GDR Groupement de recherche
MACS Modélisation, Analyse et Conduite des Systèmes dynamiques



RODIC Studio : Rapid reconfiguration of manufacturing systems: a model-based software engineering and human interaction coupled approach

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[2]Université de Strasbourg, INSA Strasbourg, CNRS, ICUBE, UMR 7357, F-67000 Strasbourg, France
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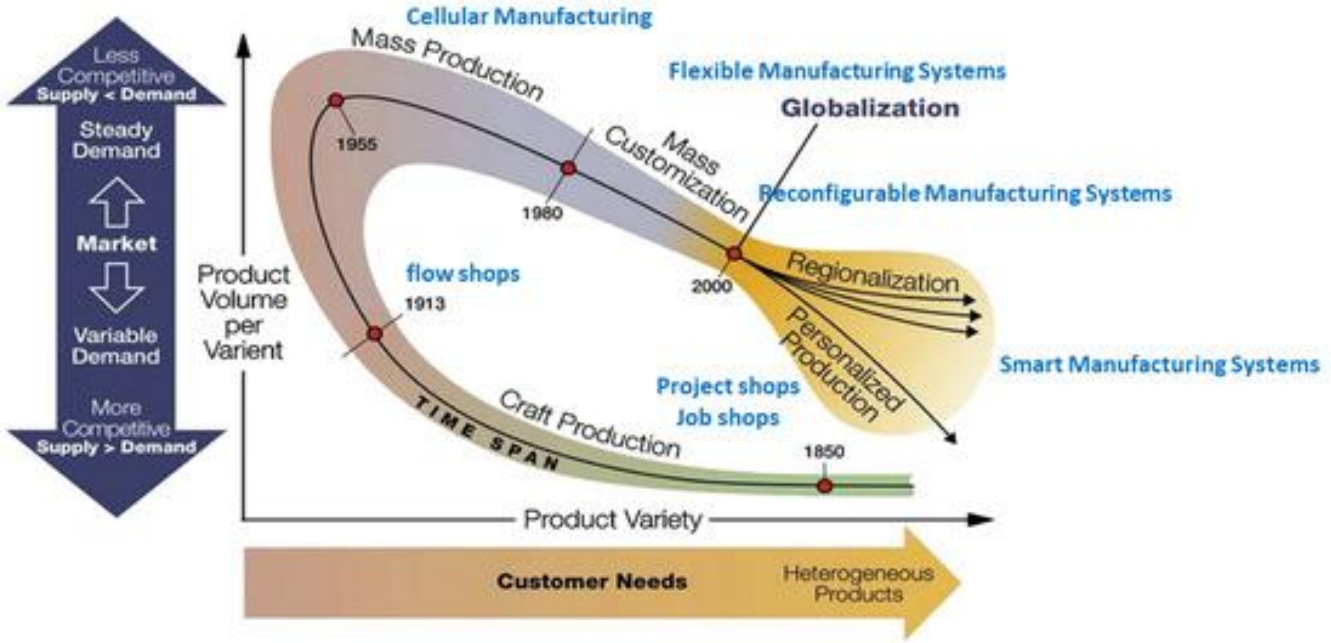
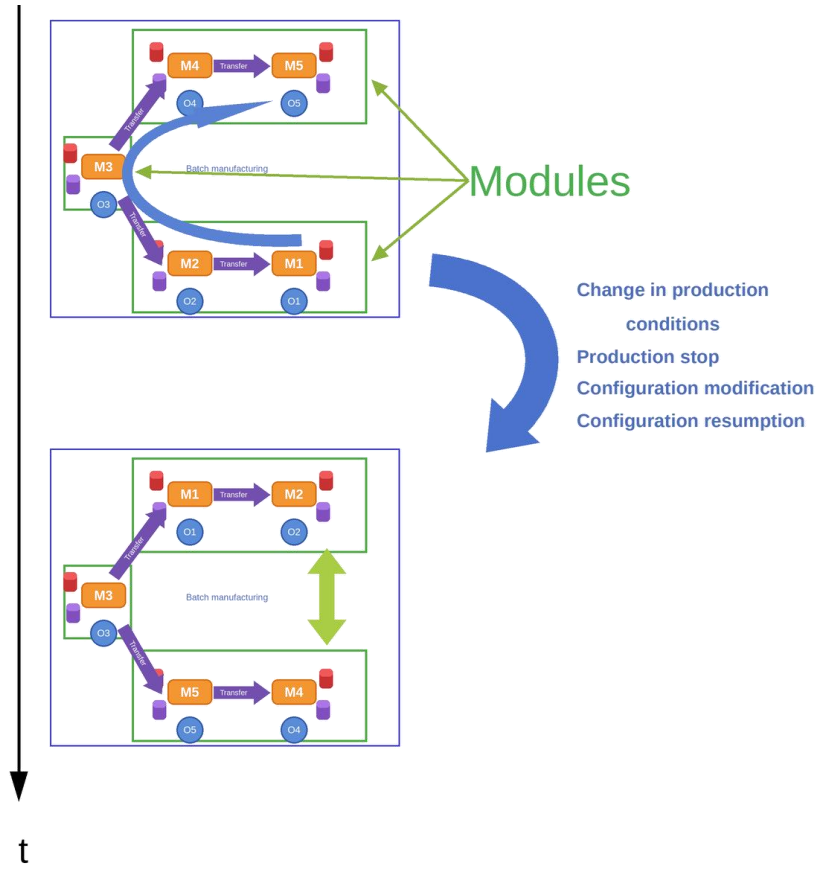
RODIC – ANR Project 2022-2026

Rapid recOnfiguration of manufacturing systems: a model-baseD software engineering and human Interaction Coupled approach

Motivation & Context: the RMSs

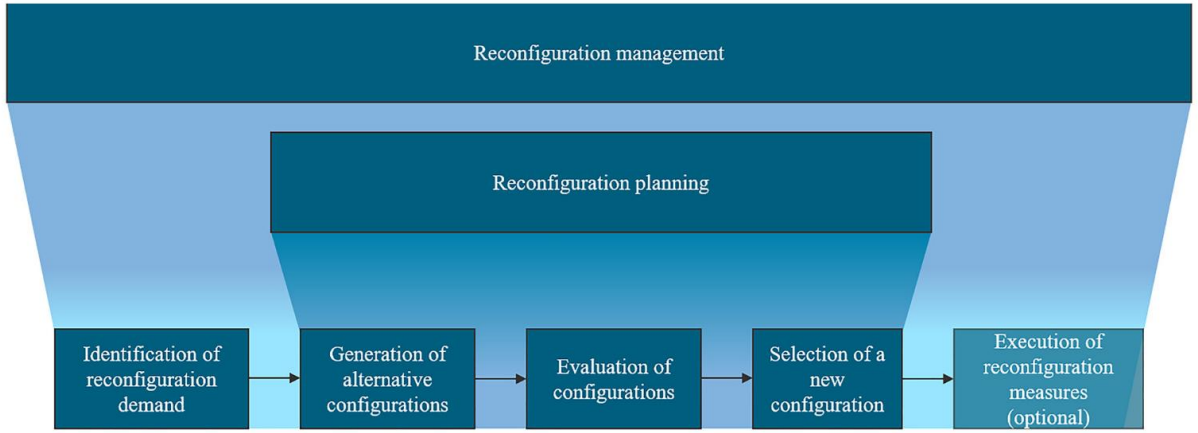




Turner, C.; Oyekan, J. Manufacturing in the Age of Human-Centric and Sustainable Industry 5.0: Application to Holonic, Flexible, Reconfigurable and Smart Manufacturing Systems. Sustainability **2023**, 15, 10169. https://doi.org/10.3390/su151310169

Industrial Context

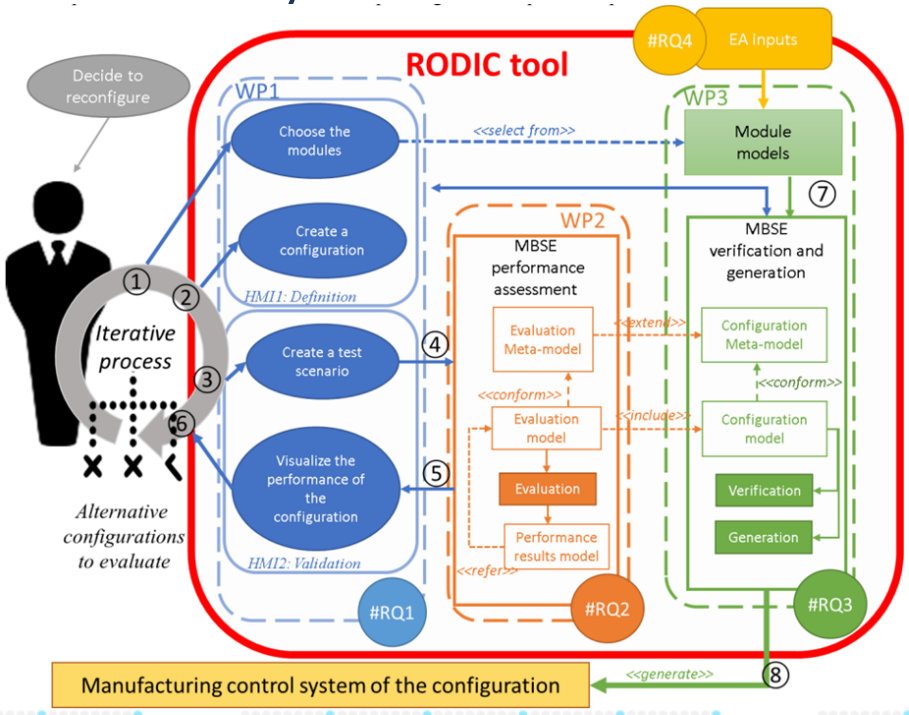
- A company has designed a reconfigurable manufacturing system
- A reconfiguration operator:
  - Has identified the need to reconfigure
  - Has developed a potential alternative configuration
  - Needs to evaluate this new configuration
- How can he do this?
  - If he has experience: rely on his judgement
  - If he is an engineer: use a spreadsheet and carry out calculations
  - If he has a Master Degree in Operations Research: develop a mathematical model
  - If he has a Master Degree in Industrial Engineering: use flow simulation



B. Maschler, T. Muller, A. Locklin, and M. Weyrich, "Transfer learning as an enhancement for reconfiguration management of cyber-physical production systems," Procedia CIRP, vol. 112, pp. 220–225, 2022.

Project Objective

- Our ambition:
  - To develop a tool that allows the evaluation of any RMS configuration under time pressure without requiring exceptional expertise
- Related research questions:
  - What functions and interfaces are essential for the operator to carry out the evaluation?
  - How should a configuration be expressed?
  - How can a configuration description be converted into an executable model?
  - How can the KPIs to be measured be expressed in a generic way?
  - How can KPI measurement be implemented during model execution?

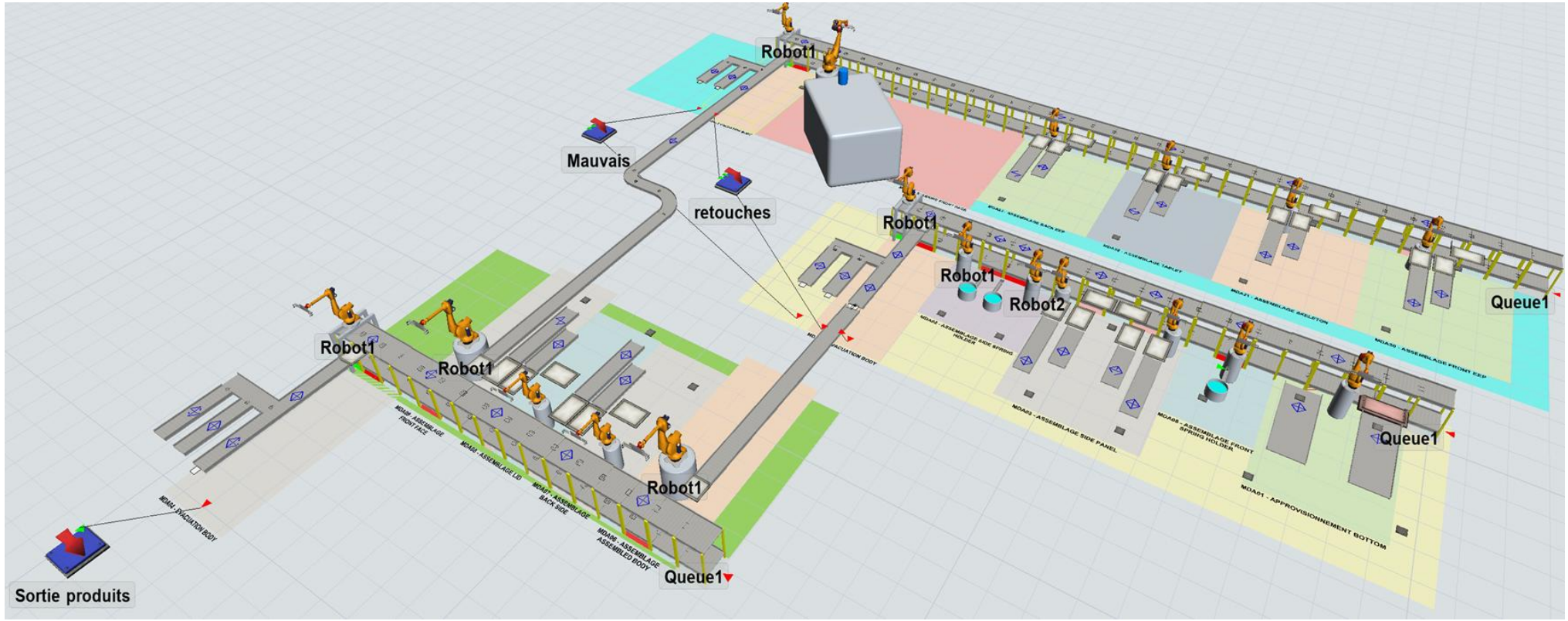


The RODIC Project in a Nutshell

- ANR 21CE10-0017-01 project From March 2022 to December 2026
- Budget 497 195€ ANR + 50 000€ Pays de Loire Region + 30 000€ LS2N
- Partners:
  - Nantes, LS2N
  - Lorient, LAB-STICC
  - Strasbourg, ICUBE
- Skills in Industrial Engineering/Software Engineering/Human Factors
- Recruitment:
  - 5 M2 trainees
  - 2 PhD students
  - 1 post-doctoral researcher 18 months
  - 1 engineer 27 months since october 2024

Project Case Studies: Living Pakets

- A Nantes-based start-up specialising in the design of high-end e-commerce packaging
- Quantitative validation of the assessment tool

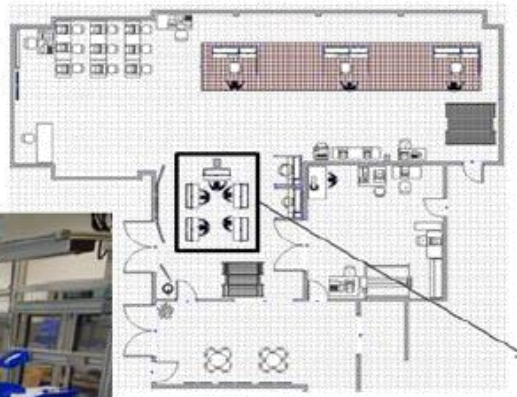


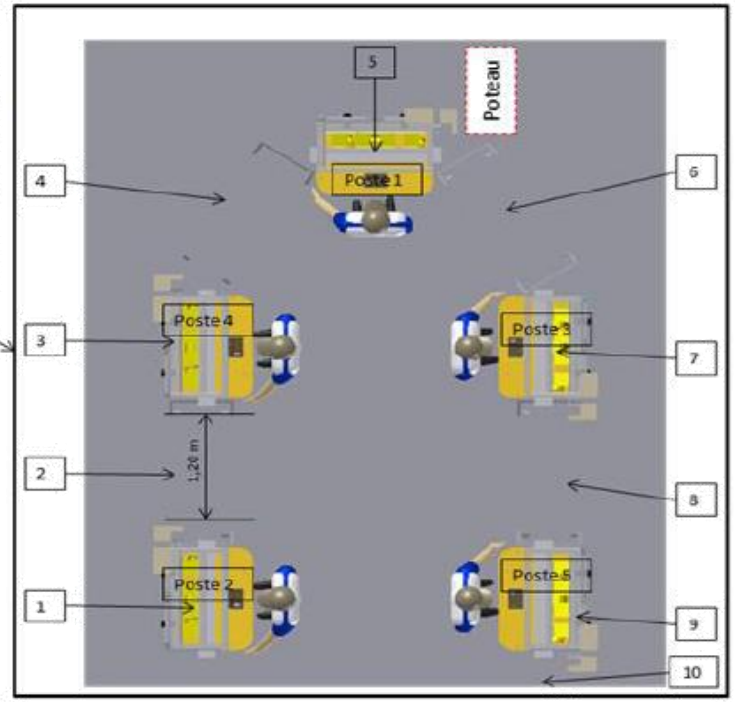
Project Case Studies: Lampex Case

- Strasbourg University School factory
- Assembly of promotional torches
- 10 assembly stations, with trolleys or conveyor belts
- Qualitative validation carried out by Master's students





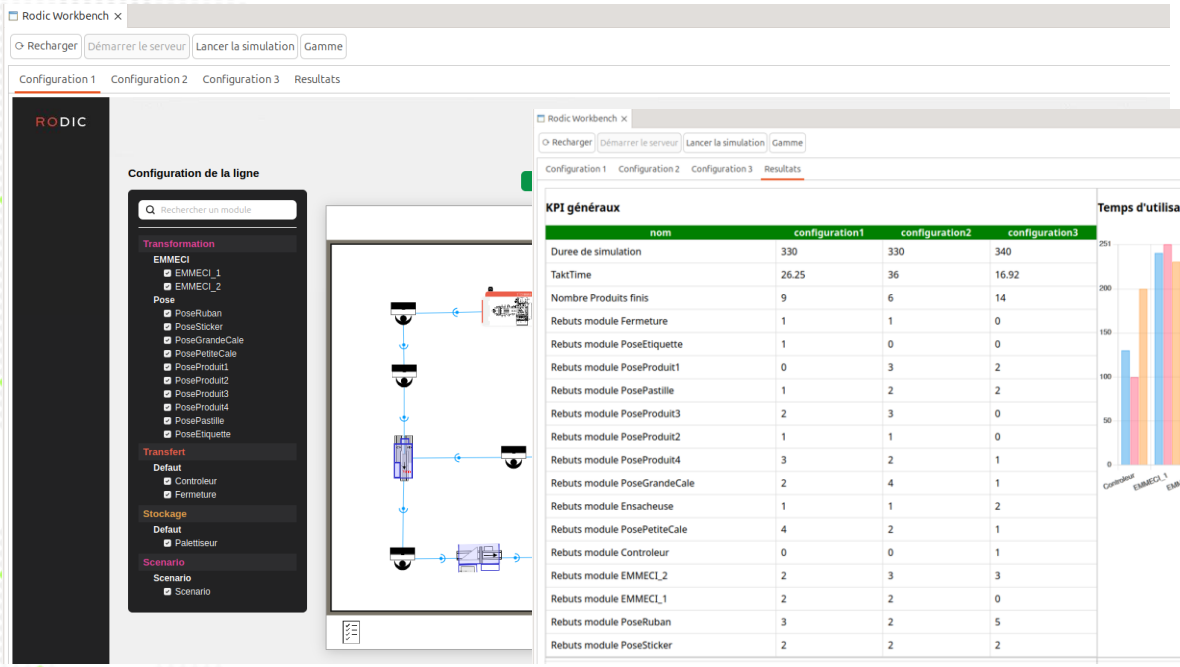




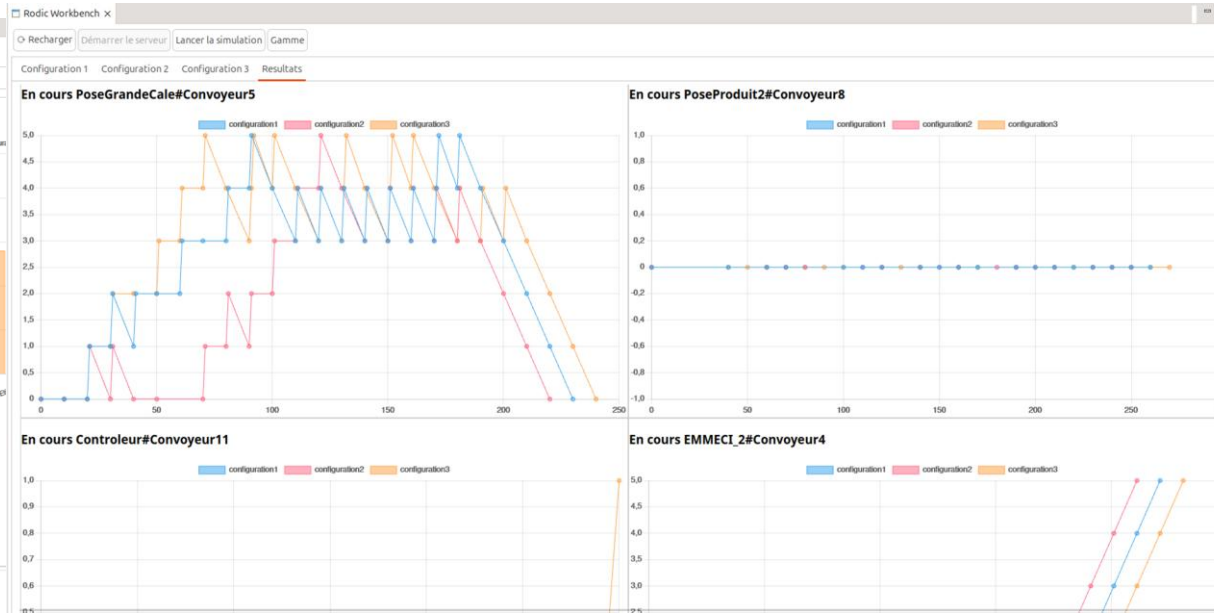
Our tool (coming soon)

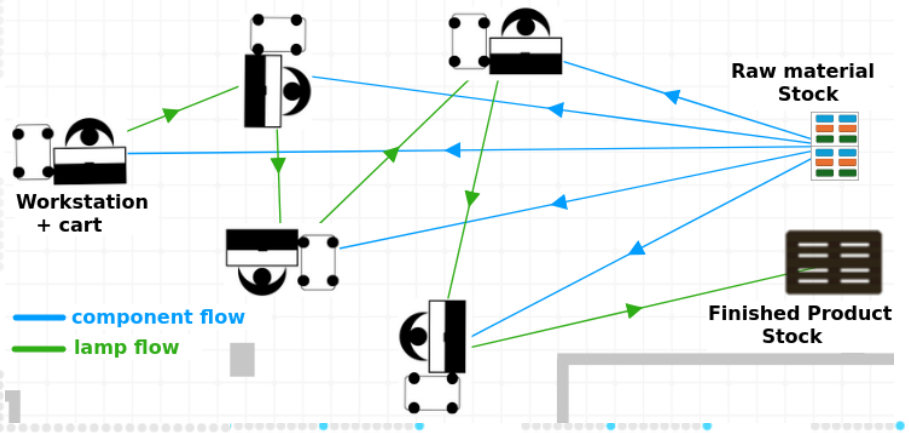


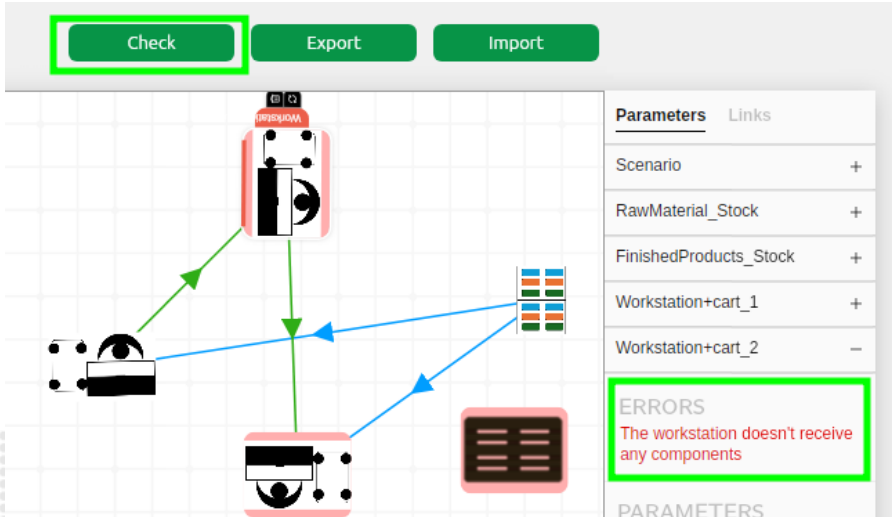
Our tool: snapshots



nom	configuration1	configuration2	configuration3
Duree de simulation	330	330	340
TaktTime	26.25	36	16.92
Nombre Produits finis	9	6	14
Rebuts module Fermeture	1	1	0
Rebuts module PoseEtiquette	1	0	0
Rebuts module PoseProduit1	0	3	2
Rebuts module PosePastille	1	2	2
Rebuts module PoseProduit3	2	3	0
Rebuts module PoseProduit2	1	1	0
Rebuts module PoseProduit4	3	2	1
Rebuts module PoseGrandeCale	2	4	1
Rebuts module Ensacheuse	1	1	2
Rebuts module PosePetiteCale	4	2	1
Rebuts module Controleur	0	0	1
Rebuts module EMMECI_2	2	3	3
Rebuts module EMMECI_1	2	2	0
Rebuts module PoseRuban	3	2	5
Rebuts module PoseSticker	2	2	2

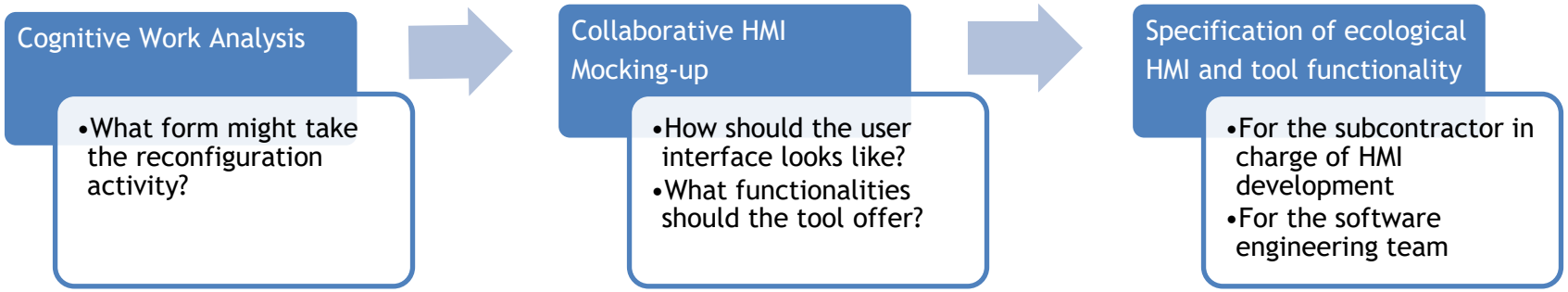






RODIC : Reconfiguration as a Human-Centered Activity

- 3 steps approach based on Simon et al. 2021



Simon, L., Guérin, C., Rauffet, P., & Lassalle, J. (2021). Using cognitive work analysis to develop predictive maintenance tool for vessels. *31st European Safety and Reliability Conference*

Cognitive Work Analysis of the Reconfiguration Activity

- Formative modelling of the reconfiguration activity:
  - What form might take the reconfiguration activity?
  - Structured as a hierarchy of abstraction
  - Built with a partner company
- Built using Naikar et al. (2013) methodology:

1. Aim of the analysis
2. Project constraints
3. Limitations of the analysis
4. Constraints of the work domain
5. Identification of the information sources
6. Construction of the abstraction hierarchy (AH)
7. Validation of the AH through activity

Naikar, N. (2013). Work domain analysis : Concepts, guidelines, and cases. CRC Press

Cognitive Work Analysis of the Reconfiguration Activity

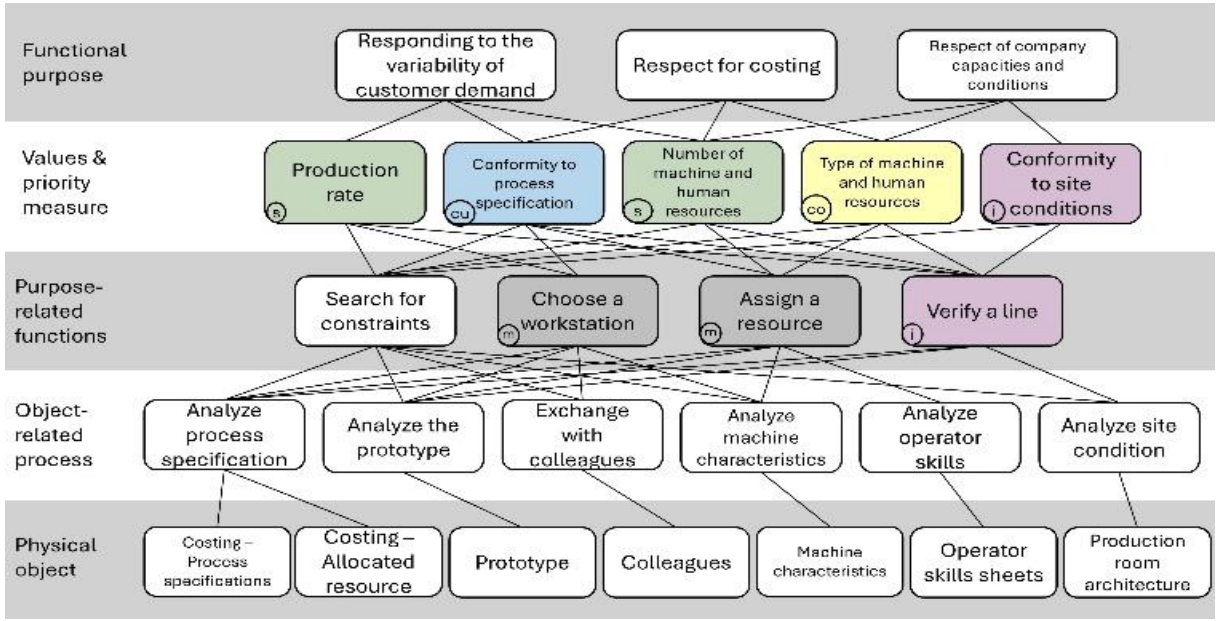
- ## Abstraction Hierarchy of the Reconfiguration activity

Reconfiguration driver

Reconfiguration constraints

Iterative activities of reconfiguration

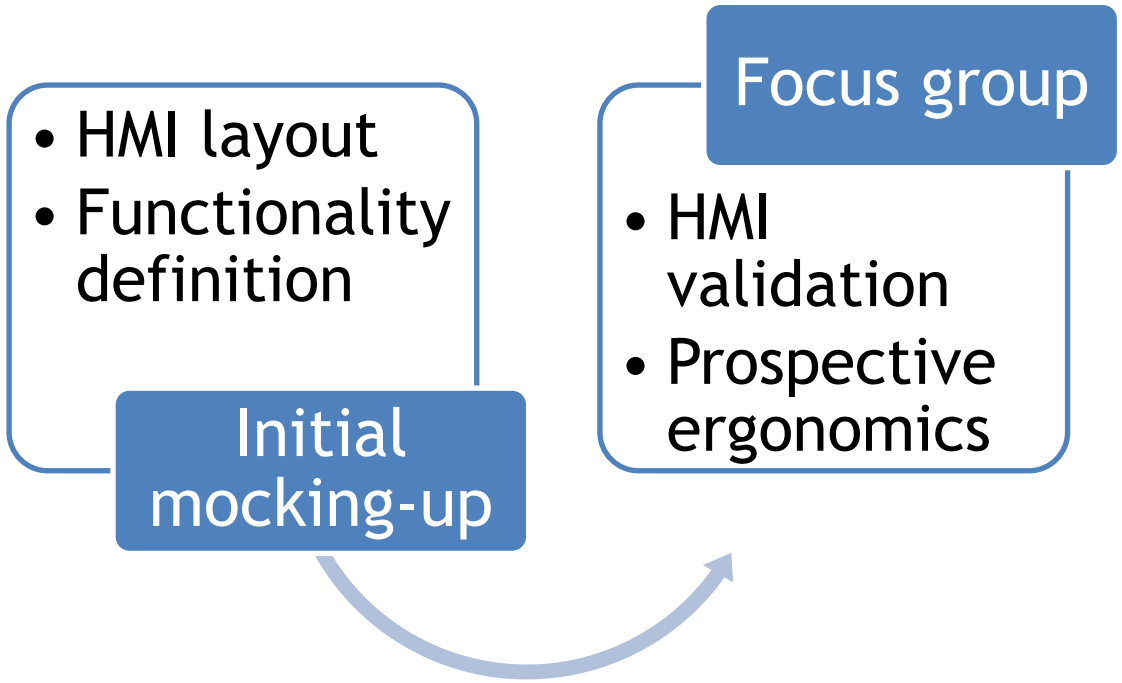
Information sources for the tool



Smith-Guerin, N., Simon, L., Guérin, C., Rauffet, P., & Berruet, P. (2025). An interdisciplinary approach between human factor and industrial engineering to a better understanding of RMS: an industrial case. 11th IFAC Conference on Manufacturing Modelling, Management and Control. https://doi.org/https://doi.org/10.1016/j.ifacol.2025.09.428

Collaborative Mocking-Up of the HMI

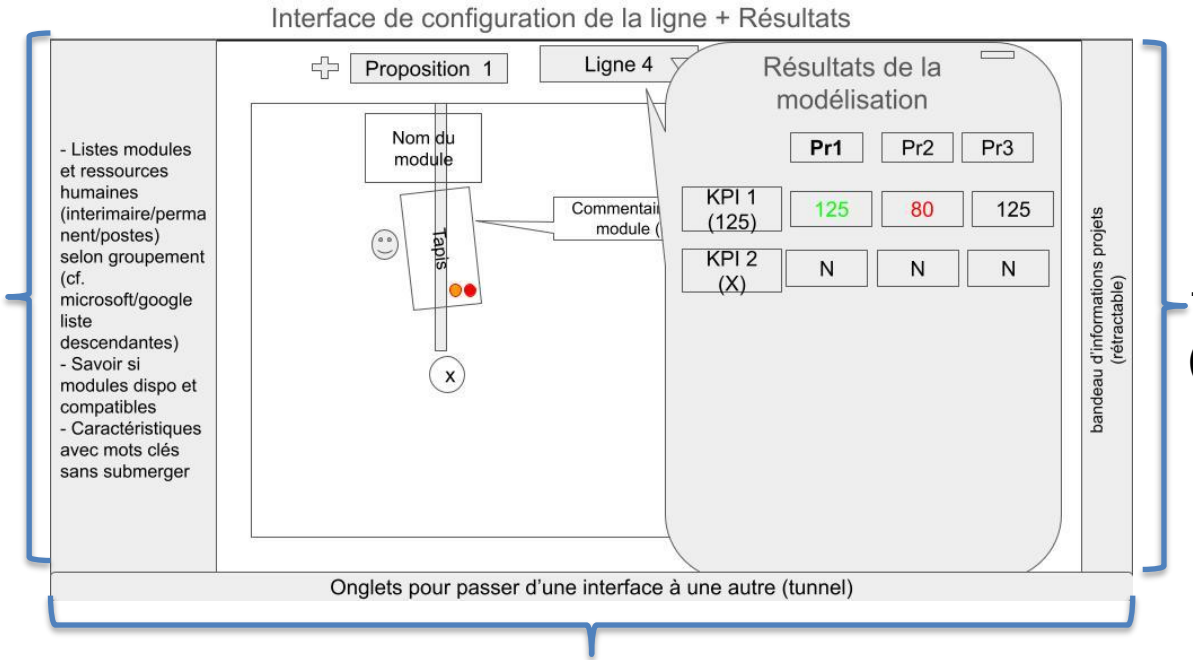
- The challenge faced:
  - Imagine, design and showing how the interface looks like without any existing real HMI
- Approach
  - Collaborative mocking-up using post-its, rough “slide” HMI, Wizard of Oz technique
  - 2-stage mocking-up



Initial Mocking-Up of the HMI

- Use of the CWA to provide the information that must be displayed :
  - Definition of the position and layout of this information
  - Definition of the way to support elicited functionality
- Remote workshop with reconfiguration expert, ergonomist, UX designer

Module list area

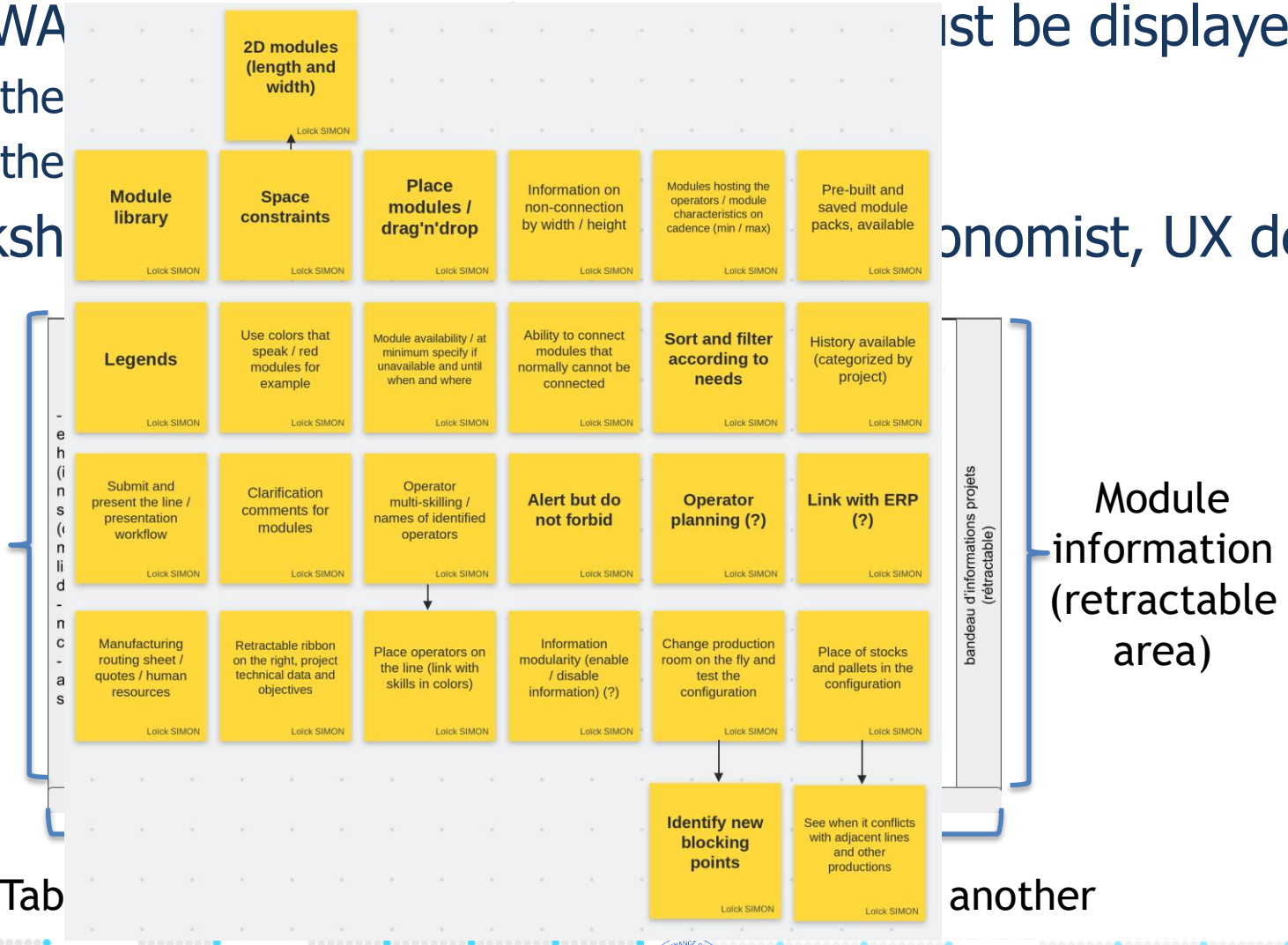


Module information (retractable area)

Tabs for easy switching from one configuration to another

Initial Mocking-Up of the HMI

- Use of the CWA … ist be displayed :
  - Definition of the …
  - Definition of the …
- Remote worksh … onomist, UX designer



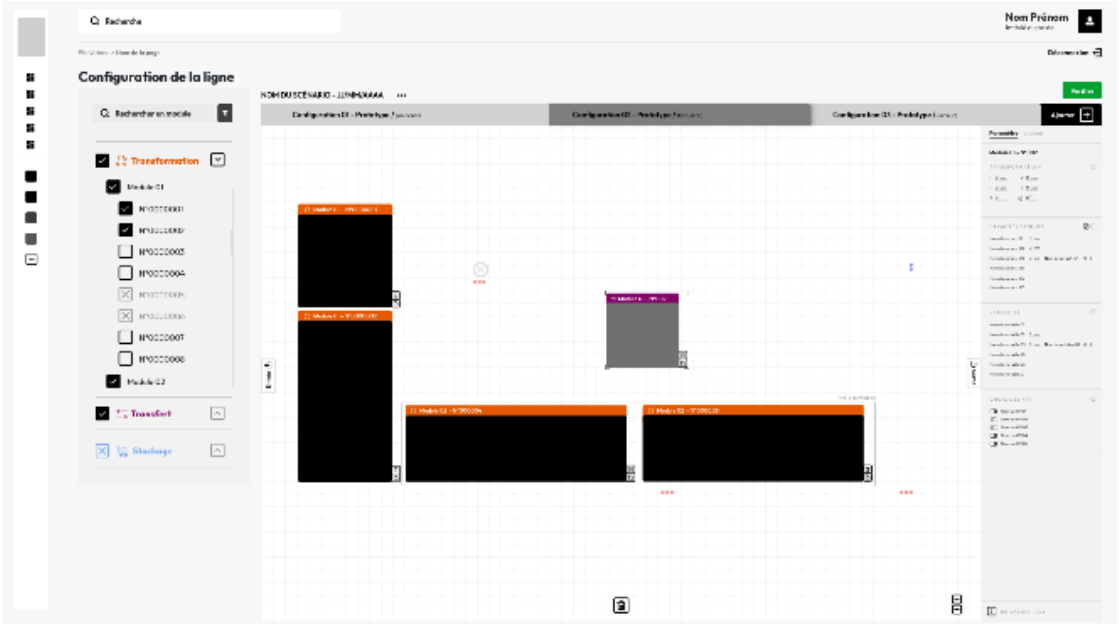
Module list area

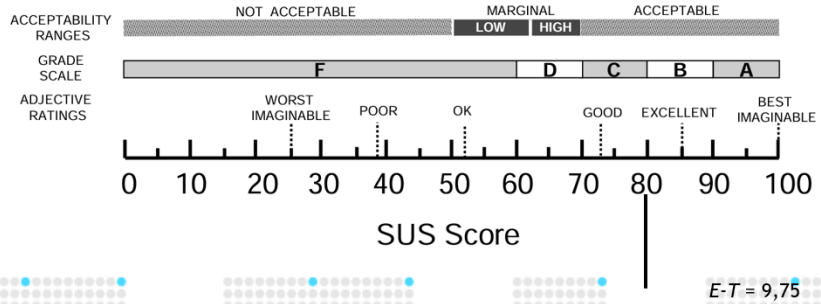
Module information (retractable area)

Tab … another

Focus Group

- Made with M2 students (Industrial Engineering & Quality)
  - 6 focus groups with 6-7 participants
  - 20 to 30 minutes interview with “rough” HMI presentation
- Four categories of requirements:
  - Interface requirements
  - Functional requirements
  - Results requirements
  - Perceived usefulness
  - Concerns raised by such a tool
- Such a tool is considered useful





Requirements from Reconfiguration Activity Analysis

Human Centred Interface

- Convenient configuration entry
- Configuration consistency check
- Configuration performance visualisation and comparison

Configuration Evaluation Framework

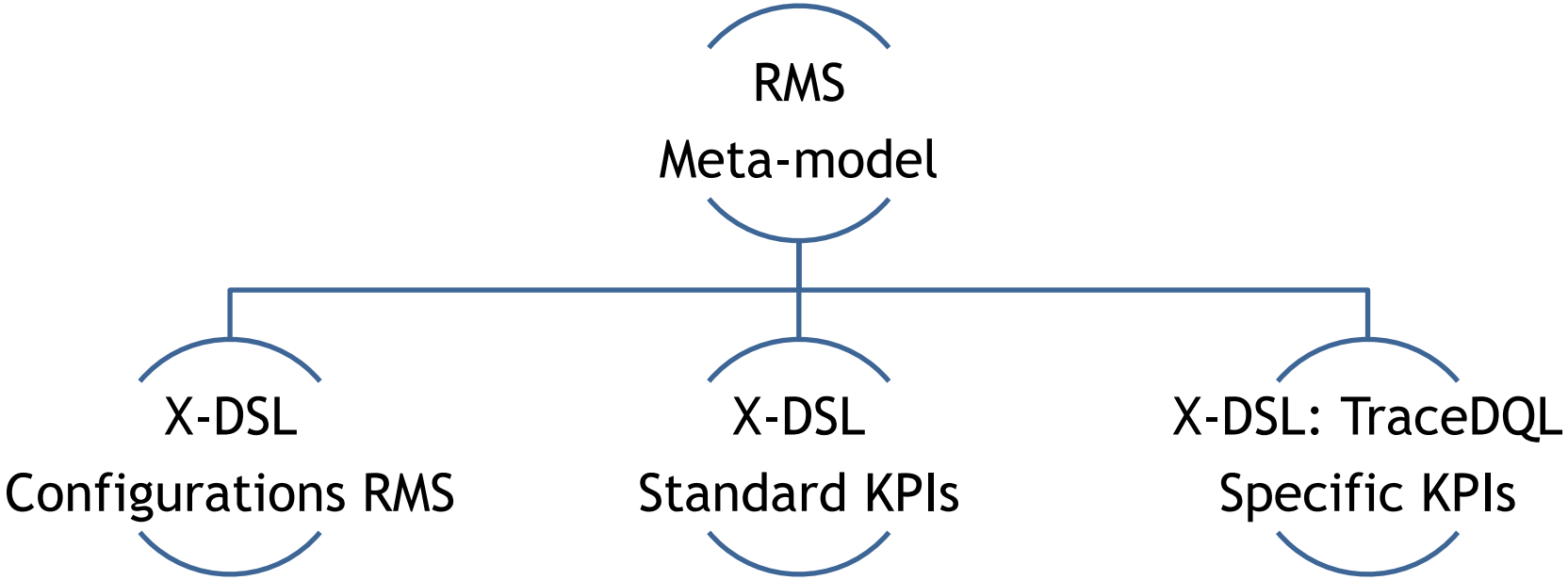
- Consistent evaluation within a seamless unified pipeline
- Stakeholder adequacy
- Modular and evolvable architecture

KPI Management Layer

- Reusable KPI definition
- Dual KPI evaluation (on-line and off-line)
- Domain concept driven KPI extraction and abstraction

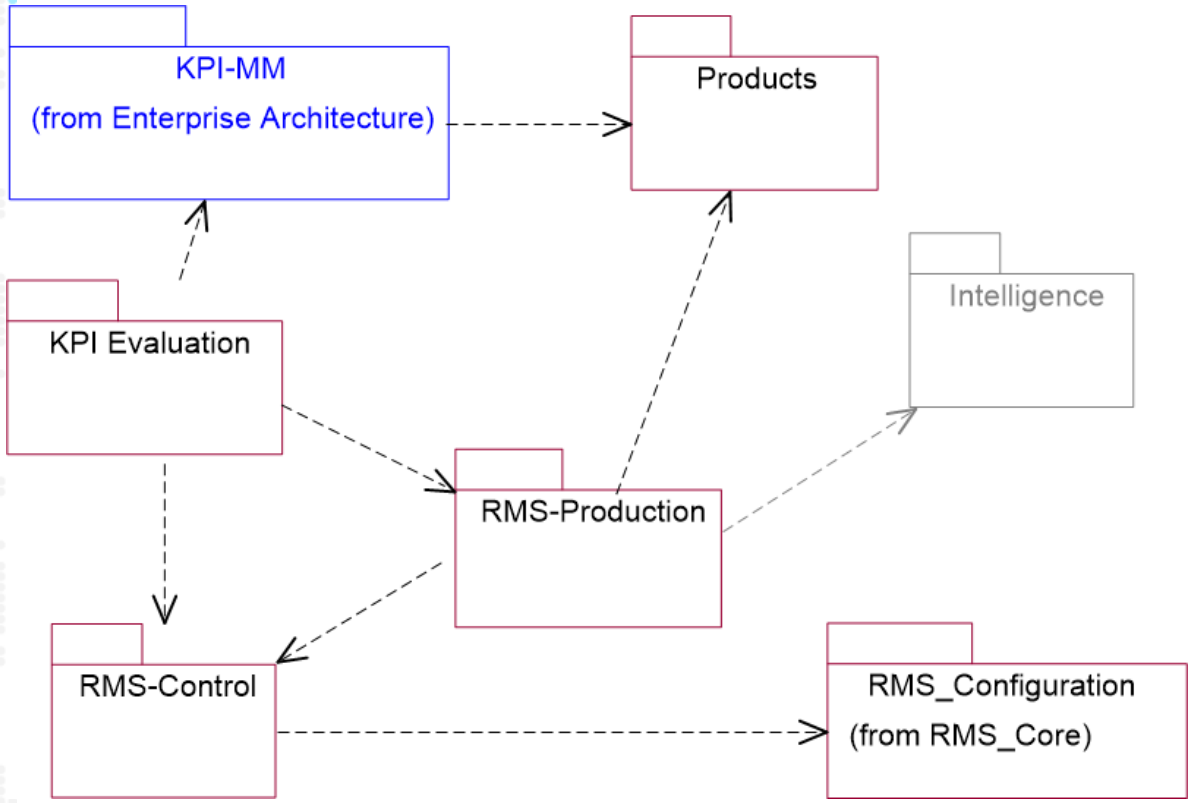
MBSE as a means of representing configurations, defining and computing KPIs in a flexible, light and tailored way

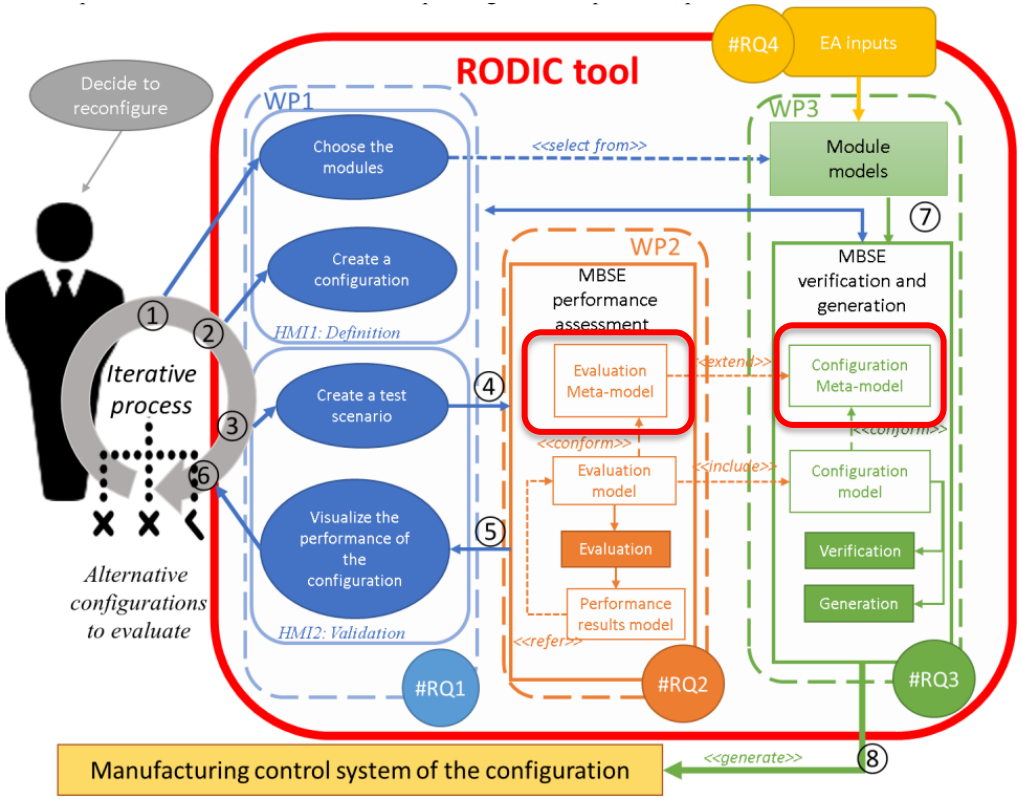
RODIC Configuration Evaluation Framework



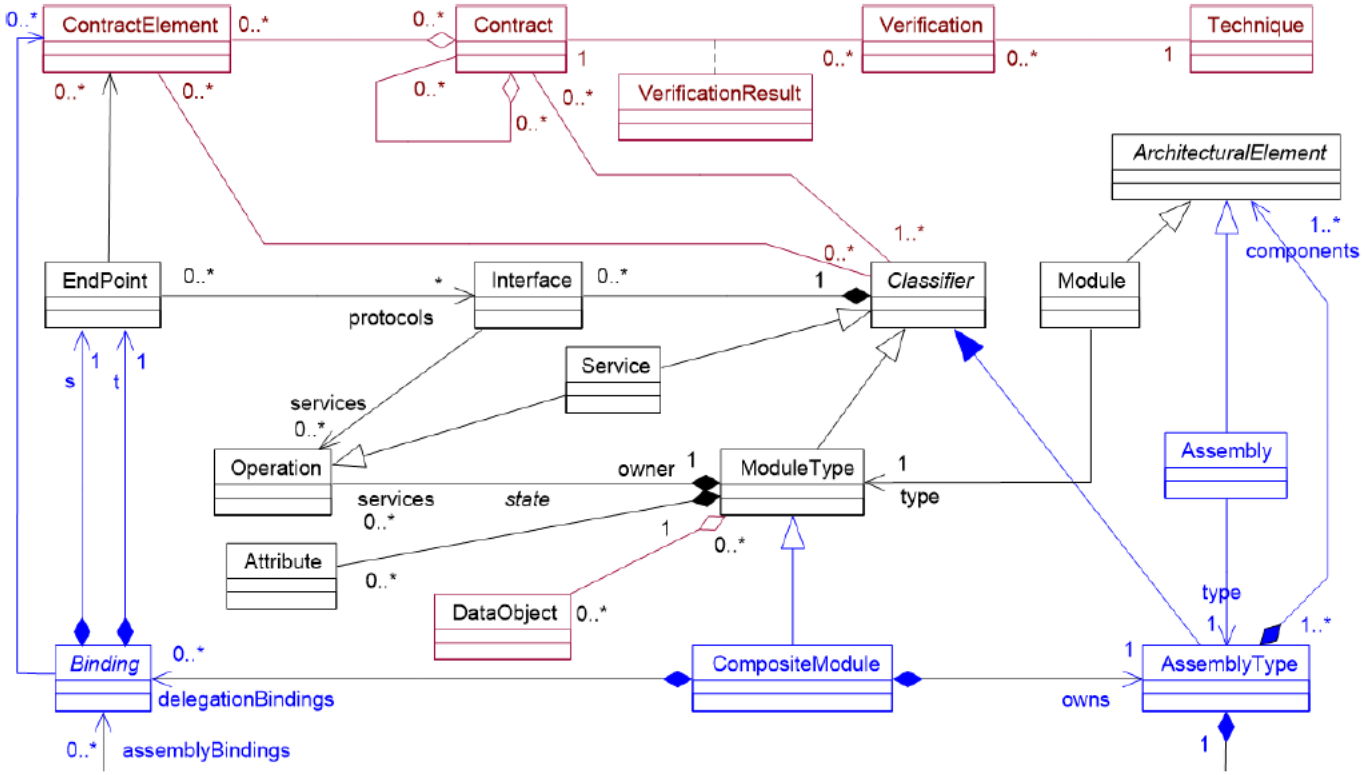
- DSL : Domain Specific Language
- X-DSL : eXecutable Domain Specific Language

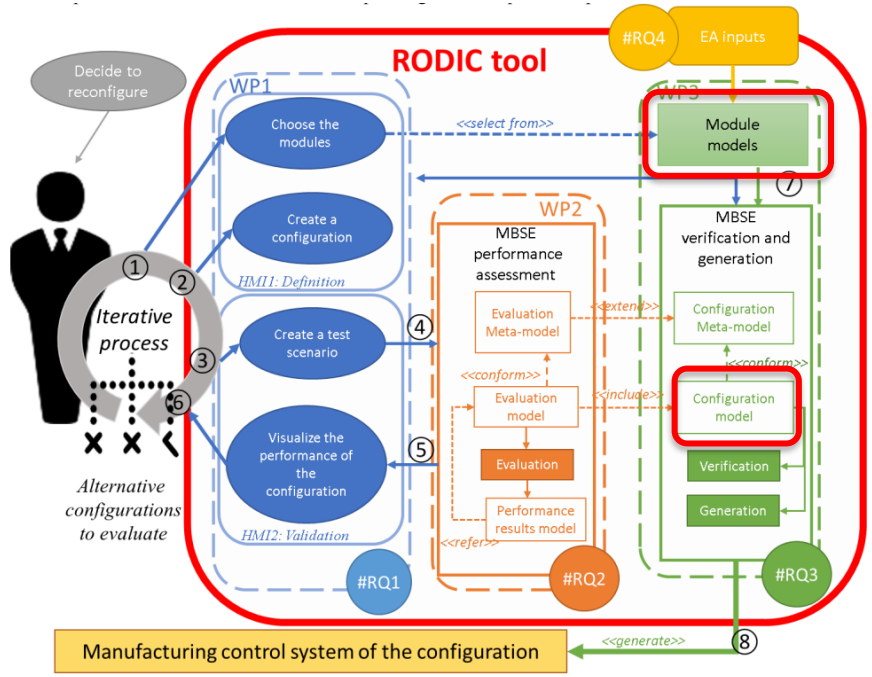
RMS Meta-Model





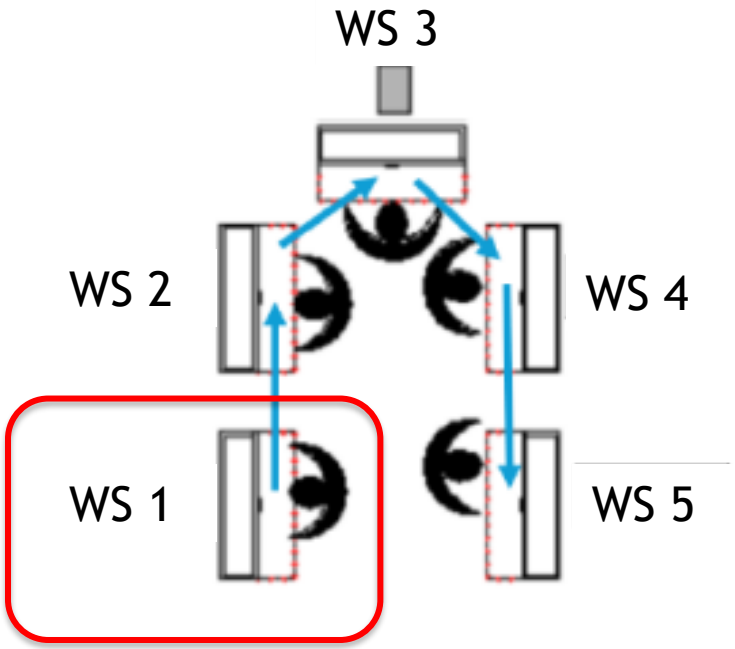
X-DSL Configurations RMS





Illustrative Example

Lampex case: Instanciation of X-DSL Configurations RMS



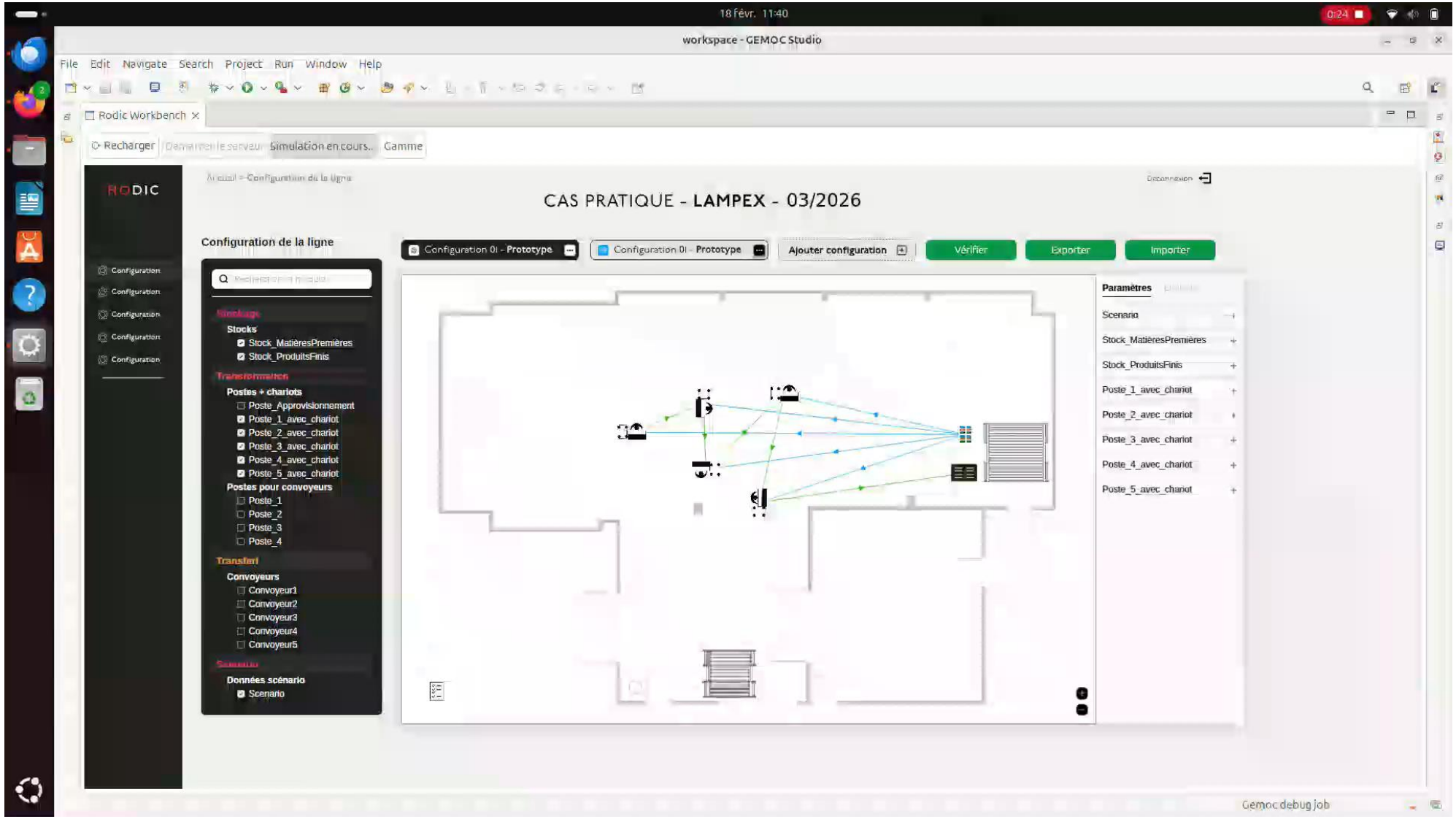
- Workstation 1 to 5 + operator = transformation module
- Workstation 1 to 5 + operator + trolley = composite transformation module
- Conveyor = transport module
- Finished product stock = storage module
- Raw material stock = storage module

Lampex case: Instanciation of X-DSL Configurations RMS

```
// ### Postes avec chariot
// 5 _Postes avec chariot_ sont disponibles
/* ---------------------------------------------------------------------------------------------
 *                                                                  POSTE DE TRAVAIL 1 CHARIOT
 * ---------------------------------------------------------------------------------------------
Module Poste_1_avec_chariot {
    type Poste_de_travail
    servicesON("Poste_de_travail.MonService1")
    provides {
        Provide "Entree_Produits(chariot)" {
            providetype "Poste_de_travail.Entree_Produits(chariot)"
        },
        Provide "Entree_Composants(MR)" {
            providetype "Poste_de_travail.Entree_Composants(MR)"
        }
    }
    requires {
        Require "Sortie_Produits(chariot)" {
            requiretype "Poste_de_travail.Sortie_Produits(chariot)"
        },
        Require "Entree_Composants" {
            requiretype "Poste_de_travail.Entree_Composants"
        },
        Require "Entree_Produits_1" {
            requiretype "Poste_de_travail.Entree_Produits_1"
        },
        Require "Entree_Produits_2" {
            requiretype "Poste_de_travail.Entree_Produits_2"
        }
    }
    initialvalues {
        InitialValue {
                        attribute "Poste_de_travail.tempsOperatoire"
                        value NumericConstant {
                                value 10.0
                        }
```

```
/* ---------------------------------------------------------------------------------------------
 *                                                                  BINDINGS
 * ---------------------------------------------------------------------------------------------
bindings {
            Binding {
        require "Poste_1_avec_chariot.Entree_Composants"
        provide "Stock_Composants.Sortie_Composants"
    },
            Binding {
        require "Poste_2_avec_chariot.Entree_Composants"
        provide "Stock_Composants.Sortie_Composants"
    },
            Binding {
        require "Poste_3_avec_chariot.Entree_Composants"
        provide "Stock_Composants.Sortie_Composants"
    },
            Binding {
        require "Poste_4_avec_chariot.Entree_Composants"
        provide "Stock_Composants.Sortie_Composants"
    },
            Binding {
        require "Poste_5_avec_chariot.Entree_Composants"
        provide "Stock_Composants.Sortie_Composants"
    },
```

RODIC Studio Demo : Performance Evaluation of a Configuration



Conclusion

- A multidisciplinary project leading to the development of a POC
- Several validation scenarios:
  - A conventionally simulated case
  - Lampex case reconfiguration completed “manually” by students, simulated both conventionally and using RODIC Studio
- Master’s students as key participants in the experiments:
  - Prospective ergonomics (reconfiguration activity)
  - Usability of RODIC Studio
- A wealth of perspectives:
  - Enrichment of the KPIs taken into account
  - Exploitation of knowledge and reconfiguration history
  - Expansion of the range of supported reconfiguration scenarios

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Thank you for giving us your attention!

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