Systemic Digital Twins for Optimizing Industrial Strategy & Operations: a Case Study

Sigma

WorldLab

Daniel KROB, INCOSE Fellow

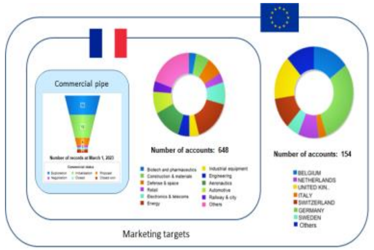
October 2023

eit Manufacturing

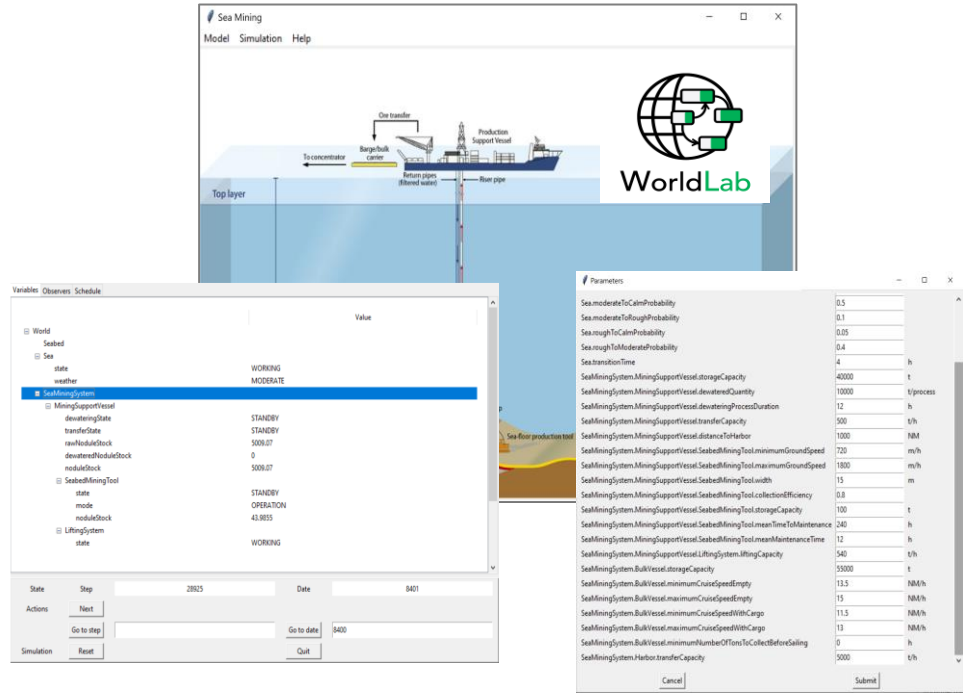
Funded by the European Union

Systemic Intelligence

Systemic Intelligence in a nutshell



Our strong scientific, technologic & business fundamentals

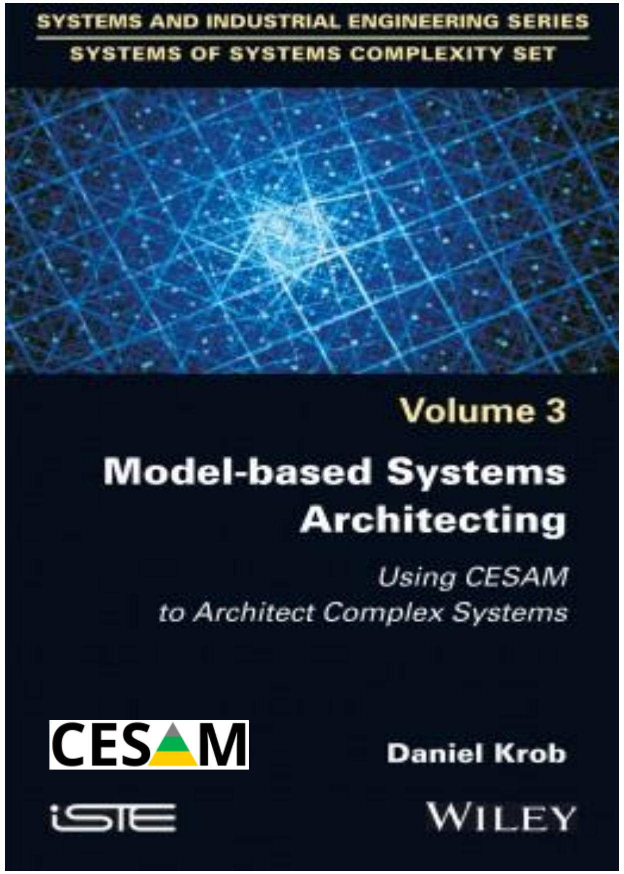


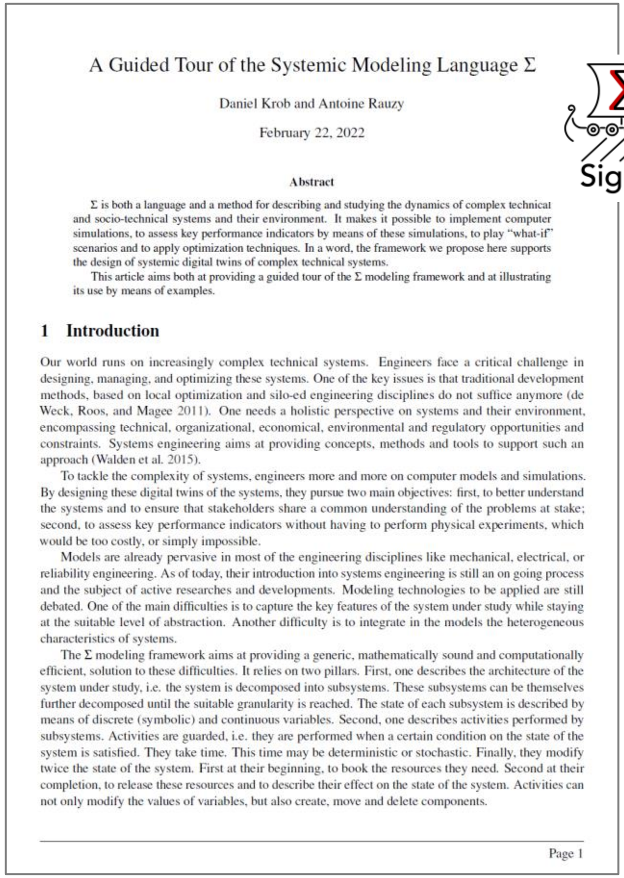
Our systemic digital twin solution: WorldLab ™

Our current customers as early adopters of our systemic digital twin solution

SYDITIL is led by a French startup, **Systemic Intelligence**, which develops the **systemic digital twin solution**, **WorldLab™**, based on a strong **scientific, technologic & business background** that helped us to obtain our **first customers** during the last 12 months.

Systemic Intelligence – The scientific pillars of systemic digital twins





A Guided Tour of the Systemic Modeling Language Σ

Daniel Krob and Antoine Rauzy

February 22, 2022

Abstract

Σ is both a language and a method for describing and studying the dynamics of complex technical and socio-technical systems and their environment. It makes it possible to implement computer simulations, to assess key performance indicators by means of these simulations, to play "what-if" scenarios and to apply optimization techniques. In a word, the framework we propose here supports the design of systemic digital twins of complex technical systems.

This article aims both at providing a guided tour of the Σ modeling framework and at illustrating its use by means of examples.

1 Introduction

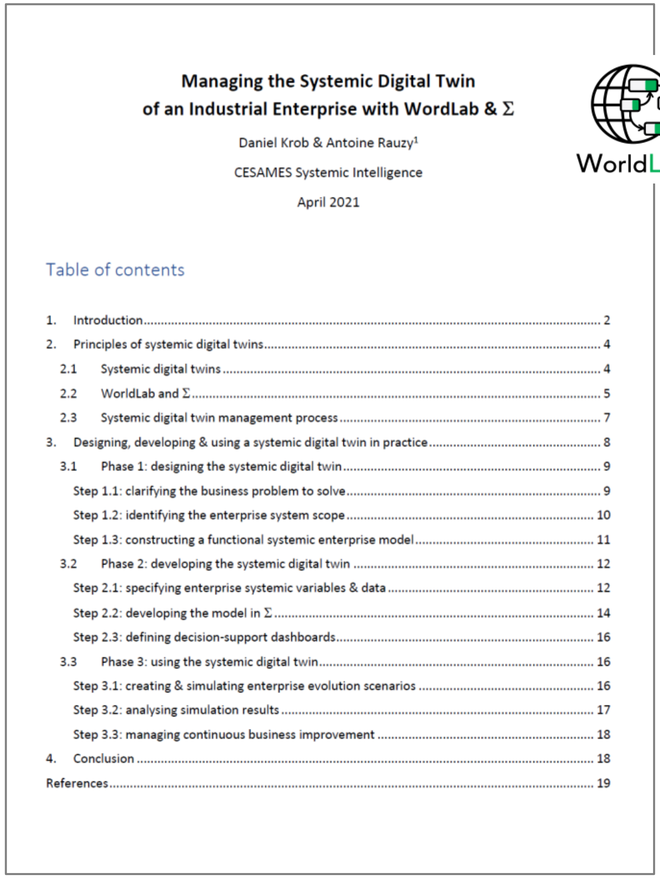
Our world runs on increasingly complex technical systems. Engineers face a critical challenge in designing, managing, and optimizing these systems. One of the key issues is that traditional development methods, based on local optimization and silo-ed engineering disciplines do not suffice anymore (de Weck, Roos, and Magee 2011). One needs a holistic perspective on systems and their environment, encompassing technical, organizational, economical, environmental and regulatory opportunities and constraints. Systems engineering aims at providing concepts, methods and tools to support such an approach (Walden et al. 2015).

To tackle the complexity of systems, engineers more and more on computer models and simulations. By designing these digital twins of the systems, they pursue two main objectives: first, to better understand the systems and to ensure that stakeholders share a common understanding of the problems at stake; second, to assess key performance indicators without having to perform physical experiments, which would be too costly, or simply impossible.

Models are already pervasive in most of the engineering disciplines like mechanical, electrical, or reliability engineering. As of today, their introduction into systems engineering is still an on going process and the subject of active researches and developments. Modeling technologies to be applied are still debated. One of the main difficulties is to capture the key features of the system under study while staying at the suitable level of abstraction. Another difficulty is to integrate in the models the heterogeneous characteristics of systems.

The Σ modeling framework aims at providing a generic, mathematically sound and computationally efficient, solution to these difficulties. It relies on two pillars. First, one describes the architecture of the system under study, i.e. the system is decomposed into subsystems. These subsystems can be themselves further decomposed until the suitable granularity is reached. The state of each subsystem is described by means of discrete (symbolic) and continuous variables. Second, one describes activities performed by subsystems. Activities are guarded, i.e. they are performed when a certain condition on the state of the system is satisfied. They take time. This time may be deterministic or stochastic. Finally, they modify twice the state of the system. First at their beginning, to book the resources they need. Second at their completion, to release these resources and to describe their effect on the state of the system. Activities can not only modify the values of variables, but also create, move and delete components.

Page 1



Managing the Systemic Digital Twin
of an Industrial Enterprise with WordLab & Σ

Daniel Krob & Antoine Rauzy[1]

CESAMES Systemic Intelligence

April 2021

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Our **systemic digital twins** rely on three main innovative pillars: 1) the **CESAM system architecting method** used in the **design phase**, 2) the new **systemic specification language Σ™** used in the **beginning of the development phase**, 3) the **WorldLab™ platform** that supports the **end of the development phase** and the **use phase**.

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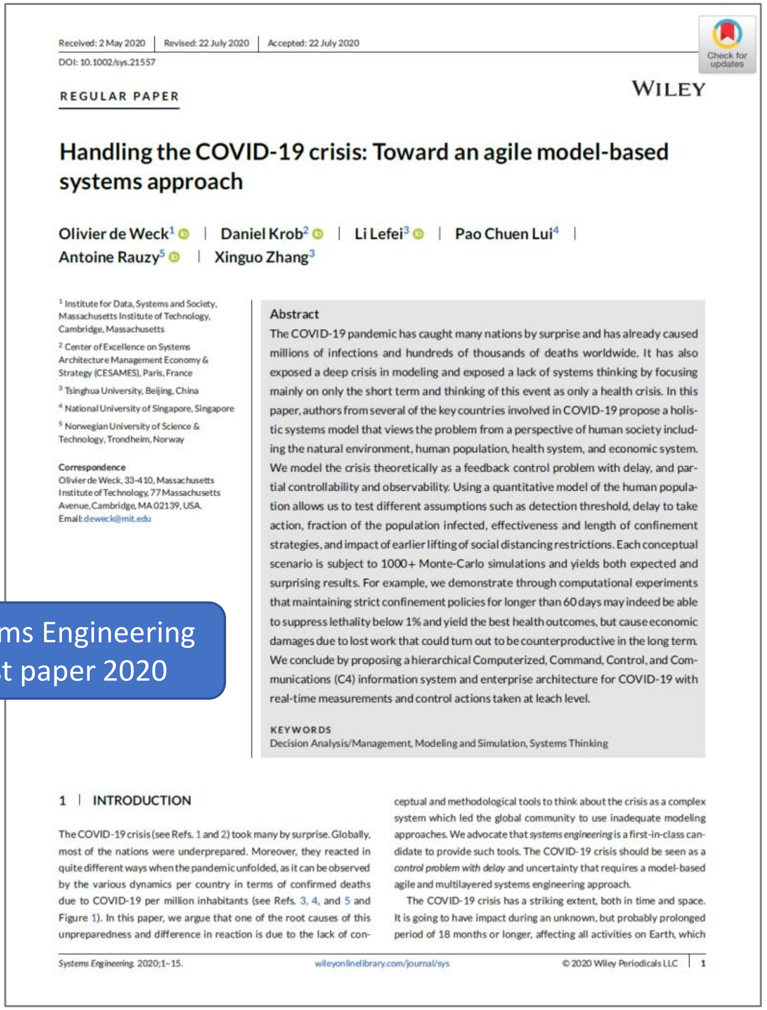
Systemic Intelligence – The starting point of our journey



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REGULAR PAPER

WILEY

Handling the COVID-19 crisis: Toward an agile model-based systems approach

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Abstract

The COVID-19 pandemic has caught many nations by surprise and has already caused millions of infections and hundreds of thousands of deaths worldwide. It has also exposed a deep crisis in modeling and exposed a lack of systems thinking by focusing mainly on only the short term and thinking of this event as only a health crisis. In this paper, authors from several of the key countries involved in COVID-19 propose a holistic systems model that views the problem from a perspective of human society including the natural environment, human population, health system, and economic system. We model the crisis theoretically as a feedback control problem with delay, and partial controllability and observability. Using a quantitative model of the human population allows us to test different assumptions such as detection threshold, delay to take action, fraction of the population infected, effectiveness and length of confinement strategies, and impact of earlier lifting of social distancing restrictions. Each conceptual scenario is subject to 1000+ Monte-Carlo simulations and yields both expected and surprising results. For example, we demonstrate through computational experiments that maintaining strict confinement policies for longer than 60 days may indeed be able to suppress lethality below 1% and yield the best health outcomes, but cause economic damages due to lost work that could turn out to be counterproductive in the long term. We conclude by proposing a hierarchical Computerized, Command, Control, and Communications (C4) information system and enterprise architecture for COVID-19 with real-time measurements and control actions taken at leach level.

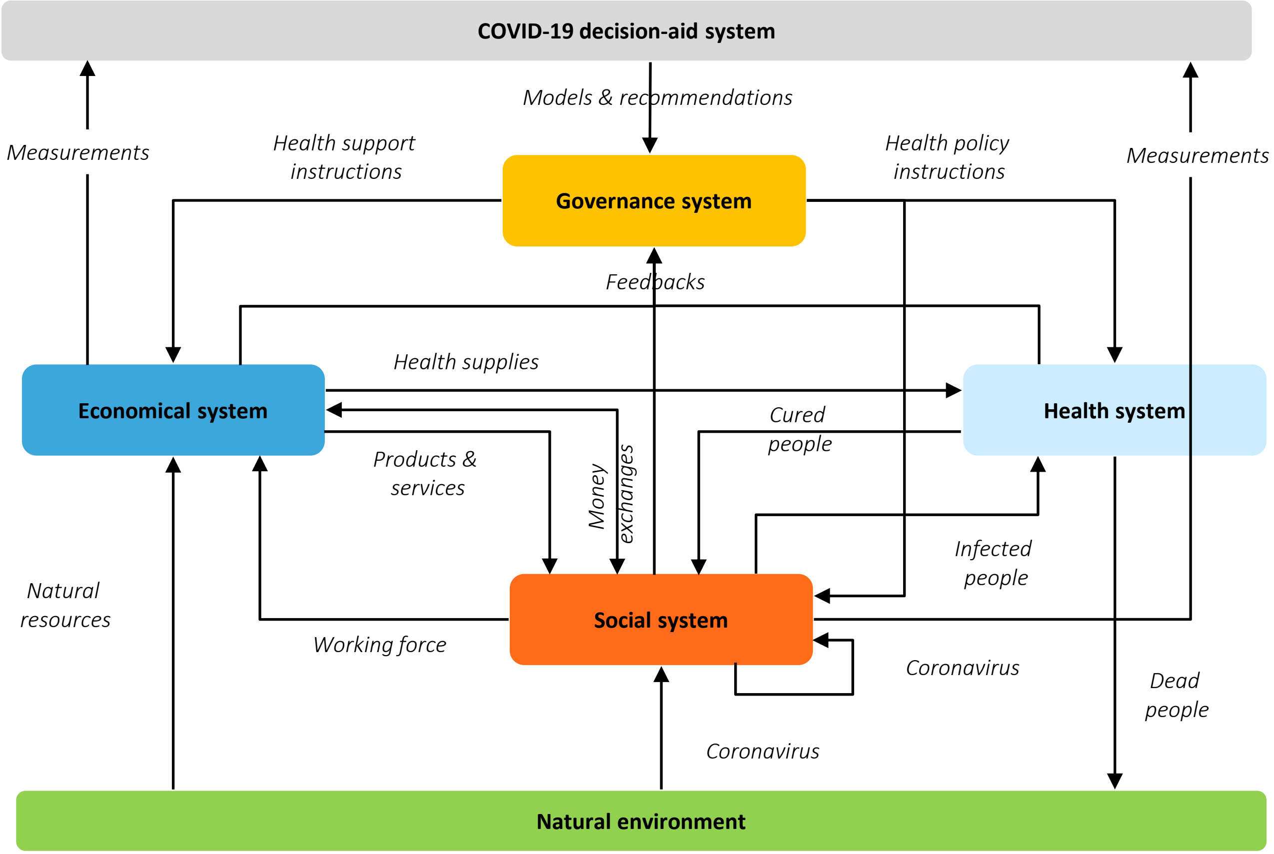
KEYWORDS
Decision Analysis/Management, Modeling and Simulation, Systems Thinking

1 | INTRODUCTION

The COVID-19 crisis (see Refs. 1 and 2) took many by surprise. Globally, most of the nations were underprepared. Moreover, they reacted in quite different ways when the pandemic unfolded, as it can be observed by the various dynamics per country in terms of confirmed deaths due to COVID-19 per million inhabitants (see Refs. 3, 4, and 5 and Figure 1). In this paper, we argue that one of the root causes of this unpreparedness and difference in reaction is due to the lack of conceptual and methodological tools to think about the crisis as a complex system which led the global community to use inadequate modeling approaches. We advocate that *systems engineering* is a first-in-class candidate to provide such tools. The COVID-19 crisis should be seen as a *control problem with delay* and uncertainty that requires a model-based agile and multilayered systems engineering approach.

The COVID-19 crisis has a striking extent, both in time and space. It is going to have impact during an unknown, but probably prolonged period of 18 months or longer, affecting all activities on Earth, which

Systems Engineering best paper 2020



A **seminal paper** where we proposed a **systemic digital twin approach** for modeling the world in the covid-19 crisis context

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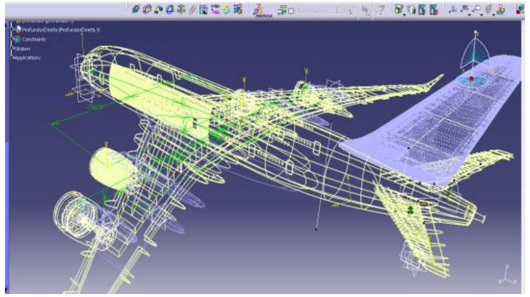
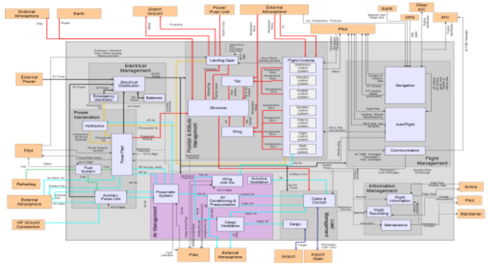
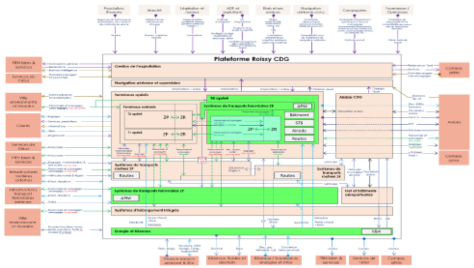
Agenda

1. **Systemic Digital Twins: an Introduction**
2. An Illustrative Case Study: Dunkirk's port

Our point of view: a functional paradigm focused on industrial processes

	Industrial products	Industrial processes
Geometrical (what can be seen from the system)	 *Example: geometric model of an aircraft*	 *Example: geometric model of an airport*
Functional (what is doing the system)	 *Example: functional model of an aircraft*	 *Example: business model of an airport*

Systemic digital twins

Systemic digital twins simulate **industrial processes** associated with **complex industrial systems** based on a **systemic vision**

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The challenge: how to be sure to take the right decisions?

- What is the optimal global architecture for an industrial system?
- What is the optimal design for a new industrial facility?
- What is the best way to manage an industrial process?
- What is the optimal way to manage an industrial ramp-up?
- What is the optimal industrial maintenance strategy to follow?

Examples of strategic industrial decisions

- How to optimize my industrial lead time during operations?
- How to minimize non quality during industrial operations?
- How to optimally reconfigure my industrial production?
- How to minimize energy & wastes during industrial operations?
- How to decrease environmental footprint during industrial operations?

Examples of operational & tactical industrial decisions

Being able to **take the right strategic & operational decisions is key** in order to **optimize industrial operations**

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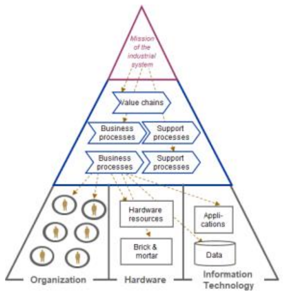
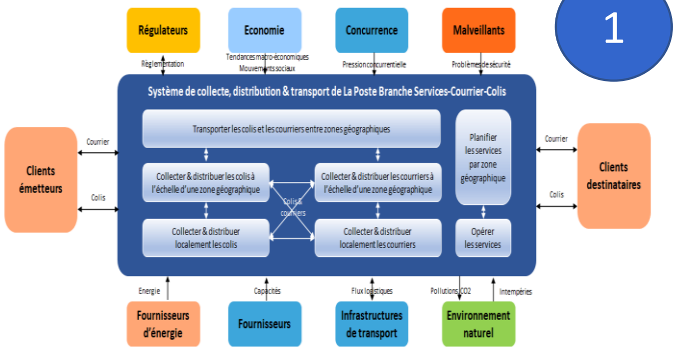
Our approach: from model-based systems engineering to simulation



Model-Based Systems Engineering (MBSE)

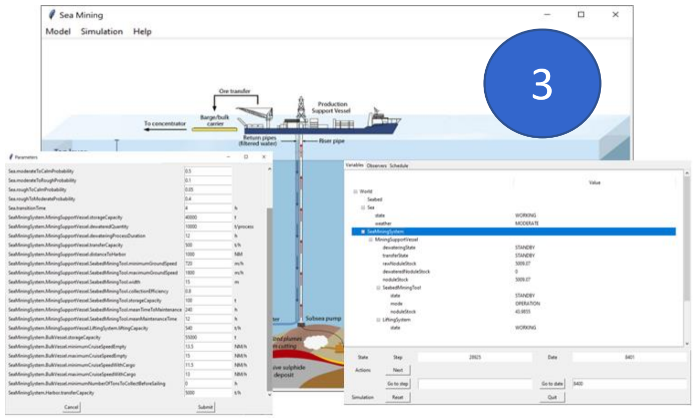


MBSE model of an industrial system

```
system World
  system Supplier ... end
  system Producer ... end
  system Consumer ... end
end

system World.Supplier
  int rawMaterial(init = 0);
end

system World.Producer
  int order(init = 0);
  int rawMaterial(init = 0);
  int product(init = 0);
end

system World.Consumer
  int product(init = 0);
end
```

2

Σ^{TM} model of an industrial system

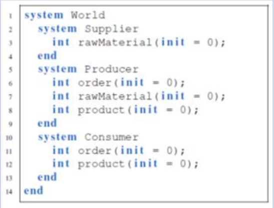


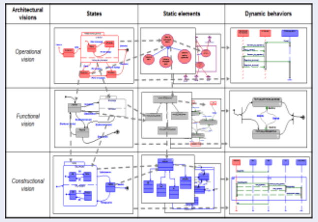
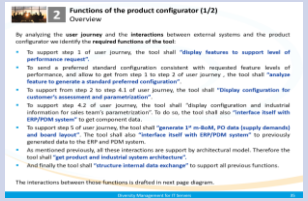
System digital twin of an industrial system

The methodological framework for the development of a systemic digital twin with Σ^{TM} and WorldLab ™

Focus: the different types of modeling languages for specifying systems

Modeling language type	Syntax used by the modeling language	Examples	Features	Fundamentals	Level of rigor	Simulation capability

Formal	Formal specification language	
		system World
		system Supplier
		int rawMaterial(init = 0);
		end
		system Producer
		int order(init = 0);
		int rawMaterial(init = 0);
		int product(init = 0);
		end
		system Consumer
		int order(init = 0);
		int product(init = 0);
		end
		end
			Formal semantics leading to compiling, simulation & strong interoperability	Mathematics	Strong	Possible

Pseudo-formal	Graphical language		No formal semantics leading to structural interoperability & simulation issues	Meta-model	Weak	Difficult since it requires a simulation semantics
Unformal	Natural language		No semantics at all leading to many possible meanings	Practice	Poor	Impossible

One shall first point out that the Σ™ **modeling language** on which relies our systemic digital twin approach is a **formal language** dedicated to **industrial system specification** which naturally supports **simulation**

Last, but not least: the ΣTM modeling language

```
system World
  system Supplier
    int rawMaterial(init = 0);
  end
  system Producer
    int order(init = 0);
    int rawMaterial(init = 0);
    int product(init = 0);
  end
  system Consumer
    int order(init = 0);
    int product(init = 0);
  end
end
```

Specification of a hierarchy of systems in ΣTM

```
system World.Supplier
  int rawMaterial(init = 0);
  bool renewing(init = false);
end

activity World.Supplier.RenewRawMaterialStock
  trigger:
    return rawMaterial<=1000 and not renewing;
  start:
    renewing = true;
  completion: {
    renewing = false;
    rawMaterial += 100;
    }
  duration:
    return 30;
end
```

Condition that triggers the activity (line 8: `return rawMaterial<=1000 and not renewing;`)

What shall be done when the activity starts (line 10: `renewing = true;`)

What shall be done when the activity stops (lines 12–13: `renewing = false;` and `rawMaterial += 100;`)

Duration of the activity (in units of time) (line 16: `return 30;`)

Specification of a business process – as an activity – in ΣTM

The **ΣTM modeling language** allows therefore naturally to specify the **hierarchical structure** and the **behaviors**, that is to say the business processes, of a given industrial system, but also the **end-user interface** with the **business indicators & alerts** that shall be computed and shown to the business users during the use of a systemic digital twin.

Agenda

1. Systemic Digital Twins: an Introduction
2. **An Illustrative Case Study: Dunkirk's port**

A case study of WorldLab™ technology: Dunkirk's port

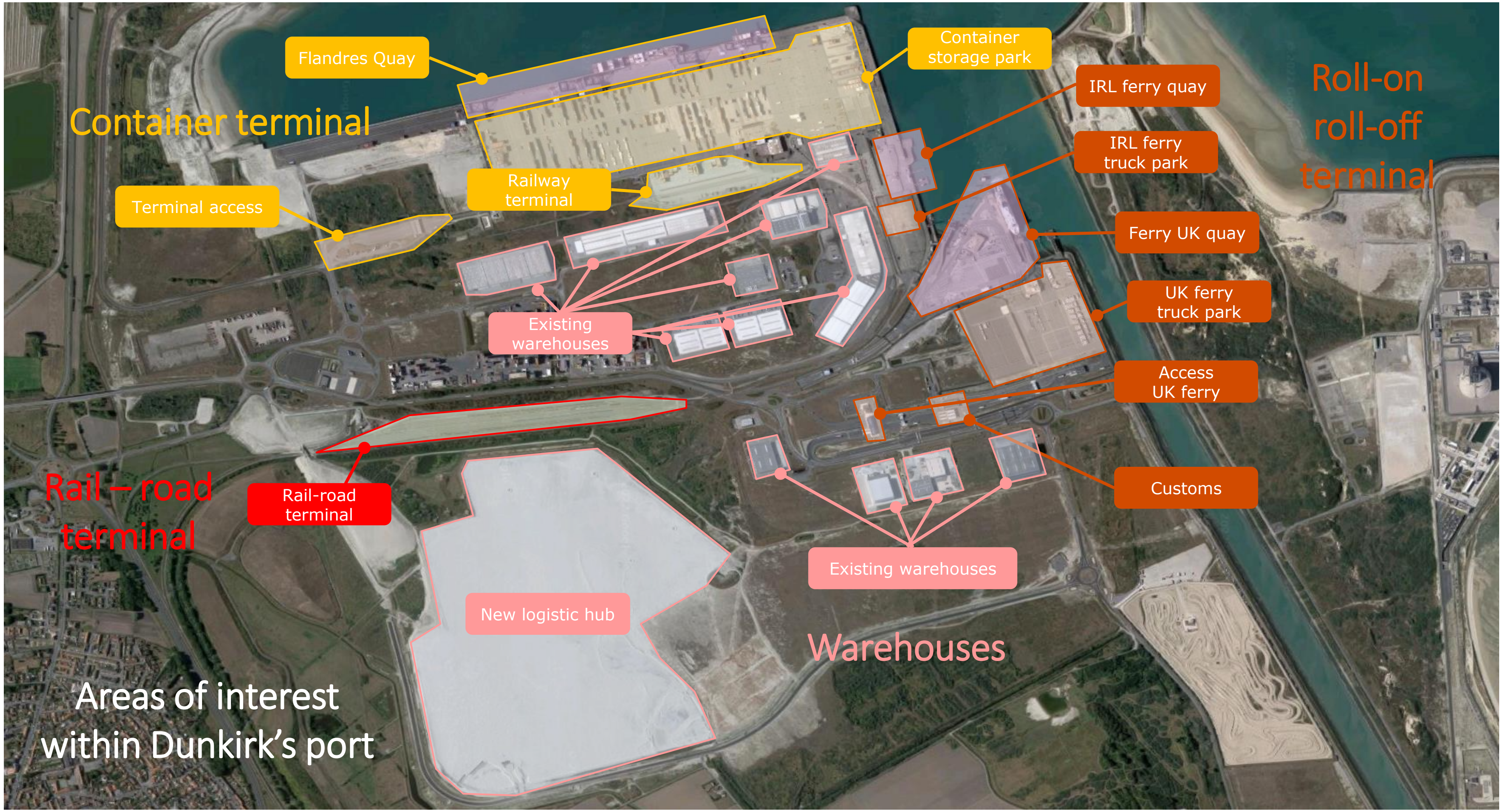
Motivation of the case study

Coal traffic

Container traffic

Due to **environmental regulations**, the **old coal traffic is being replaced by a new container traffic**, which has a **huge impact** on the port infrastructures since coal and containers require totally different logistics. There is therefore a strong need to **secure the corresponding investments** that have to be done by the general direction of the port.

A case study of WorldLab™ technology: Dunkirk's port
Overview of the case study

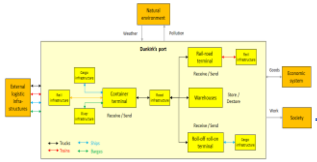


A case study of WorldLab™ technology: Dunkirk's port
Organization of the case study

Phase 1:
Design
of the systemic
digital twin

Business scenarios & goals

Phase 3:
Use
of the systemic
digital twin



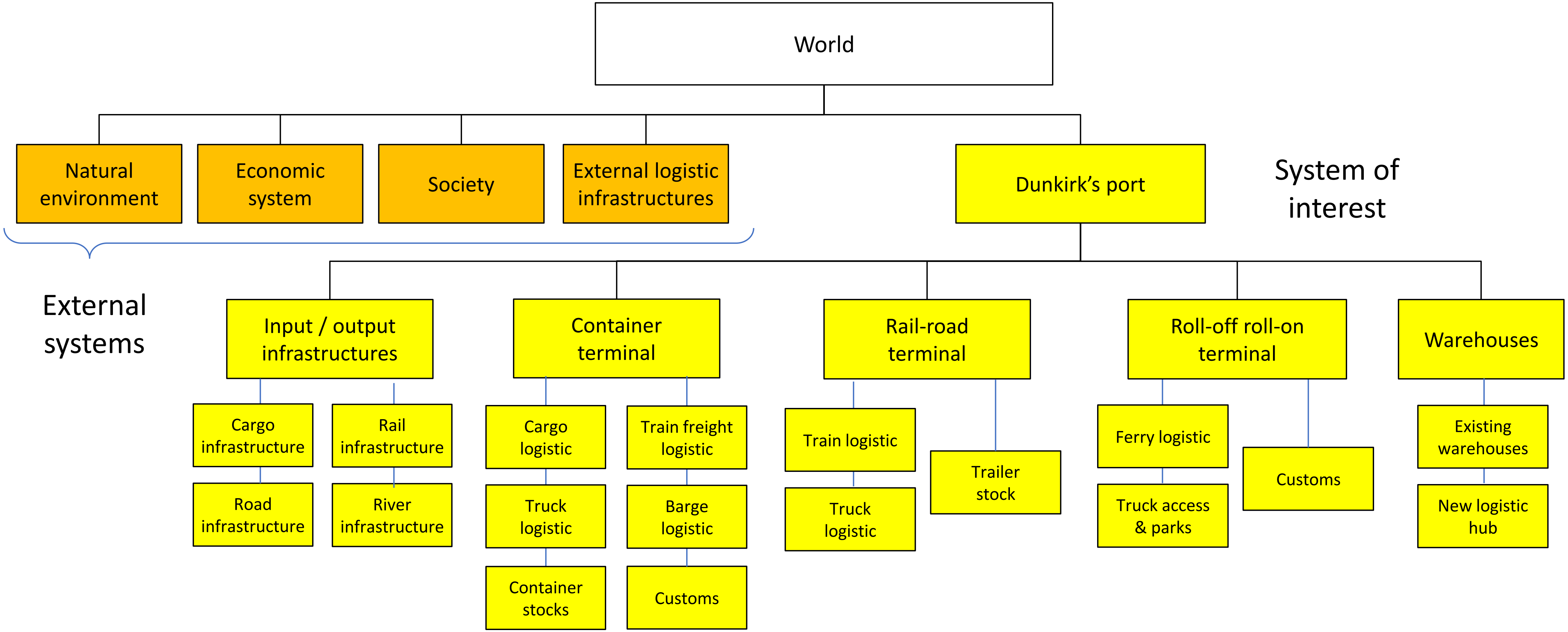
MBSE model & data for the system of interest

Phase 2:
Development
of the systemic
digital twin

Systemic digital twin for the system of interest

Standard process for managing a systemic digital twin

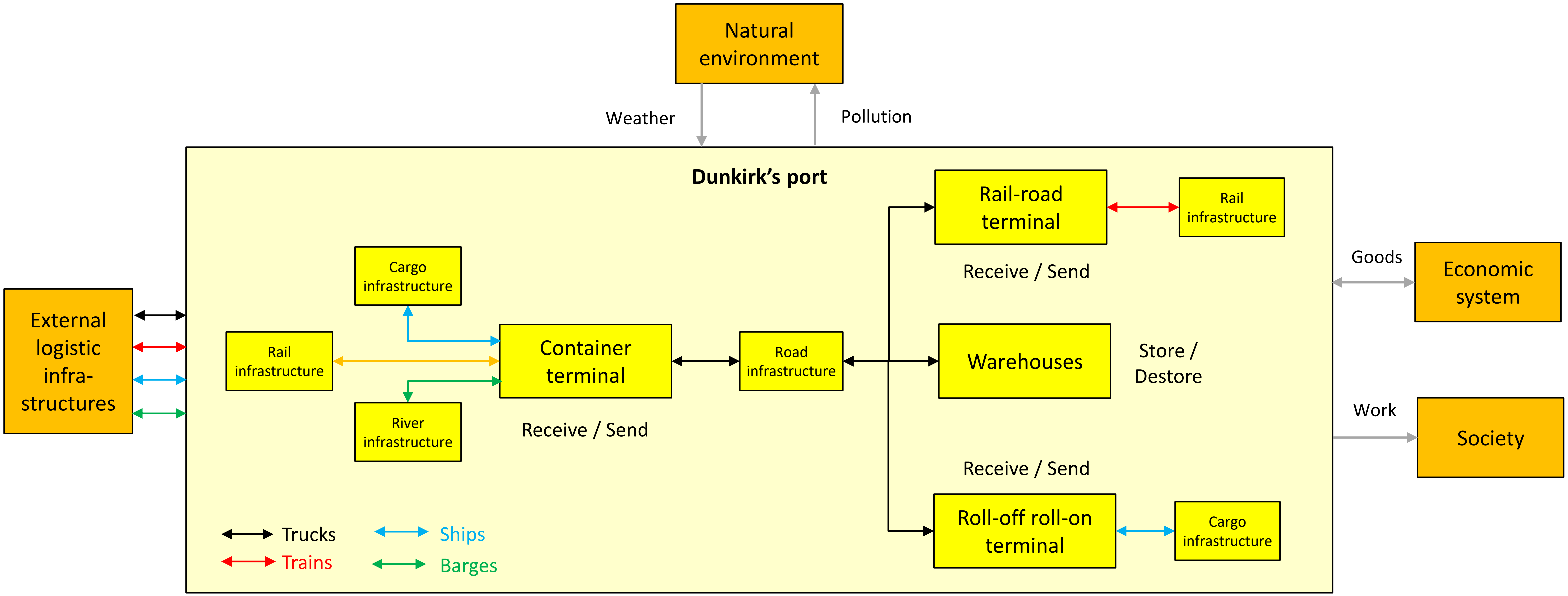
A case study of WorldLab™ technology: Dunkirk's port
Phase 1: design of the systemic digital twin (1/3)



System breakdown of the environment of the system of interest

A case study of WorldLab™ technology: Dunkirk's port

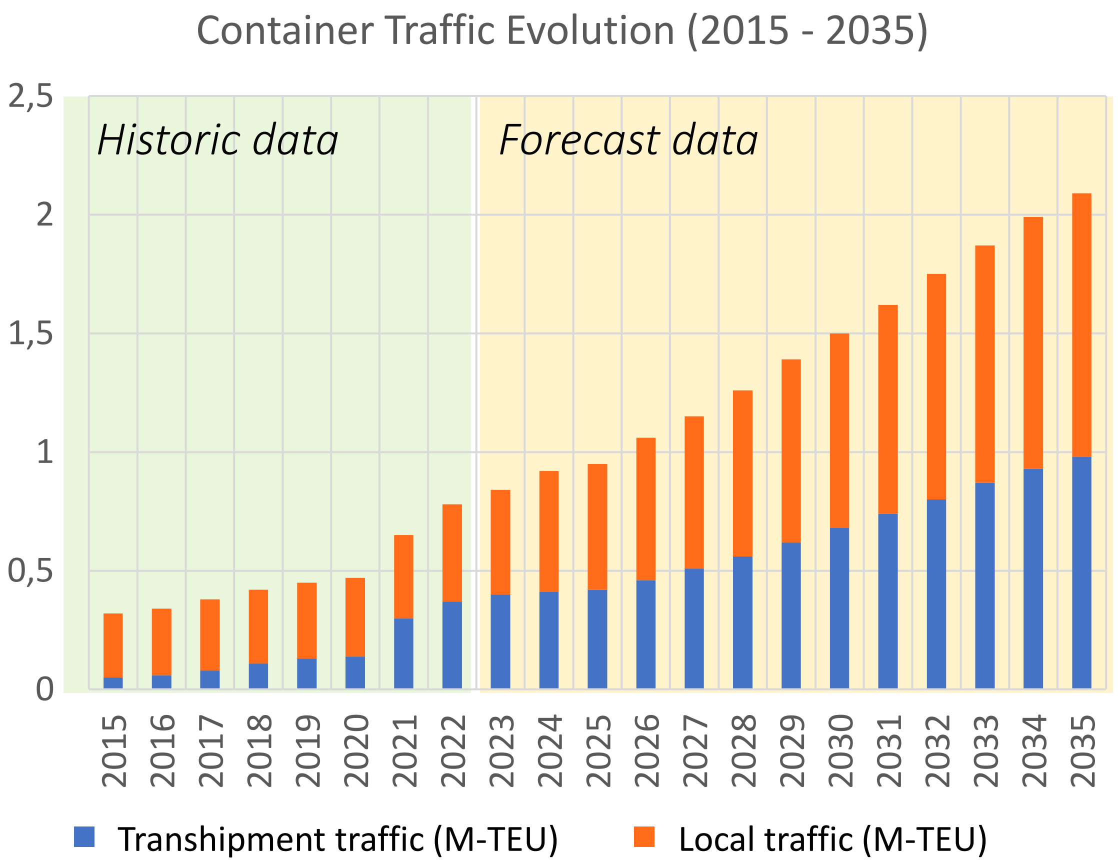
Phase 1: design of the systemic digital twin (2/3)

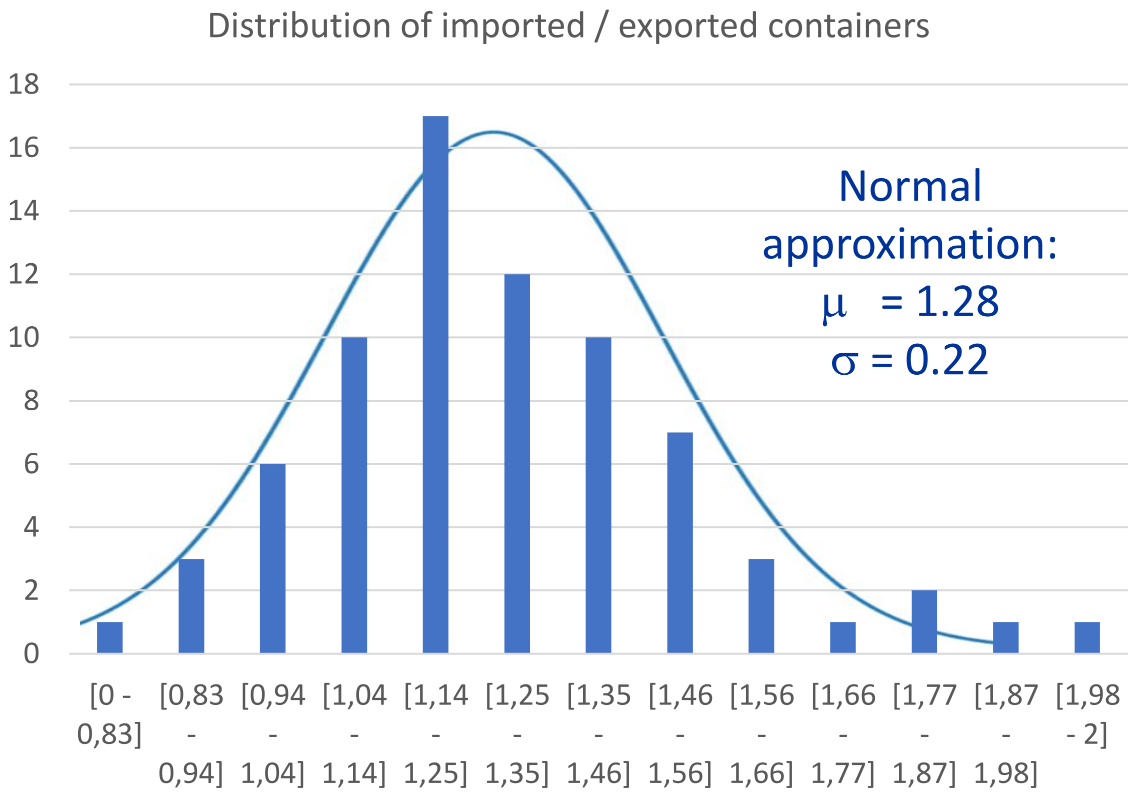


Main activities & interactions within the environment of the system of interest

A case study of WorldLab™ technology: Dunkirk's port
Phase 1: design of the systemic digital twin (3/3)

TEU: Twenty-foot Equivalent Unit

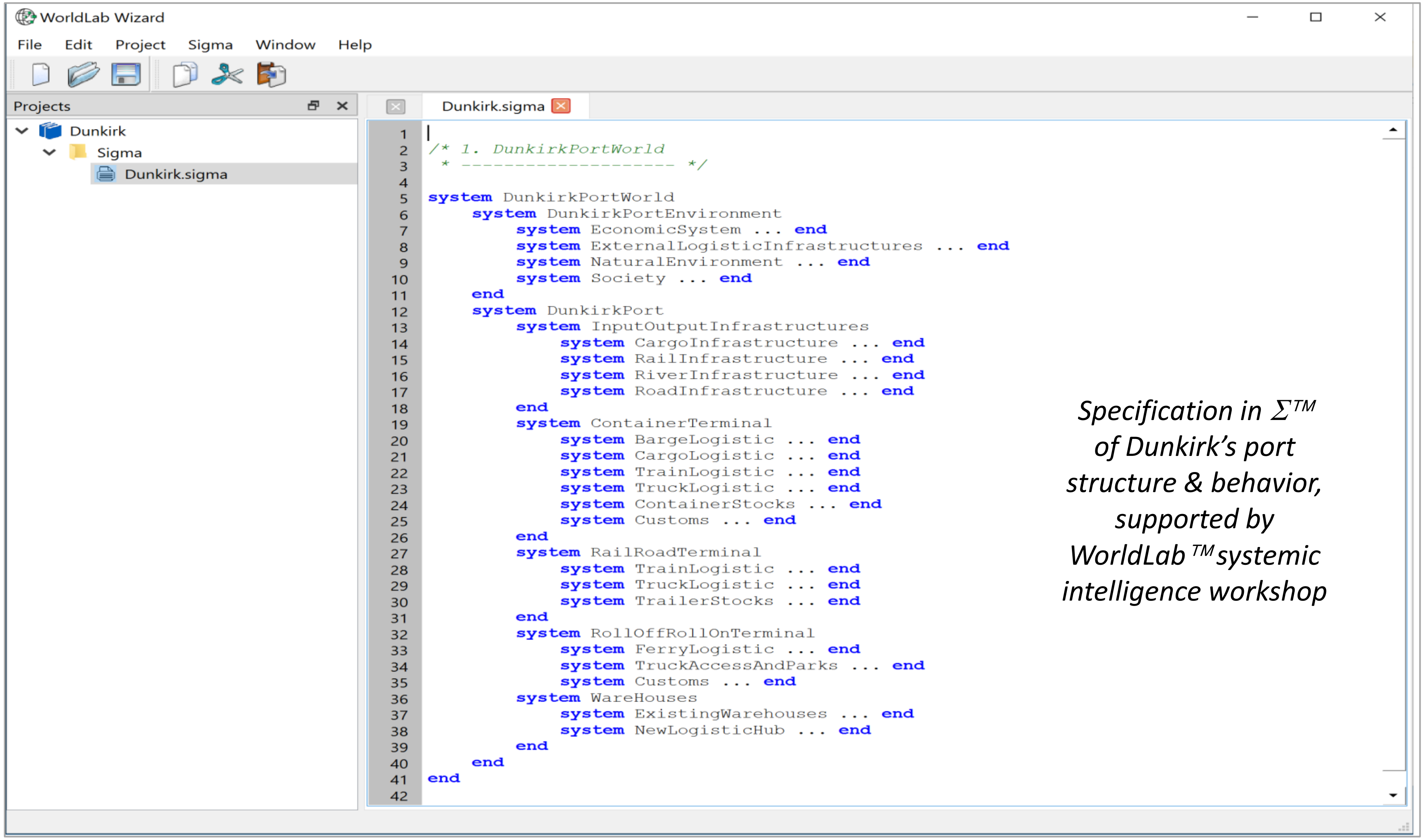




Example of key business data & associated data analysis for the environment of the system of interest

A case study of WorldLab™ technology: Dunkirk's port

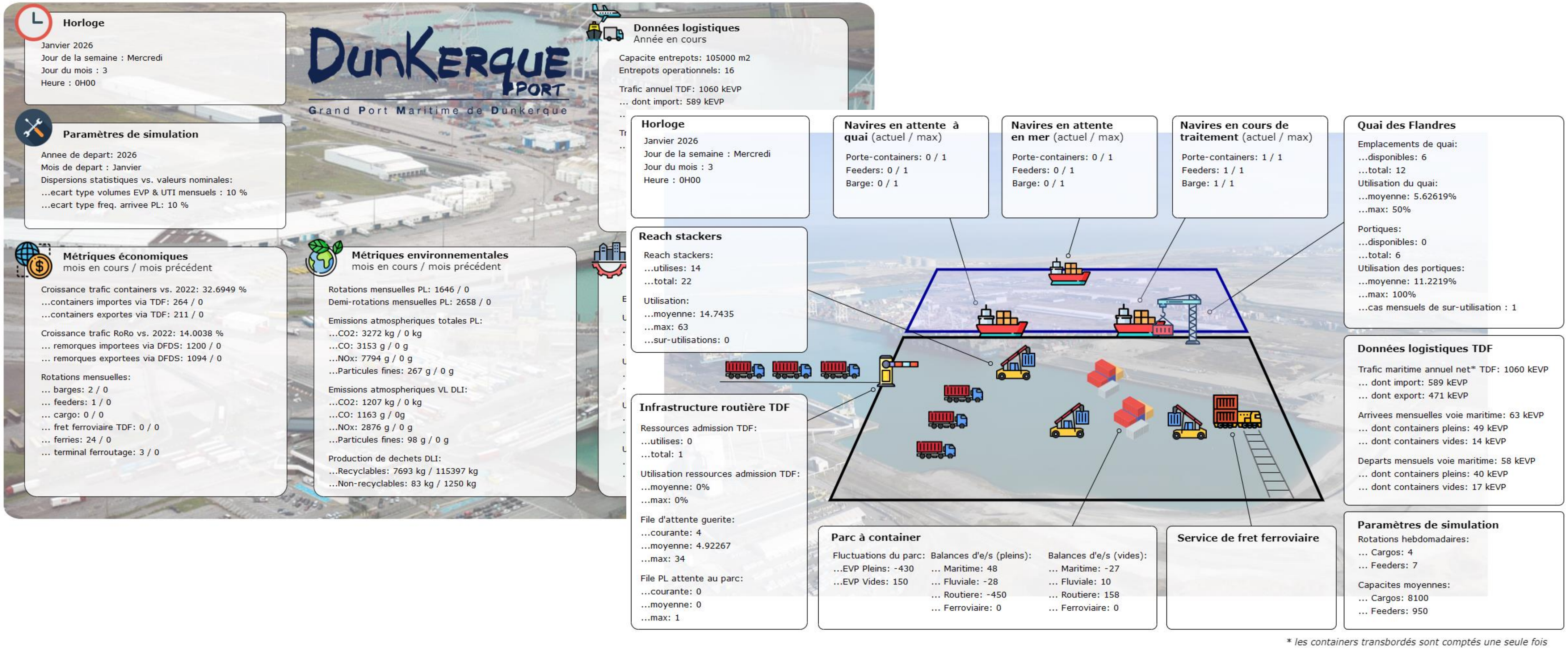
Phase 2: development of the systemic digital twin (1/2)




```
|
/* 1. DunkirkPortWorld
 * -------------------- */

system DunkirkPortWorld
    system DunkirkPortEnvironment
        system EconomicSystem ... end
        system ExternalLogisticInfrastructures ... end
        system NaturalEnvironment ... end
        system Society ... end
    end
    system DunkirkPort
        system InputOutputInfrastructures
            system CargoInfrastructure ... end
            system RailInfrastructure ... end
            system RiverInfrastructure ... end
            system RoadInfrastructure ... end
        end
        system ContainerTerminal
            system BargeLogistic ... end
            system CargoLogistic ... end
            system TrainLogistic ... end
            system TruckLogistic ... end
            system ContainerStocks ... end
            system Customs ... end
        end
        system RailRoadTerminal
            system TrainLogistic ... end
            system TruckLogistic ... end
            system TrailerStocks ... end
        end
        system RollOffRollOnTerminal
            system FerryLogistic ... end
            system TruckAccessAndParks ... end
            system Customs ... end
        system WareHouses
            system ExistingWarehouses ... end
            system NewLogisticHub ... end
        end
    end
end
```

Specification in Σ™ of Dunkirk's port structure & behavior, supported by WorldLab™ systemic intelligence workshop

A case study of WorldLab™ technology: Dunkirk's port
Phase 2: development of the systemic digital twin (2/2)



Examples of dashboards with key performance indicators for Dunkirk's port

A case study of WorldLab™ technology: Dunkirk's port

Phase 3: use of the systemic digital twin – Example of container terminal access (1/3)

Business analysis:
container terminal access

Context: the admission of trucks to the container terminal is a process carried out manually in two stages (queue & control). This process is suitable today for the current flow of containers transported by road, but will undoubtedly pose capacity problems in the future.

Infrastructure, environmental & economic challenges

- Anticipate blocking of terminal access
- Control waiting times for truck drivers

- Control / limit the impact on air pollution of the increase in the number of trucks that are serving the container terminal.

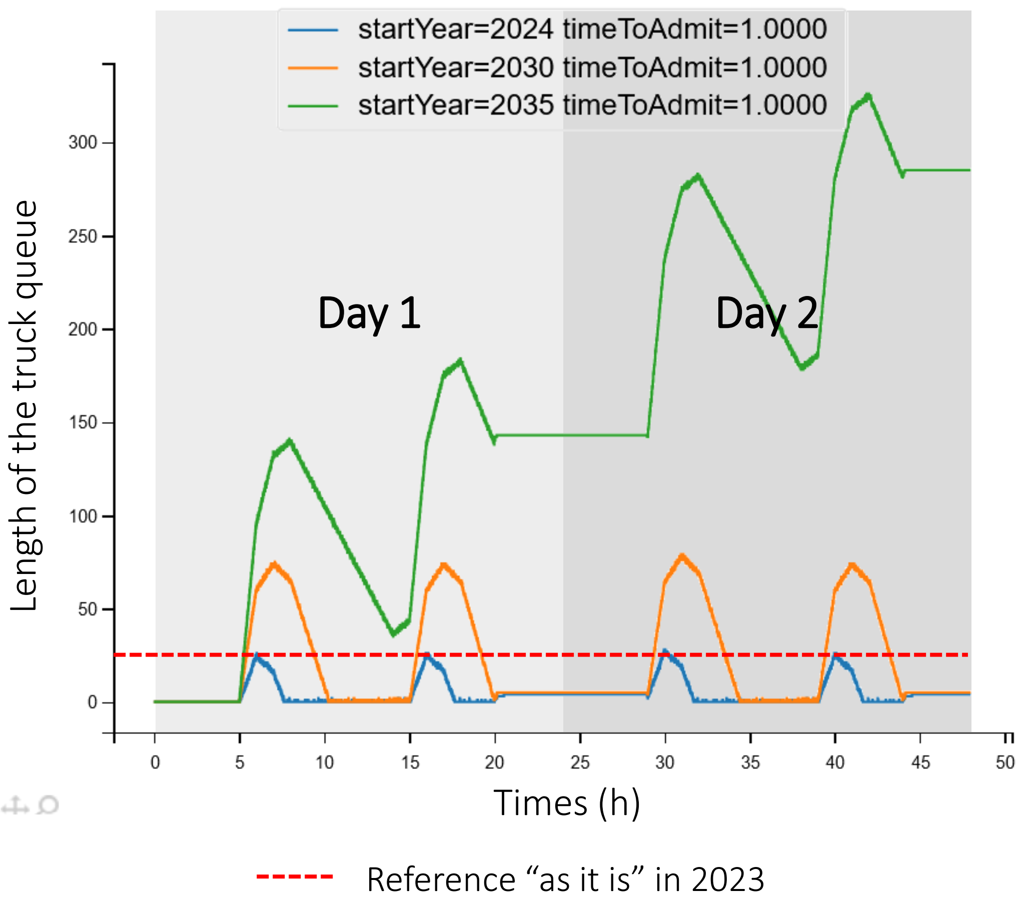
- Avoid loss of customers due to poor quality of service
- Avoid forwarding traffic to other ports

Example of business analysis for Dunkirk's port, supported by WorldLab ™ systemic intelligence workshop

A case study of WorldLab™ technology: Dunkirk's port

Phase 3: use of the systemic digital twin – Example of container terminal access (2/3)

Number of trucks that are waiting at the entrance of the container terminal – simulation of 2 days

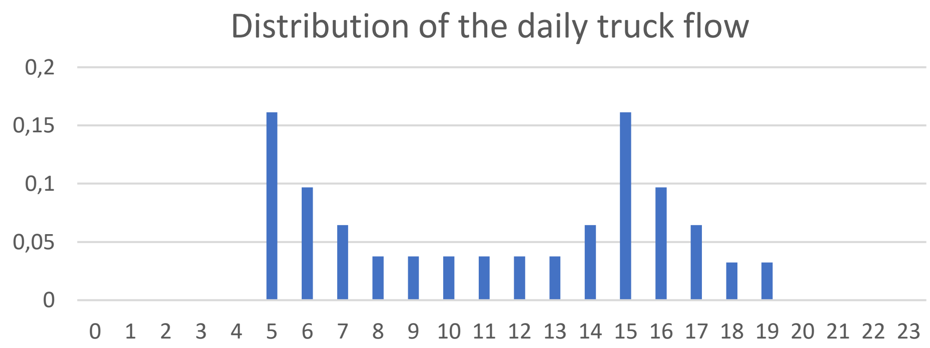


Hypothesis:

- Future logistic flows according to Dunkirk's port objectives
- Arrival of trucks following an empirical hourly distribution, as illustrated below
- Each truck transports the equivalent of 2 TEU (Twenty-foot Equivalent Unit)
- 1 single admission queue with 1 min processing time at the most restrictive point

Observation:

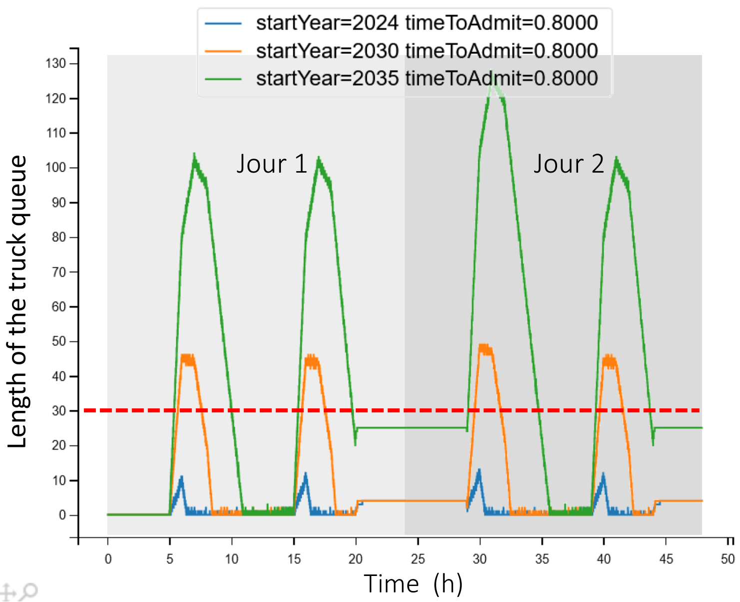
Uncontrolled access waiting time starting from 2035



A case study of WorldLab™ technology: Dunkirk's port

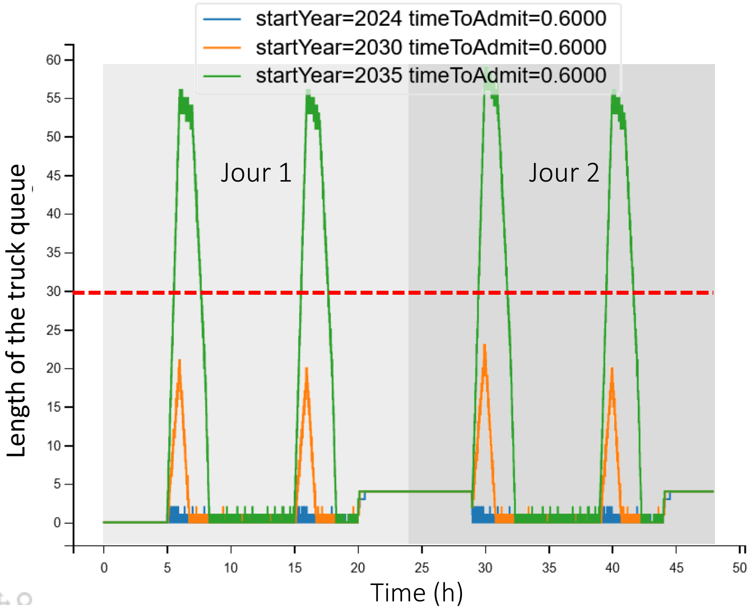
Phase 3: use of the systemic digital twin – Example of container terminal access (3/3)

----- Reference "as it is" in 2023



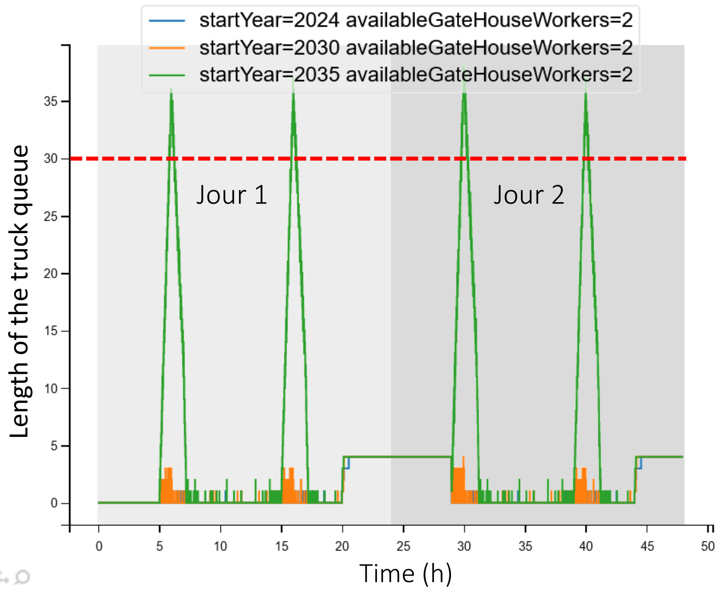
- 1 queue
- Mean admission time ~ 45 s

Max queue length in 2035: ~ 130 trucks



- 1 queue
- Mean admission time ~ 35 s

Max queue length in 2035: ~ 55 trucks



- 2 queues
- Mean admission time = 1 min

Max queue length in 2035: < 40 trucks

To reduce the waiting time, the **most effective solution for 2035** seems to be to **open a second queue**, without having to considerably reduce the processing time, which requires doubling all the resources managing admission to the terminal.

Thanks for your questions

CESAMES

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