Systemic Digital Twins
for Mastering Complex Industrial Operations & Strategy

How to Optimize Industrial Operations?

From Modelling to Simulation of Complex Industrial Systems

Case study: supporting an aircraft industrial ramp-up

Daniel KROB (INCOSE Fellow)

June 2024

Systemic Intelligence

Sigma

WorldLab

Agenda

1. **Systemic Intelligence: who are we?**
2. Systemic digital twin: why? what? how?
3. A case study: supporting an aircraft industrial ramp-up

Systemic Intelligence

Who are we?

Core competences

- Systems architecture
- Enterprise architecture & transformation
- Iterative & collaborative systems engineering
- Agile@scale architecture
- Product lines architecture
- Model-based systems engineering (MBSE)
- **Systemic digital twins**

Offers

Transformation support
Industrial system modeling & simulation expertise
Coaching & training

Team

≈ 40
people

Income

8 M€
2023

Offices

Paris
Toulouse
Shanghai

Creation

École Polytechnique
Spin-off - 2011

Partners

INCOSE • Systematic (Paris Region Deep Tech Ecosystem) • Dassault Systèmes • Tsinghua University

On-the-job training programs

AIRBUS GROUP • ARIANE GROUPE • NISSAN • RENAULT • SAFRAN • SCHNEIDER ELECTRIC • STELLANTIS

CESAM method

≈10,000
trained professionals for 10 years

Community

CESAM COMMUNITY
Our systems architect community

Events

- CSD&M Paris & Beijing
- Industrial Enterprise Architecture Day
- Top executive club

LinkedIn

≈ 10,000
followers

Systemic Intelligence is a part of **CESAMES group**, a spin-off of the industrial chair “Engineering of complex systems” of Ecole Polytechnique. We are specialized in **systems architecting & engineering** and propose **modeling & simulation techniques** to better mastering industrial complexity.

Systemic Intelligence

Our chief officers

Daniel KROB, chief executive officer of Systemic Intelligence, is a former institute professor in Ecole Polytechnique, the top 1st engineering university in France, currently also Distinguished Visiting Professor in Tsinghua University, the top 1st engineering university in China. He is a leading **world expert in system modeling**, recognized as Fellow of the International Council on Systems Engineering (INCOSE).

Antoine RAUZY, chief scientific & technological officer of Systemic Intelligence, is professor in CentraleSupélec in France and in the Norwegian University of Science & Technology in Norway. He is a leading **world expert in system simulation** and developed the AltaRica model-based safety technology, currently used worldwide in the industry for supporting safety studies.

Systemic Intelligence

Our industrial ecosystem

Our first systemic digital twin customers

Aeronautics

AIRBUS Commercial Aircrafts
AVIC
COMAC
SAFRAN Group

+ CORAC, Daher Dassault Aviation

Automotive

NISSAN
MITSUBISHI MOTORS
GROUPE RENAULT
STELLANTIS
Valeo

+ Mitsubishi

Energy

EDF
framatome
Schneider Electric

+ Rolls Royce, Technip

Defense & space

AIRBUS Defence & Space
AIRBUS Helicopters
arianeGroup
SAFRAN Electronics & Defense

+ Dassault Aviation, Kawasaki, Thalès

Construction

GROUPE ADP
BOUYGUES CONSTRUCTION
OTIS
somfy

+ Eiffage, Saint-Gobain, Vinci

High tech

HUAWEI
IDEMIA
SoftBank Robotics

+ A3BC, Dassault Systèmes, PTC

Innovation & services

bpifrance
dgac
Secrétariat général pour l'investissement
stelliant
SystemX

+ Caisse des dépôts, Opéra National de Paris, Pôle Emploi

Logistics

Dunkerque Port
La Poste
fives

Mining

BHP
Nordic Mining
DEBSWANA – Mining diamonds, enriching the nation

Railway

ALSTOM
Eurail
RATP
SNCF Réseau

Our current ecosystem of industrial customers at CESAMES group level

Agenda

1. Systemic Intelligence: who are we?
2. **Systemic digital twin: why? what? how?**
3. A case study: supporting an aircraft industrial ramp-up

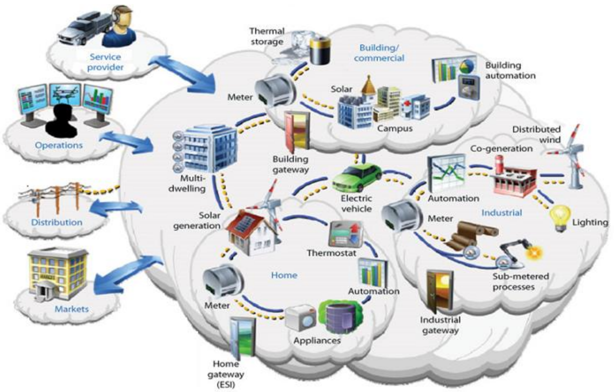
Systemic Intelligence

Why

The business scope of a systemic digital twin (1/2)

AIRBUS Canada

Optimizing
complex supply chains



Optimizing complex operations and maintenance

Dunkerque Port
La Poste
fives
Nordic Mining
SNCF Réseau

stellantis

Minimizing industrial risk

AIRBUS Canada
fives

Optimizing complex manufacturing

Modern industries must **optimize complex interdependent operational ecosystems**, such as their supply chain, their production systems, their distribution systems, their customer operations, their maintenance systems, etc., taking into consideration **complex economical, political, social, technological, legal & environmental constraints** from a tactical and strategic perspective.

Systemic Intelligence

Why

The business scope of a systemic digital twin (2/2)

- What is the optimal global architecture for an industrial system?
- What is the optimal design for a new industrial facility?
- What is the industrial evolution scenario with less risks & costs?
- 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

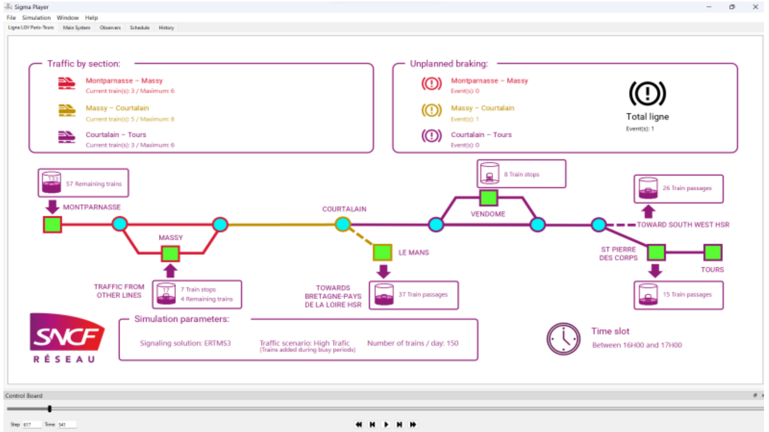
- How to optimize my industrial lead time during operations?
- How to minimize non quality during industrial operations?
- How to determine the root causes of an operational inefficiency?
- How to optimally reconfigure my industrial production?
- How to minimize energy & wastes during industrial operations?
- How to decrease environmental footprint during industrial operations?

Examples of operational & tactical industrial decisions

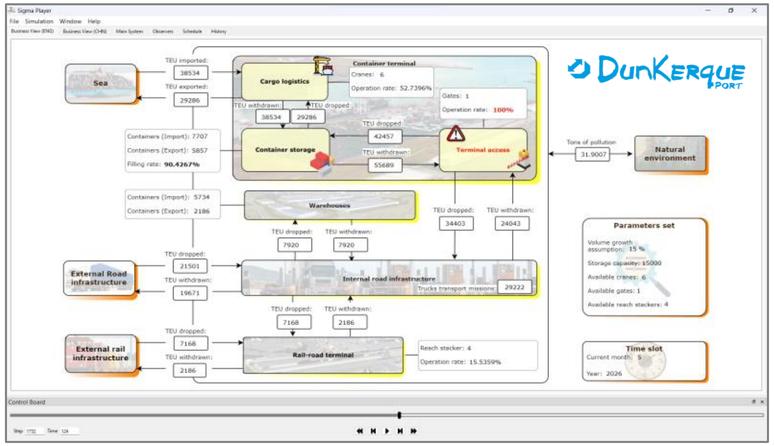
Optimization of industrial operations rely on many different types of **operational, tactical & strategic industrial decisions**

Why ?

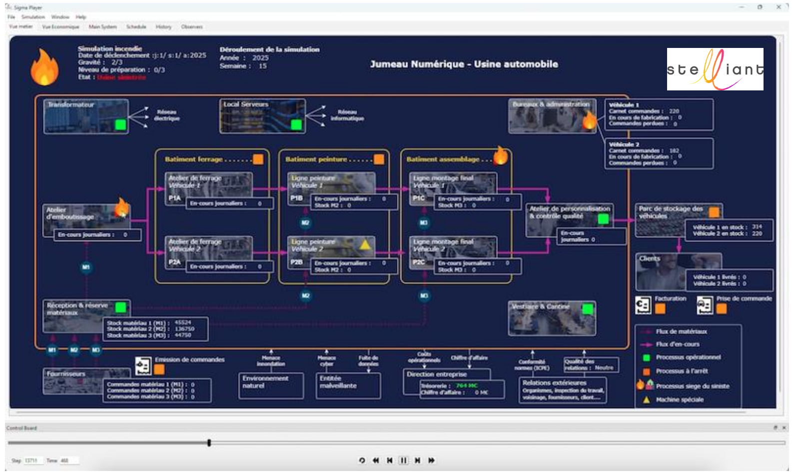
Examples of application scopes of actual systemic digital twins in the industry



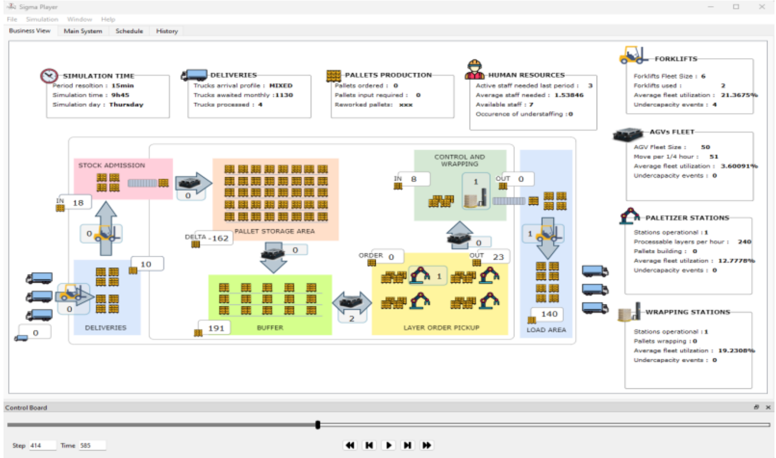
***Trade-off:** comparison of 4 control-command railway architectures under 3 traffic growth hypotheses*



***Strategic decision:** identification of nature and time of industrial investments under container traffic growth hypotheses*



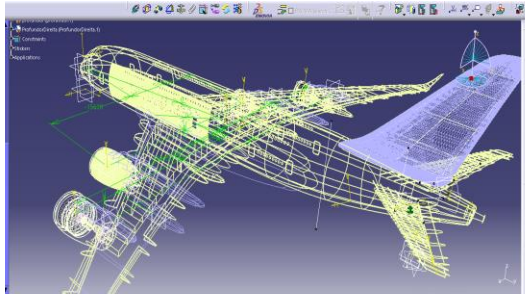
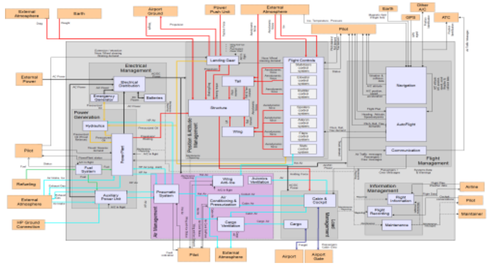
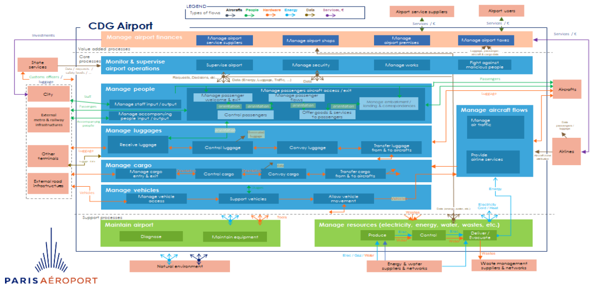
***Risk management:** design of the best insurance strategy to cover industrial risks (fire, flood, cyber-attack)*



***Design:** identification of the best architecture for an automated warehouse depending on the traffic to manage*

What

The functional scope of a systemic digital twin (1/2)

	Products	**Processes**
Geometry (where is located the system)	 *Example: geometric model of an aircraft*	 *Example: geometric model of an airport*
Behaviour (what is doing the system)	 *Example: functional model of an aircraft*	 *Example: business processes of an airport*

Systemic digital twins

Systemic digital twins address these challenges by **simulating & optimizing** **processes** associated with **complex industrial systems**

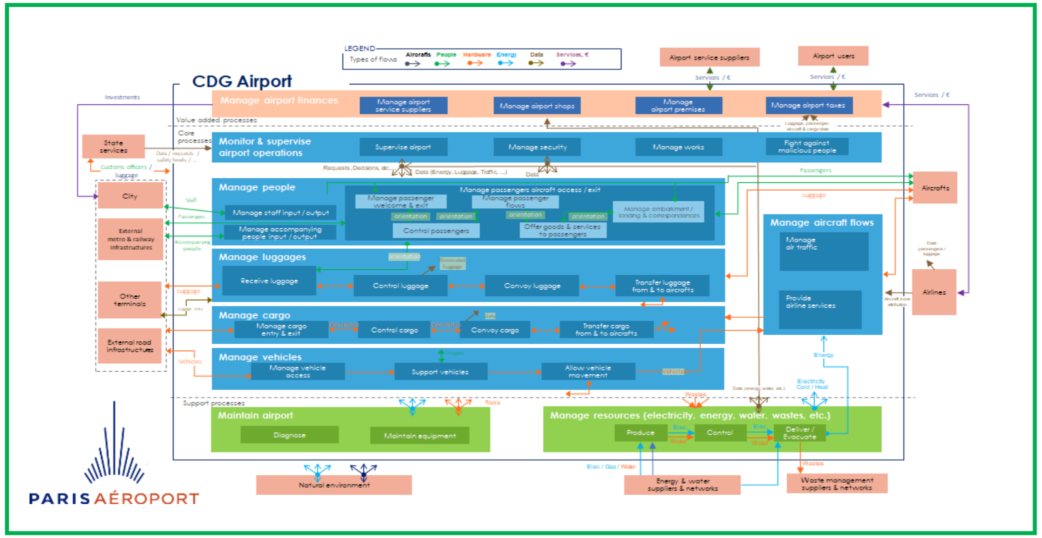
What

The functional scope of a systemic digital twin (2/2)

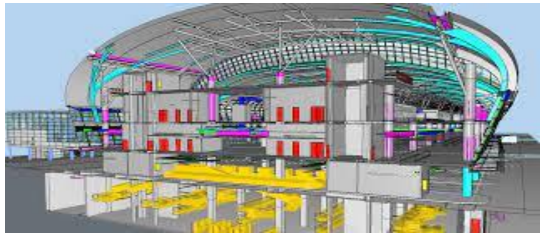
IOT & RFID infrastructure

Smart devices

Systemic digital twins



Business processes



Digital mock-ups

Building Information Modeling (BIM)

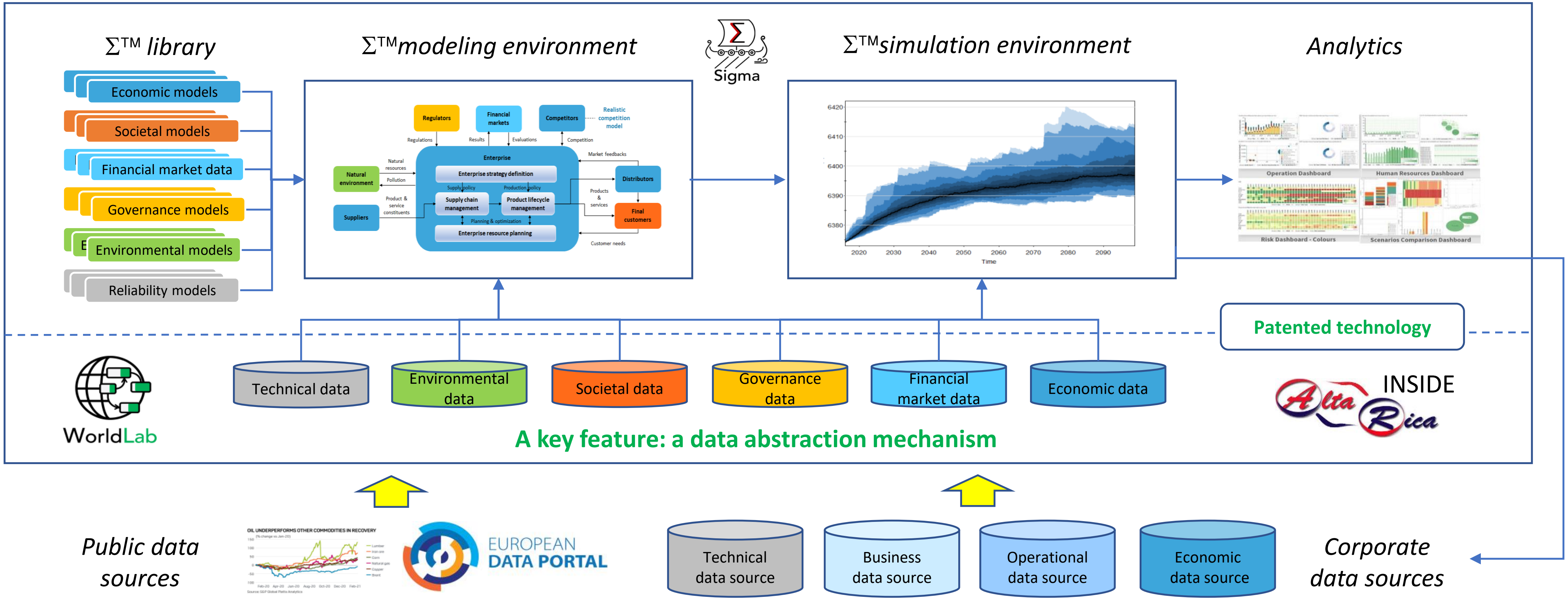
Our functional digital twin philosophy where business processes are at the core of a digital twin

Contrarily to the market (e.g. Ansys, Bosch, Dassault Systèmes, PTC, Siemens, etc.) that focuses either on data-related infrastructure or on geometric representations, we believe that digital twins must use a **functional point of view:** they shall be able to **model & simulate the behavior, i.e. the business processes, of an industrial system**, starting from operational data and ending by enriching decision dashboards or digital mock-ups, which put business models at the core of a digital twin. This is why we took an **enterprise architecture behavioral approach** which is our key difference with respect to existing digital twin technology.

Systemic Intelligence

How

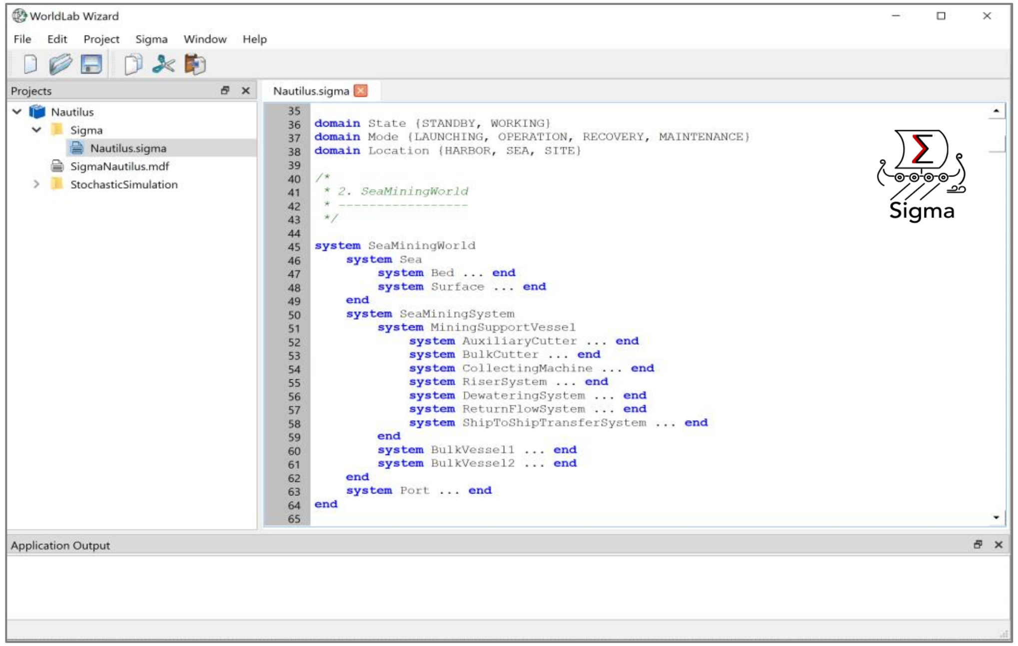
The technological scope of a systemic digital twin (1/2)



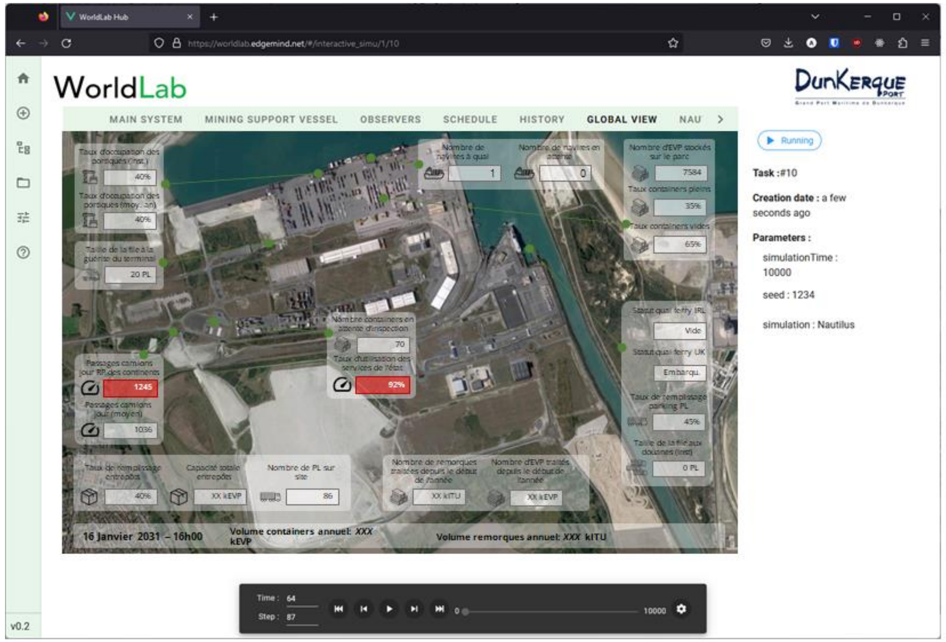
To support our vision, we developed the **WorldLab™ patented technology** – built on the **proven infrastructure of the AltaRica safety & reliability analysis tool**, developed by Antoine RAUZY during the last 20 years and industrially used in many industrial sectors – which is a **systemic intelligence workshop** that offers systemic modelling and scenario stochastic simulation & evaluation capabilities.

How

The technological scope of a systemic digital twin (2/2)



WorldLab ™ Workshop



WorldLab ™ Hub

The **WorldLab™ technology** has two sides dedicated to two different types of users: 1) the **WorldLab™ Workshop** is a system modeling & simulation standalone workshop where a **system modeling engineer** can model a given industrial system, using our system specification language Σ™, and prototype the associated systemic digital twin, 2) the **WorldLab™ Hub**, generated through the WorldLab™ Workshop, is the Web interface dedicated to the **business users** where one can simulate a systemic digital twin, evaluate business indicators and compare business scenarios associated with the modeled industrial system.

Systemic Intelligence

How

The Σ™ modeling language at the core of WorldLab™ (1/2)

Sigma

```
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 Σ™

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

activity World.Supplier.RenewRawMaterialStock
  trigger:
    return rawMaterial<=1000 and not renewing;   ← Condition that triggers the activity
  start:
    renewing = true;   ← What shall be done when the activity starts
  completion: {
    renewing = false;
    rawMaterial += 100;   ← What shall be done when the activity stops
    }
  duration:
    return 30;   ← Duration of the activity (in units of time)
end
```

Specification of a business process – as an activity – in Σ™

The **Σ™ formal modeling language** allows 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.

Systemic Intelligence

How

The Σ™ modeling language at the core of WorldLab™ (2/2)

```
activity World.Consumer.ConsumeProduct
  trigger:
    return product>=1000 and not consuming;
  start:
    consuming = true;
  completion: {
    consuming = false;
    product -= uniformDeviate(1, 2.5);
    }
  duration:
    return 1;
end
```

Example of a stochastic quantity with explicit probabilistic distribution

```
activity World.Consumer.ConsumeProduct
  trigger:
    return product>=1000 and not consuming;
  start:
    consuming = true;
  completion: {
    consuming = false;
    product -= 1;
    }
  duration:
    return triangularDeviate(1, 5, 2);
end
```

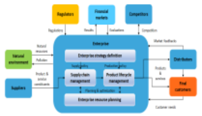
Example of a stochastic duration with explicit probabilistic distribution

Stochastic behaviors can be captured within Σ™ in two different ways, either via variables manipulated by **activities** or via **durations**. One can express in Σ™ such stochastic behaviors either through a number of **exact probabilistic distributions** (e.g. Normal laws, uniform laws, exponential laws, etc.) or through **empirical distributions** (i.e. experimental timed sequences).

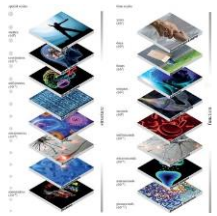
How

The key unique features of WorldLab™

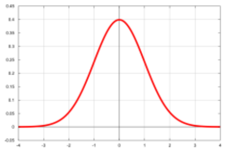
- **Quick maintainability –** A systemic digital twin is specified in the **object-oriented modeling language Σ™** which is easy to use for any person with an algorithmic-design background. This choice also allows to **easily develop & maintain among time** a systemic digital twin, with a gain of effort from 5 to 10 with respect to the competition.



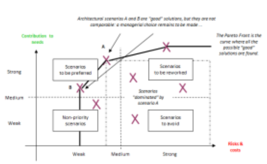
- **Heterogeneity –** A systemic digital twin can integrate **various heterogeneous features**, such as technical functions, maintenance policies, societal behaviors, financial market evolutions, regulatory strategies or meteorologic conditions, into a **single unique systemic model**, allowing to analyze a given industrial system from all these various perspectives.



- **Multi-scales –** Our modeling language especially allows to model and manage **multi space and temporal scales** allowing to **capture the hierarchical space & time structure** of any complex industrial system, which is currently not offered by the existing similar languages.



- **Hazards – Hazards** can be effectively captured in a systemic digital twin: each variable specified in the Σ™ modeling language can be a random variable with a specific probability distribution – either explicit or pragmatic – allowing to capture **random quantities & random delays** and to manage **stochastic simulations** for a given industrial system.

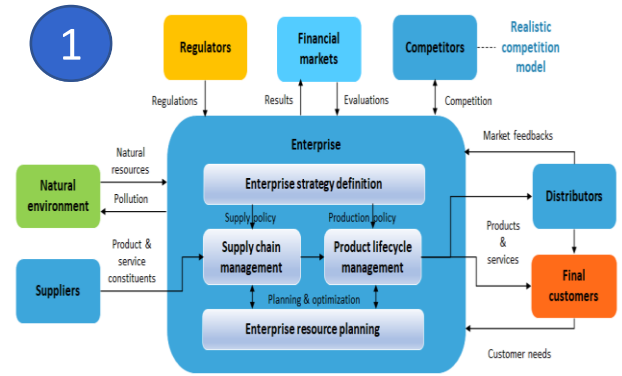


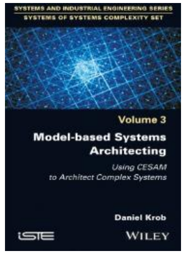
- **Virtual experiences –** The WorldLab™ platform proposes dedicated features for **managing virtual experiences** where one can **evaluate & prioritize business evolution scenarios** and achieve **multi-criteria optimization**, e.g. maximizing production when minimizing delays & energy consumption, with respect to a given industrial system.

Systemic Intelligence

In practice

Systemic digital twins do connect MBSE to simulation





MBSE model of an industrial system

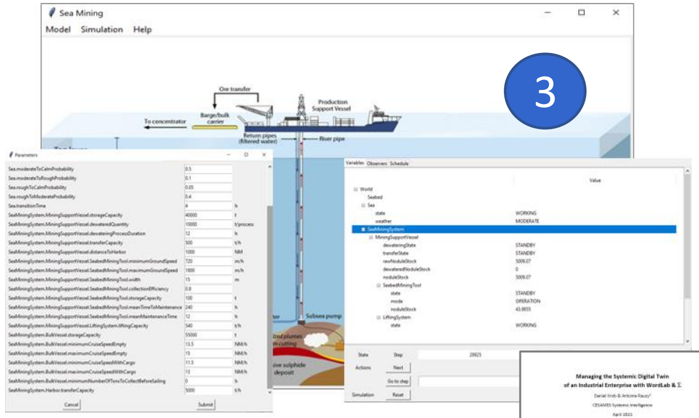
```
system World
  system Supplier ... end
  system Producer ... end
  system Consumer ... end
end

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

Sigma

Σ™ model of an industrial system

WorldLab



Systemic digital twin of an Industrial system

Principle of the development of a systemic digital twin of an industrial system with Σ™ and WorldLab™

The **WorldLab™ technology** especially allows to **produce automatically systemic digital twins** of an industrial system from a **MBSE model** through a **specification** designed in our **Σ™ formal modeling language**.

Systemic Intelligence

Agenda

1. Systemic Intelligence: who are we?
2. Systemic digital twin: why? what? how?
3. **A case study: supporting an aircraft industrial ramp-up**

A case study: supporting an industrial ramp-up

A bit of context

AIRBUS
Canada

The A220 aircraft, formerly the CSeries of Bombardier

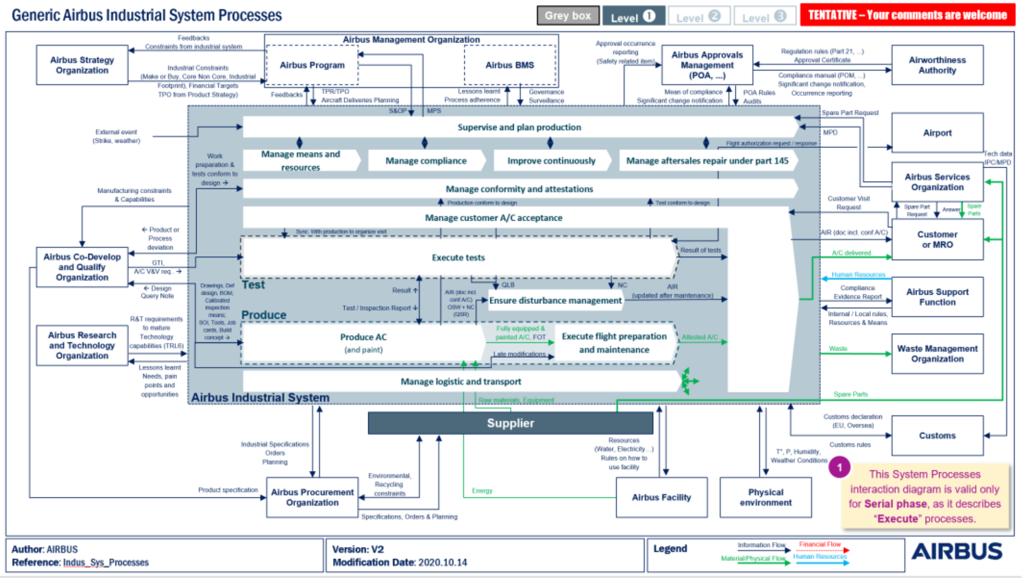
The Final Assembly Line (FAL) of the A220 aircraft in Mirabel (Canada)

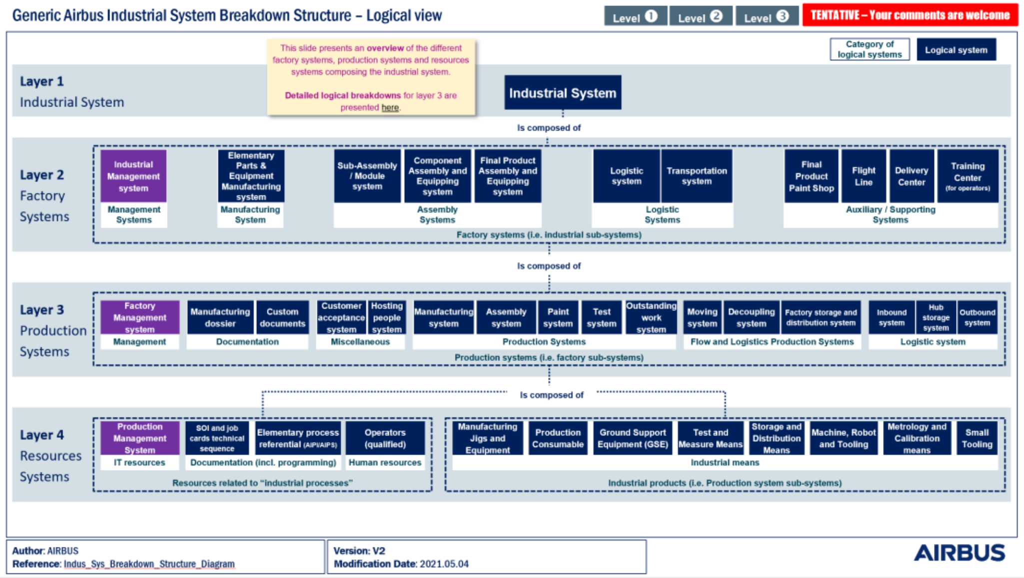
Airbus Canada produces the **A220 aircraft** and has an important backlog which obliges to **manage a strong ramp-up** of its industrial production, but a first attempt in this direction failed …

A case study: supporting an industrial ramp-up

Towards a systemic digital twin for the A220 industrial system

How to achieve a **systemic model of the A220 industrial system** that may be used as the key input of a **systemic digital twin** that shall support **strategic planning** in order to help **Airbus A220 industrial program** to **analyze & solve the weaknesses of the A220 industrial system**?





Examples of generic industrial systems architectural views

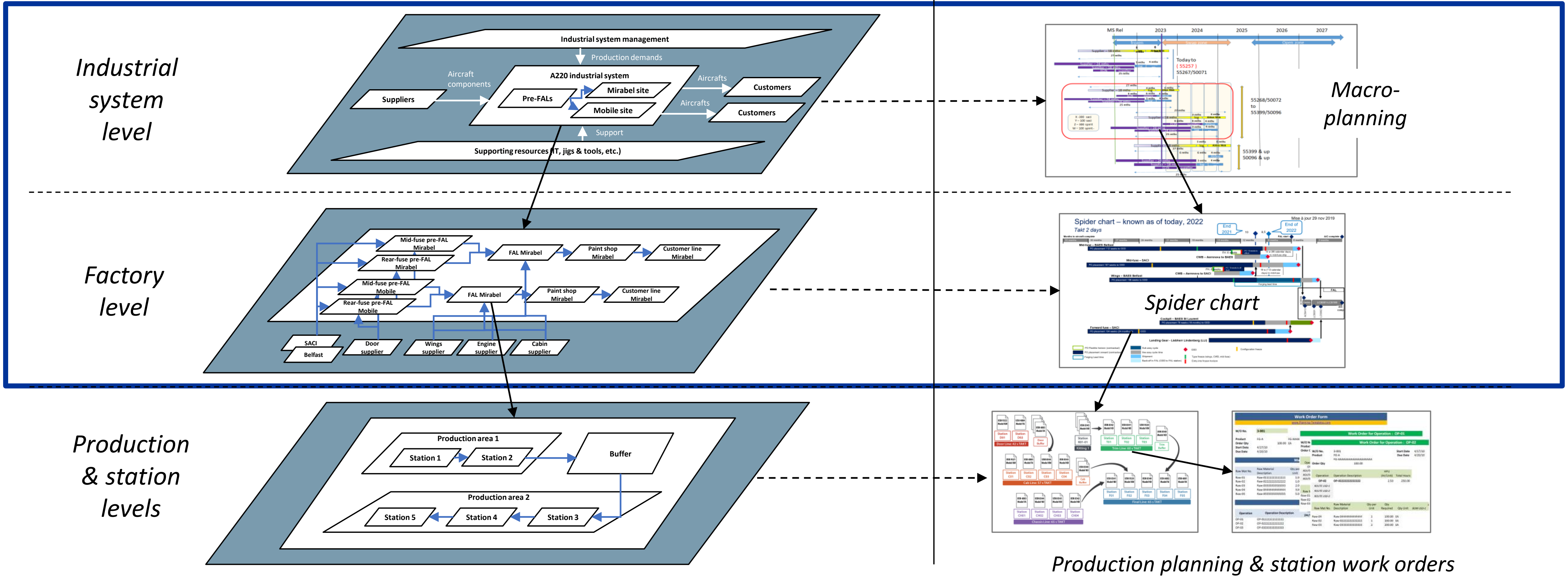
Fundamentals of industrial system modeling

Our enterprise architecture modeling framework

Our focus

Structural & functional vision
(focus on entities & processes)

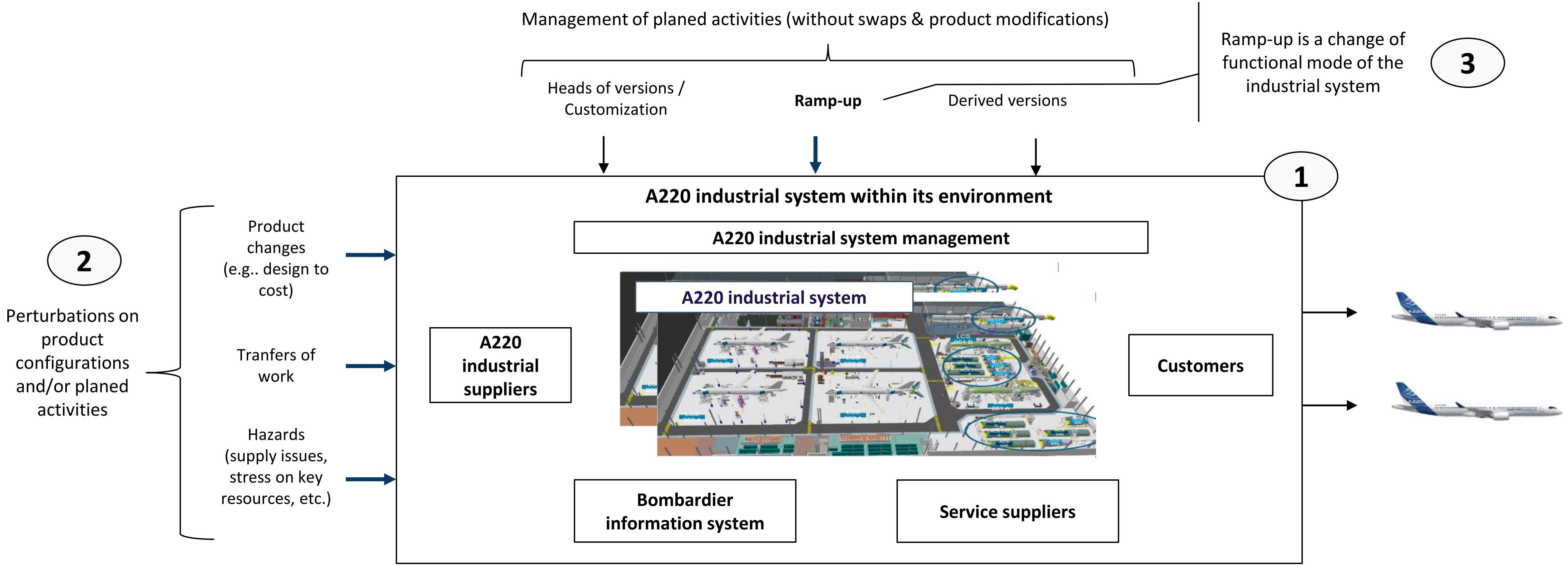
Planning vision
(focus on activity scheduling)



Systemic Intelligence

Fundamentals of industrial system modeling

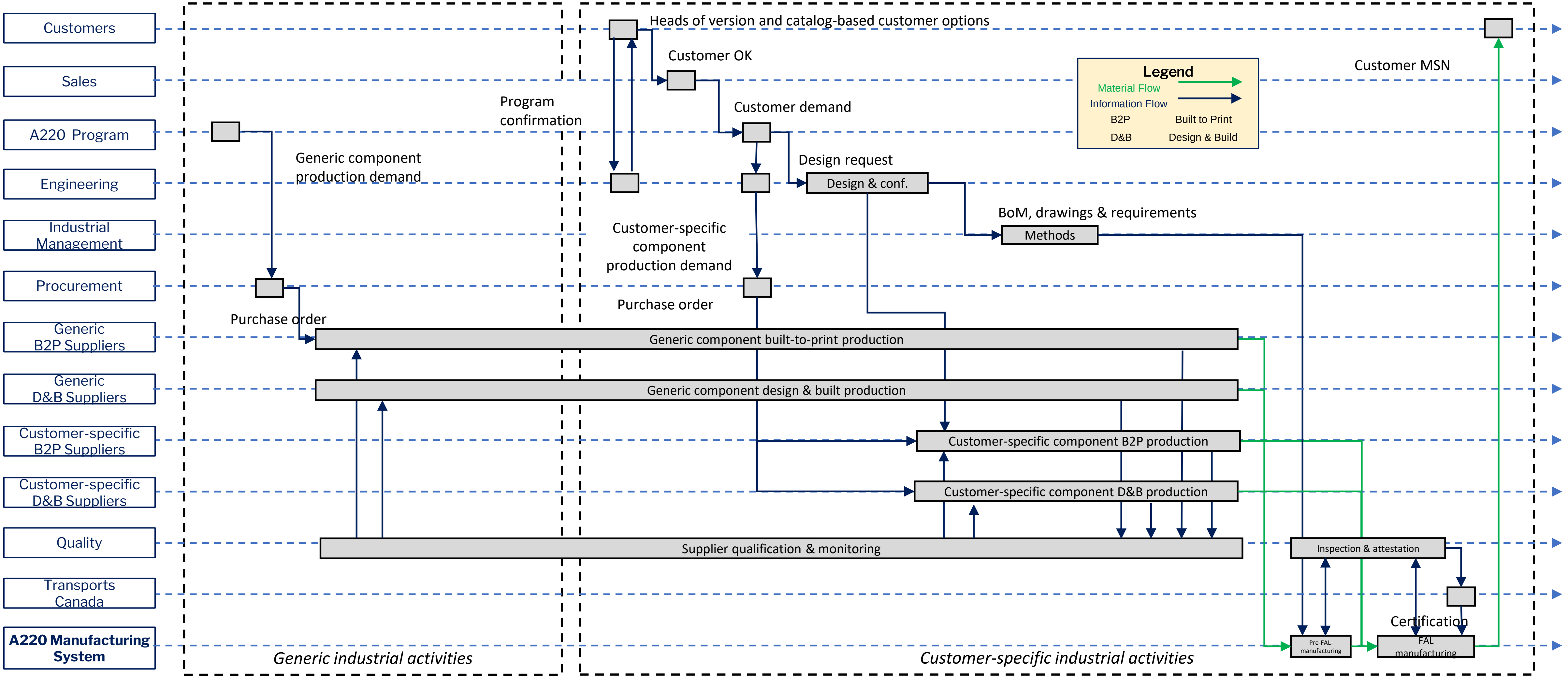
Principle of our modeling approach



A model of the A220 industrial system was achieved in **two steps**: 1) identifying the **A220 industrial system landscape**, i.e. the **normal components of an ideal industrial system**, **without perturbation**, 2) **integrating** then **perturbations** to obtain an **as-realistic-as-possible model** for the actual A220 industrial system. This shall help us to understand 3) **when / whether ramp-up is feasible**.

Step 1: understanding the ideal A220 industrial system

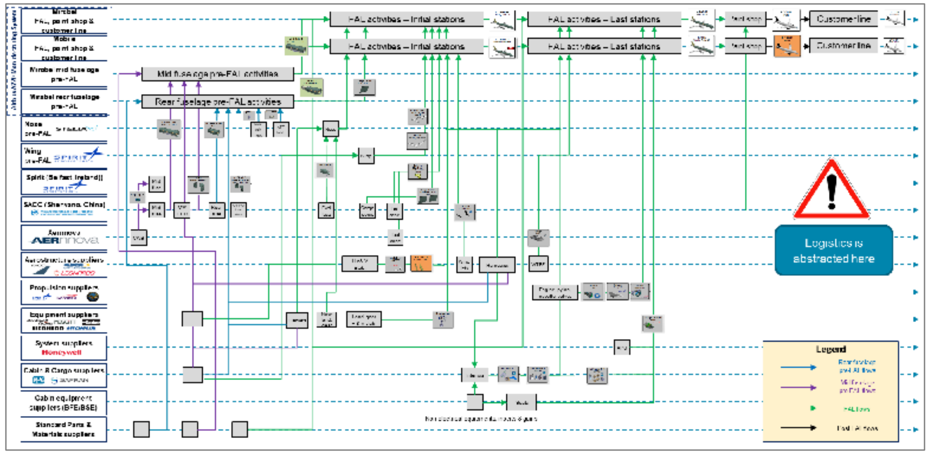
Overall structural & functional vision



Systemic Intelligence

Step 1: understanding the ideal A220 industrial system

Other key views

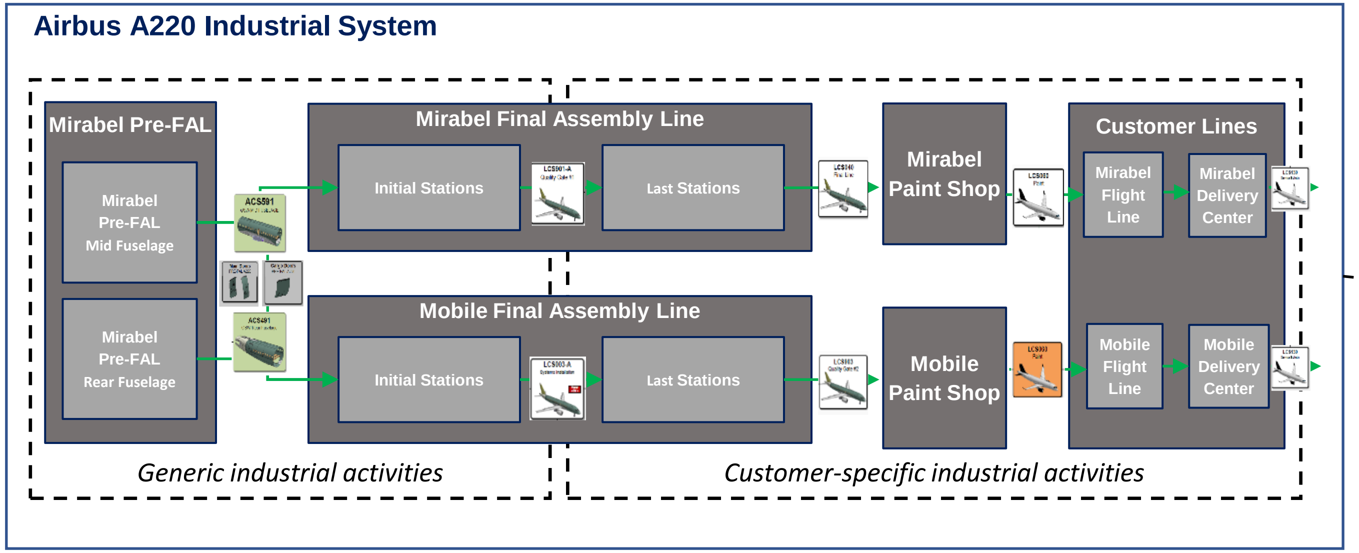


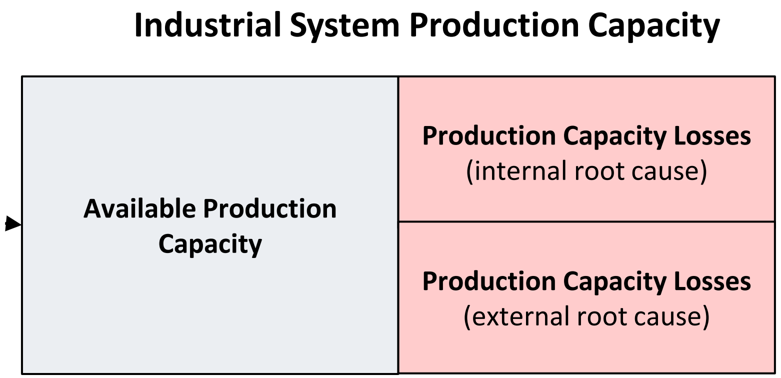
Structural & function and planning views at system level

Structural & function and planning views at factory level

Step 2: understanding the actual A220 industrial system

A preliminary remark





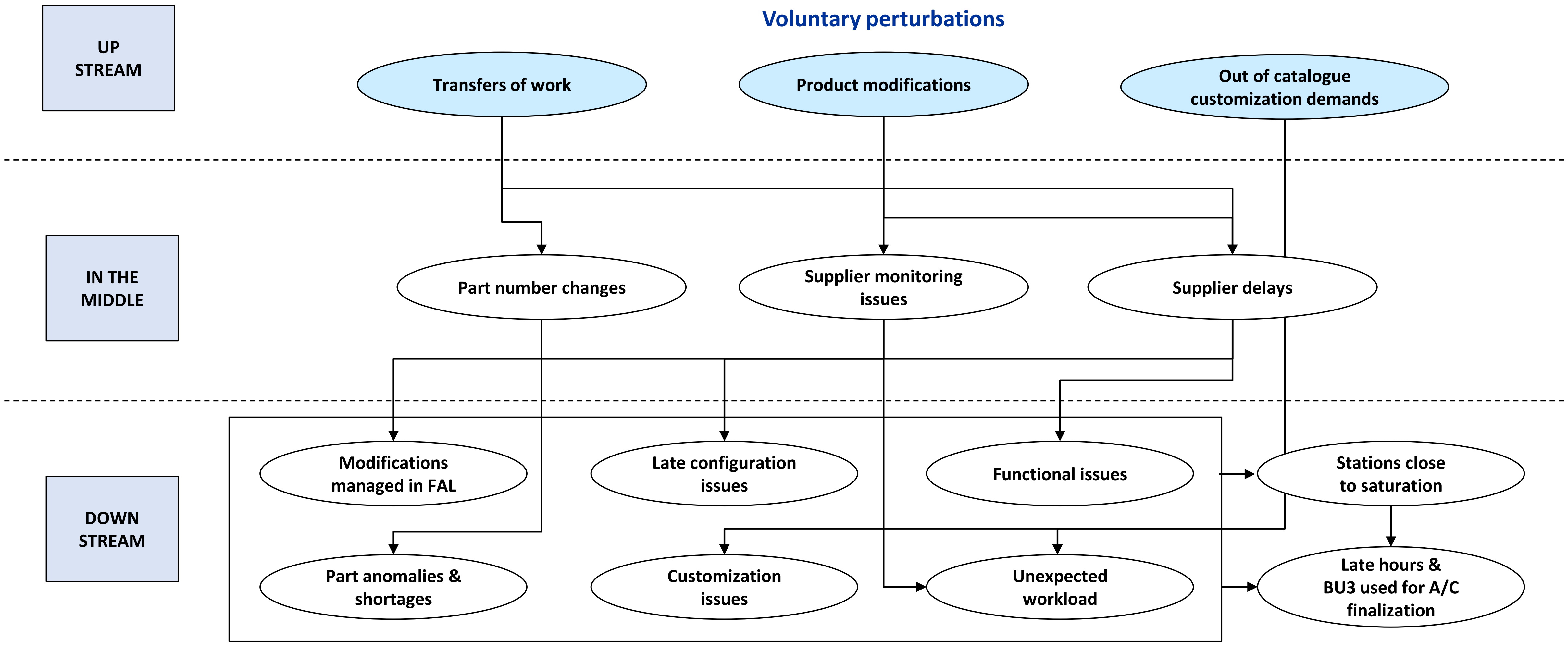
Produced Quantity (aircraft / month) = **Available Production Capacity** (hour / month) / **Takt Time** (hour / aircraft)

The **relationship between the production throughput and the takt time** of an industrial system shows that the feasibility of a ramp-up depends on the mastering of the **production capability losses** which may have **internal or external origins** (perturbations on the industrial system, wastes of / stresses on existing capabilities, crises, etc.).

Systemic Intelligence

Step 2: understanding the actual A220 industrial system

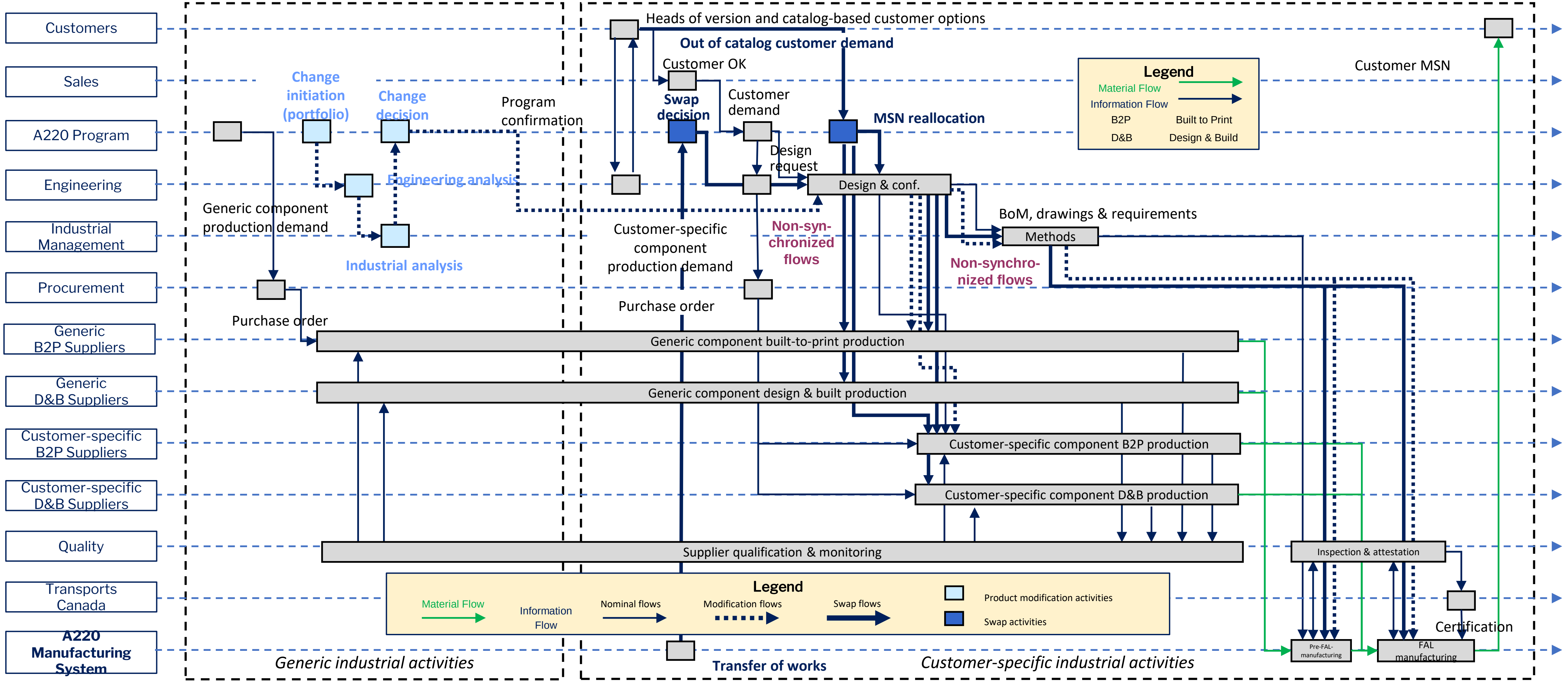
Key issues identified in our field analysis managed through interviews & documentation analysis



Systemic Intelligence

Step 2: understanding the actual A220 industrial system

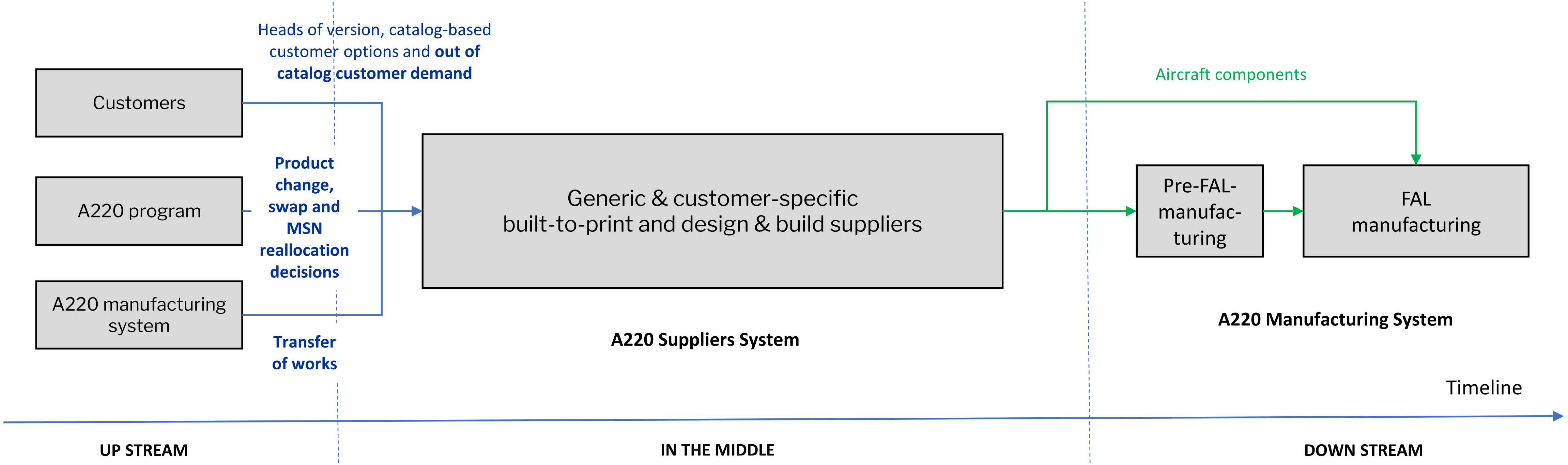
The resulting final model for the A220 industrial system



Systemic Intelligence

Step 2: understanding the actual A220 industrial system

The key finding that motivated the development of a systemic digital twin

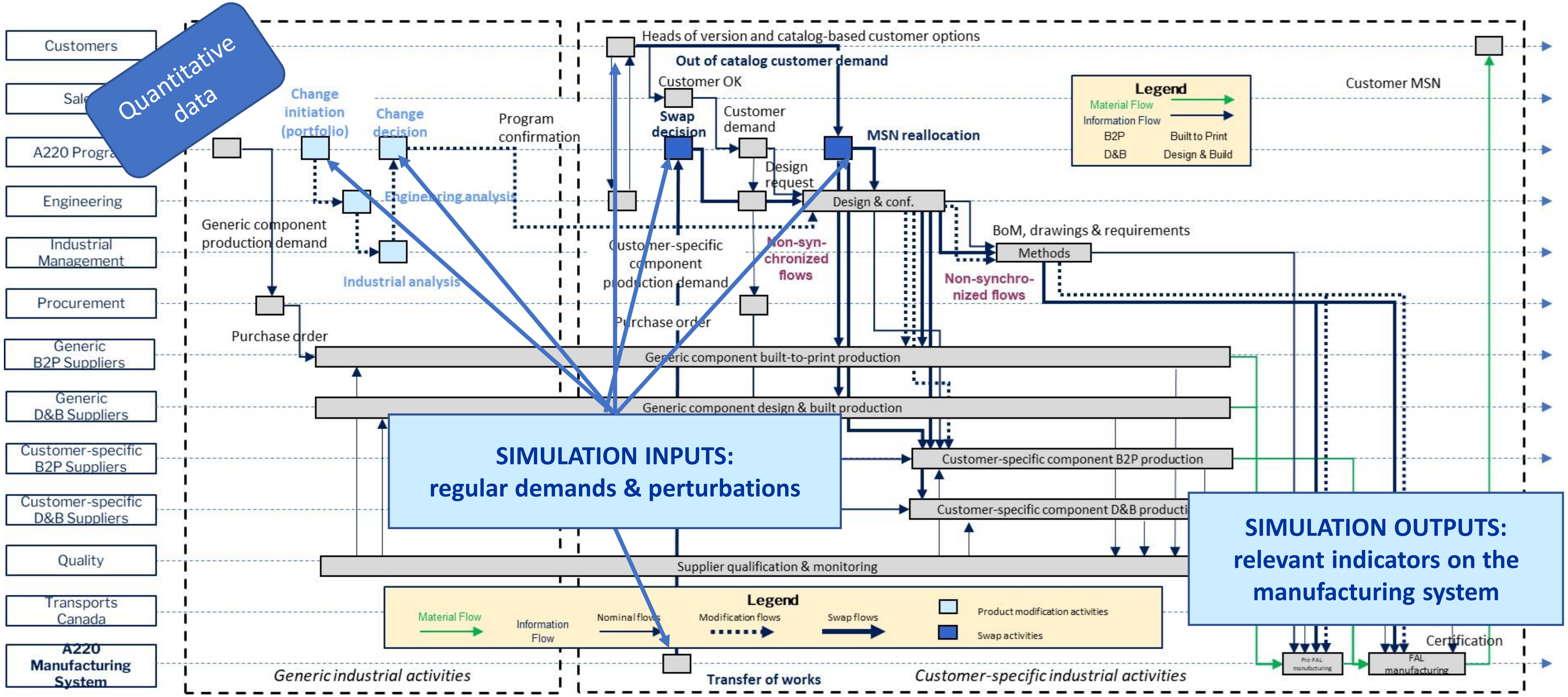


The **origins of the main down-stream issues**, as observed in the A220 manufacturing system (heavy correcting work in pre-FAL, extra work in working parties, part non-quality, missing parts, etc.), are **located up-stream**, i.e. when a number of perturbations (out-of-catalogue customer demands, product changes, transfers of works, swaps, MSN reallocations) are initiated on the A220 industrial system and then propagated within the A220 suppliers system. To master the resulting impacts on the manufacturing system, it is therefore key to **understand, measure and monitor what happens up-stream and in-the-middle** of the A220 industrial process.

Systemic Intelligence

Step 3: developing & using the systemic digital twin

Principle of a systemic digital twin for the A220 industrial system



A **quantitative systemic digital twin for the A220 extended industrial system** shall allow to evaluate **relevant industrial indicators** on the manufacturing system depending on the injected **demands & perturbations**

Contact

Daniel KROB – President

daniel.krob@systemic-intelligence.net

+33 (0)6 60 42 34 49

Systemic Intelligence Group
Private limited company with share capital of 103.750 €
Legal address: 10, rue de Penthièvre – 75008 Paris – France
Office: c/o Morning – 69-71, rue de Miromesnil – 75008 Paris – France
SIRET: 805 084 670 00035 – APE: 7490B

Systemic Intelligence