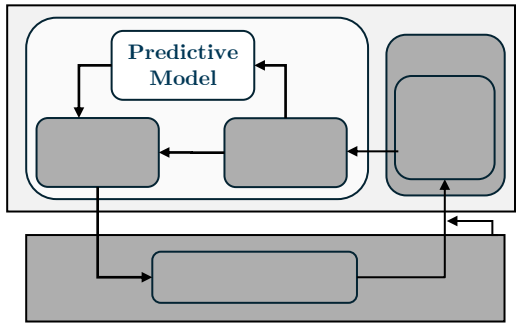
1. Domain Model Instantiation



2. Service Task Configuration



Models: Predictive Model

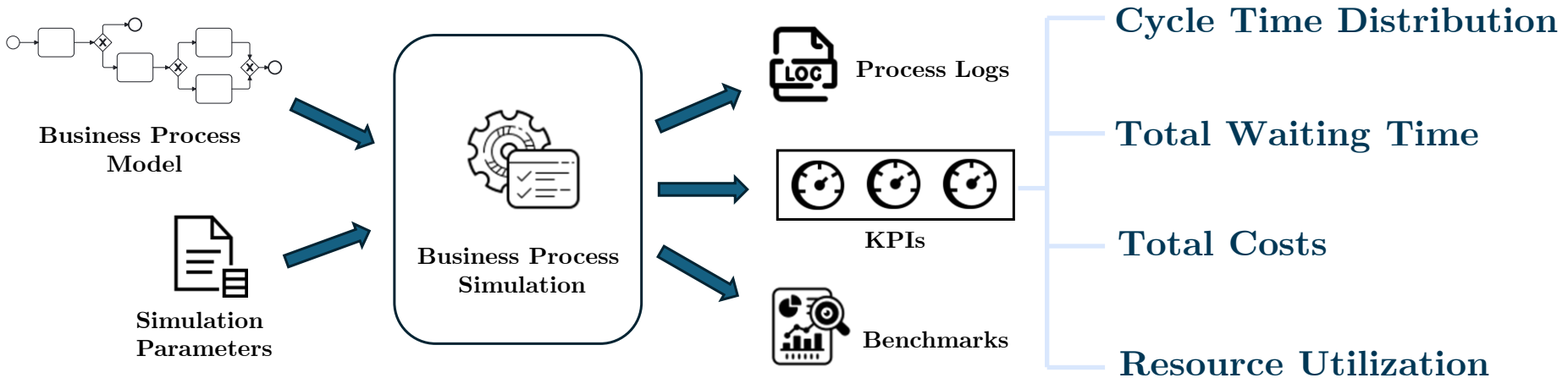


Goal: Build a model to virtually estimate the impacts of changes in process performance

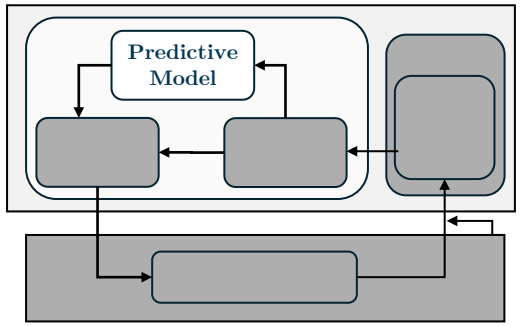
Business Process Simulation

General Parameters
- # of Process Instances
- Resource Pool
- Timetables
- ...

BPMN Parameters
- Assign a Resource to a specific task
- Duration of a task
- ....

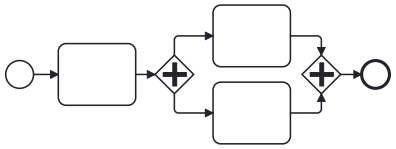


Models: Predictive Model



A **Data-Driven Process Simulation** has been integrated to estimate the impact of a process optimizations by leveraging real-time data

ADAPTIVE-TWIN Implements BIMP Process Simulator Java Engine based on the *token-based* mechanism

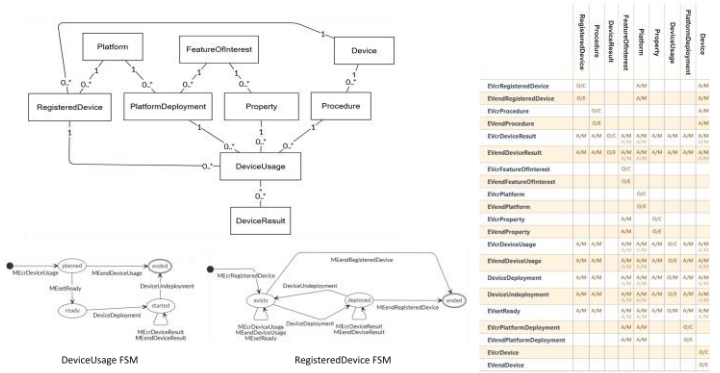


Actual Process Model P1
(process model)

+

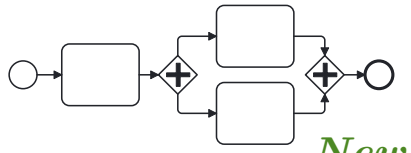
Process Changes
for optimization

+



MERODE Domain Model
(process data)

=



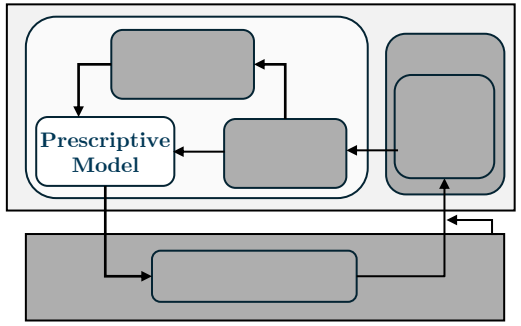
New!

Data-Driven Simulation
Process Model **P1'**
(process model)

+

Simulation Parameters

Models: Prescriptive Model

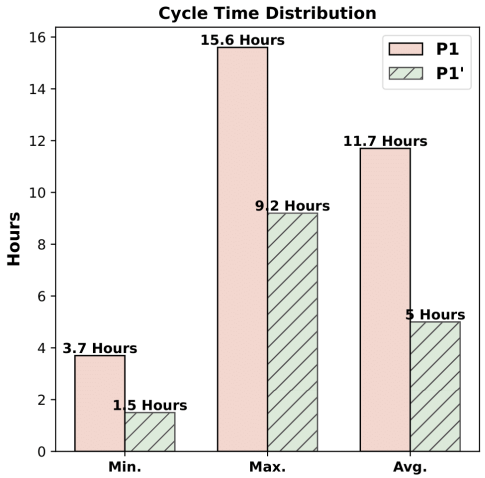


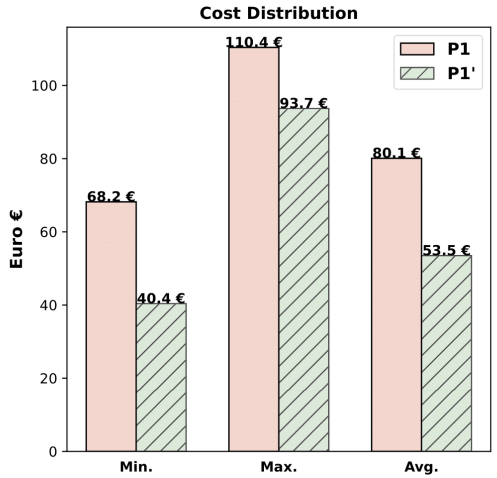
Goal: Derive feedback to estimate the impacts of changes in process performance

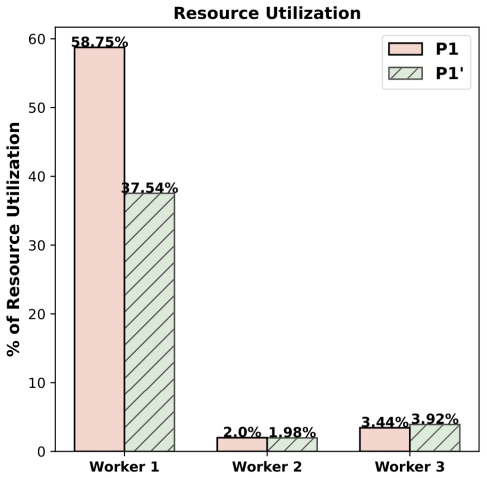
Optimized Business Process *P1'* *New!*

- **KPIs**
- **Event Logs**

Simulation reports an improvement in comparing the performance of ***P1*** and ***P1'***







- ✓ Reduction of Total Cycle Time
- ✓ Reduction of Total Process Costs
- ✓ Improved Resource Distribution

Conclusion

Digital Process Twin can offer new interesting opportunities

- **Rapid prototyping** of business processes including new changes
- Implementation and Assessment of process changes in a **safe and controlled environment**
- **Predict the future vs Analyzing the past**

Point of Concerns

- **Source data needs to be accurate and well-collected**
- **Design high-fidelity descriptive models**
- Simulations and advanced analysis **require data analysis expertise** (i.e., make right assumptions in business process simulations)

Limitation

Quantitative analysis of the Business Process

> Business Process Simulation allows to estimates quantitative performances only

The Domain Data Model for IoT

> The Domain Data Model is specific for IoT-Enhanced Business Processes

ADAPTIVE-TWIN is in the "Tool-Chain" concept

> The current approach requires further development to integrate all components into a single solution

Future Work

Enhance the Accuracy of Business Process Digital Replica

> Integrating additional models to address different perspective of the process replica

Introduce new Analysis on the Business Process Digital Replica

> Integrating additional analysis such as real-time process prediction or model properties (i.e., soundness, safeness)

Evaluation of the approach on a More Complex Scenarios

> Applying the approach to a larger scenario to evaluate its scalability and robustness

Thank you

Ivan Compagnucci[1], Barbara Re[2], Monique Snoeck[3], Estefanía Serral Asensio[3]

[1] Gran Sasso Science Institute, Italy
[2] University of Camerino, Italy
[3] KU Leuven, Belgium