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Recommendations

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Supplement

ITU-T Y Suppl. 73 (02/2023)

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

ITU-T Y.4600 – Concept and use cases of a digital twin in smart sustainable cities

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Supplement 73 to ITU-T Y-series Recommendations

ITU-T Y.4600 – Concept and use cases of a digital twin in smart sustainable cities

Summary

Supplement 73 to ITU-T Y-series Recommendations: establishes the concept of a digital twin as a virtual representation that serves as the real-time digital counterpart of a physical object or process; describes use cases of digital twins in smart sustainable cities; and identifies challenges and opportunities for digital twins in smart sustainable cities.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y Suppl. 73	2023-02-10	20	11.1002/1000/15473

Keywords

Digital twin, digital twin in smart sustainable cities, smart city digital twin, smart sustainable cities.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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ITU-T Y.4600 – Concept and use cases of a digital twin in smart sustainable cities

1 Scope

This Supplement establishes the concept and use cases of a digital twin that can be referenced by digital twin applications in smart sustainable cities. This Supplement includes:

– the concept of a digital twin in smart sustainable cities;
– common vocabulary for digital twins in smart sustainable cities;
– use cases of digital twins in smart sustainable cities;
– challenges and opportunities for digital twins in smart sustainable cities;
– observations and suggestions.

2 References

[ITU-T Y.4600] Recommendation ITU-T Y.4600 (2022), *Requirements and capabilities of a digital twin system for smart cities*.

[ITU-T Y.4601] Recommendation ITU-T Y.4601 (2023), *Requirements and capability framework of a digital twin for smart firefighting*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following term defined elsewhere:

3.1.1 digital twin [ITU-T Y.4600]: A digital representation of an object of interest.

NOTE – A digital twin may require different capabilities (e.g., synchronization, real-time support) according to the specific domain of application.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

COVID-19 Coronavirus Disease 2019

IoT Internet of Things

PoC Proof of Concept

5 Conventions

None.

6 Concept of digital twins in smart sustainable cities

6.1 Concept

A digital twin model was first introduced in 2002 as an ideal concept for product lifecycle management. The name was originally *mirrored spaces model*, that later became *information mirroring model*. The model was finally referred to as a *digital twin*. Although the name has changed over time, the concept and model have remained the same [b-Grieves].

One of the main factors for the recent introduction and popularity of digital twins in various areas is that the underlying technologies have matured sufficiently and apply the digital twin concept to new areas. Example technologies are:

– making a 3D model of a physical object created as its digital twin model;

– visualizing the model through technologies such as augmented reality and virtual reality;

– developing virtual dynamics models of functions and operations of the object;

– collecting data while the actual operations of the object are monitored in real-time;

– analysing data through big data, deep learning, artificial intelligence, etc.;

– simulating future situations of the object through its virtual model and data analysis;

– reproducing past states with accumulated data history.

Several standards that are under development or have been published specify (or are specifying) a digital twin from a technical perspective.

[ITU-T Y.4600] specifies a digital twin from the perspective of a smart city. A smart city digital twin helps increase visibility of human-infrastructure-strategy interactions by allowing the simulation of plans before implementing them and exposing problems before they become reality in a digital replica of the city. This enables city planners to find the best strategies to achieve a specific goal or strategies that have similar effects while minimizing budget and resource usage.

Figure 1 reproduces both Figures 3 and 1 of [ITU-T Y.4600], showing an example of a digital twin of a city and the concept of a smart city digital twin system, respectively.

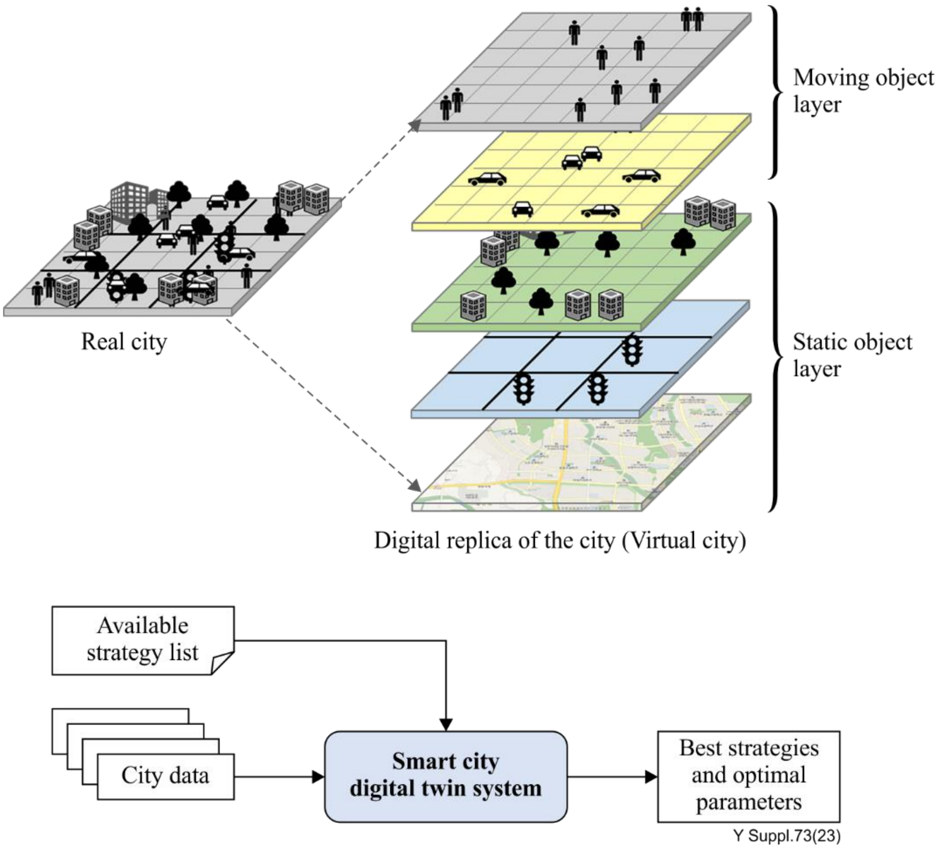

Figure 1 – Concept of a digital twin in a smart city

[b-ISO 23247-1] introduces a digital twin in manufacturing as a fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation. The objectives of a digital twin in manufacturing are to assist with detecting anomalies in manufacturing processes and to achieve various functional objectives such as real-time control, off-line analytics, health check, predictive maintenance, synchronous monitoring or alarm, manufacturing operations management optimization, in-process adaptation, big data analytics and machine learning.

In [b-ISO 23247-1], the Internet of things (IoT) is considered to be the underlying technology that supports digital twins. Figure 2 shows the IoT framework for digital twins in manufacturing introduced in [b-ISO 23247-1].

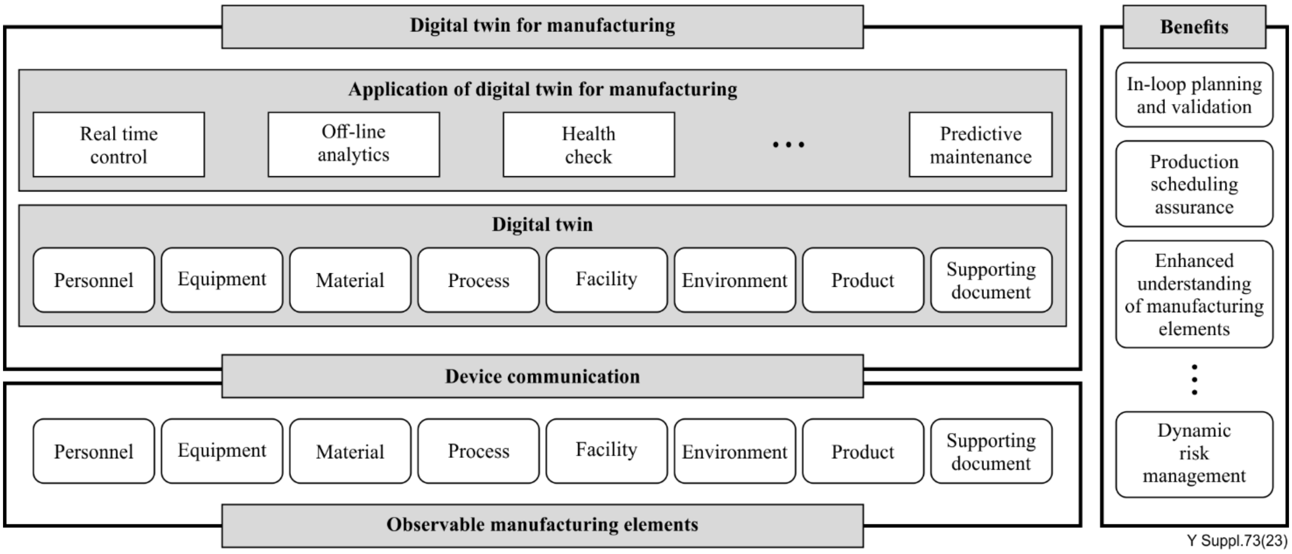

Figure 2 – Concept of a digital twin in manufacturing

6.2 Benefits

Though many documents, on-line articles and standards discussed in clause 6.1 introduce the benefits of digital twin in various ways, they can be summarized as follows.

– Process optimization:

What-if simulations based on digital twin behaviour models can help find better operation processes according to any change of the associated physical object.

– Predictive maintenance:

The behaviour model of a digital twin for a physical object can simulate its operation behaviours according to given input parameters. This simulation feature can determine what will happen after an abnormal change and prevent breakdowns before they occur.

– Real-time monitoring and proactive control:

Digital twins connected to physical objects enable real-time monitoring. Real-time monitoring and data analysis can proactively control physical objects.

– Improved efficiency and availability:

Process optimization, predictive maintenance, real-time monitoring and proactive control reduce production cost and down time of facilities.

– Better decision making:

The interworking of digital twins can make it easier to identify the causes for an interrelated and composite problem, analyse interrelations and mutual side effects occurring between its domains, and collaborate among stakeholders throughout its ecosystem.

7 Use cases of a digital twin in smart sustainable cities

7.1 Smart firefighting

7.1.1 Overview

[ITU-T Y.4601] introduces a digital twin for smart firefighting. It utilizes fire scene data to analyse, simulate and model the fire scene, and consequently provides a digital representation of its previous, current and future state. The goal of this use case is to help firefighters enhance situational awareness, understand the fire environment and improve the ability of the fire service. See Table 7-1.

Table 7-1 – Summary of smart firefighting

ID	Case number 1
Use case name	Smart firefighting
Application field	Smart city
Life cycle stage(s)/phase(s) coverage	Concept, development, production, utilization, support and retirement
Status	Prototype, proof of concept (PoC), in operation
Scope	Support of real-time rescue strategy optimization and visualization based on real-time fire information
Initial (problem) situation	Security measures focused on fire precaution only
Objective(s)	Helping firefighter enhance situational awareness, understand the fire environment and improve the ability of the fire service
Short description (not more than 150 words)	Collection, analysis, and modelling of measured data are used to support real-time rescue strategy optimization and visualization based on real-time fire information. 1. Data collection and pre-processing of the fire scene; 2. Visualizing and analysing the fire scene; 3. Establishing real-time rescue strategy
Stakeholders	Fire brigade, fire station, firefighter.
Key technologies	Fire station, firefighting, visualization, 3D modelling
Relevant standards	[ITU-T Y.4601] specifies requirements and a capability framework for a digital twin for smart firefighting. [ITU-T Y.4600] specifies requirements and capabilities for a digital twin system for smart cities. [b-ISO 23247-1] establishes a framework to support the creation of digital twins for observable manufacturing elements.
Standardization needs	Framework for smart firefighting in [ITU-T Y.4601]
Remaining issues and items for further study	

7.1.2 Process flow

Figure 3 shows the process flow of smart firefighting.

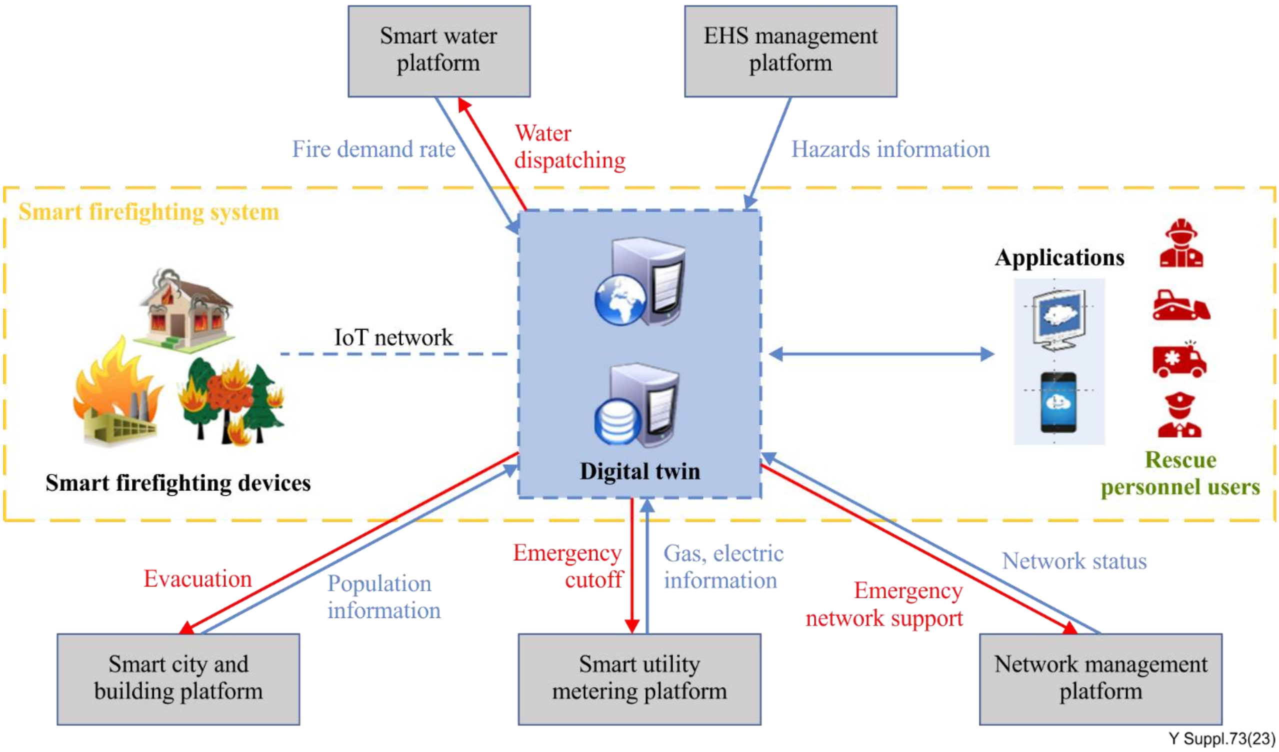

Figure 3 – Process flow for smart firefighting [ITU-T Y.4601]

7.2 Air quality management

7.2.1 Overview

Smart sustainable cities and communities require air quality management to reduce threats to respiratory health for citizens. Such management observes variables including weather parameters, temperature, particulate matter levels, presence of harmful gases in the atmosphere, as well as emissions from factories and vehicles. The purpose of this use case is to provide clean air to citizens by use of a digital twin for air quality management. Table 7-2 summarizes air quality management using a digital twin.

Table 7-2 – Summary of the air quality management using a digital twin

ID	Case number 2
Use case name	Air quality management
Application field	Smart sustainable city
Life cycle stage(s)/phase(s) coverage	Concept, development, production, utilization, support and retirement
Status	Prototype, PoC, in operation
Scope	Support the policies and services for air quality management using a digital twin
Initial (problem) situation	Difficult to predict the results of changes in policies and services for air quality management
Objective(s)	Managing air quality of smart sustainable cities and communities
Short description (not more than 150 words)	Air quality management using a digital twin supports the selection of policies and services to provide clean air, as follows: 1. mirroring and monitoring air quality of a smart sustainable city; 2. modelling and simulating policies and services for air quality management; 3. enforcing the policies and services for air quality management

Table 7-2 – Summary of the air quality management using a digital twin

Stakeholders	City administrators, city service providers and vendors
Key technologies	Smart sustainable city, modelling, simulation, visualization
Relevant standards	[ITU-T Y.4600] specifies requirements and capabilities for a digital twin system for smart sustainable cities. [b-ISO 23247-1] establishes a framework to support the creation of digital twins for observable manufacturing elements
Standardization needs	Definition of the concepts and requirements for collaboration between digital twin systems in multiple domains, where air quality control is in scope
Remaining issues and items for further study	Need to develop ITU-T Recommendation regarding a digital twin for air quality management of smart sustainable cities

7.2.2 Process flow

Figure 4 shows the process flow for air quality management using a digital twin.

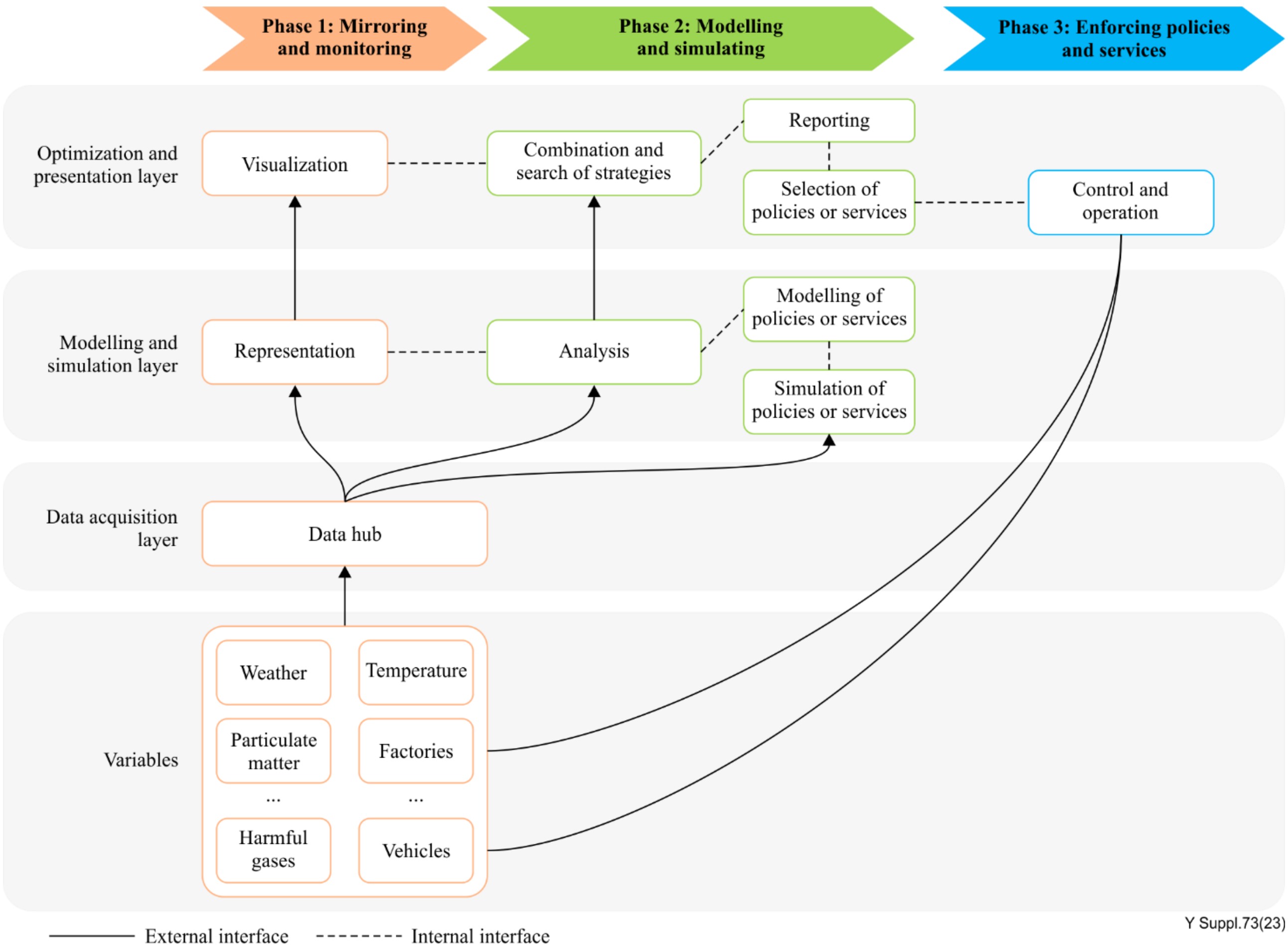

Figure 4 – Process flow for air quality management using a digital twin

Phase 1: Mirroring and monitoring of a smart sustainable city

– Step 1

Variables in a smart sustainable city are mirrored in digital representation.

– Step 2

Variables including weather parameters, temperature, particulate matter levels, presence of harmful gases in the atmosphere, as well as emissions from factories and vehicles, are monitored by collecting data from various kinds of sensor and meter.

– Step 3

Production of a visualization model for air quality management in a smart sustainable city.

Phase 2: Modelling and simulating the optimized policies and services

– Step 1

Appropriate variables for air quality management are selected and modelled for policies and services;

– Step 2

Simulation of changes in air quality according to policies and services;

– Step 3:

Analysis of the integrated simulation results.

Phase 3: Enforcing policies and services for air quality management

– Step 1

Determination of optimized policies and services for air quality management using simulation results.

– Step 2

Enforcement of optimized policies and services for air quality management for citizens.

– Step 3

Collection and evaluation of citizen satisfaction with the optimized policies and services.

7.3 Response to infectious diseases

7.3.1 Overview

From the end of 2019, an infectious disease, coronavirus disease (COVID-19) led to a deadly pandemic. Response to such infectious disease in smart sustainable cities is involved in multiple domains including manufacturing, transportation and medical treatment. For example, manufacturers need to respond with sufficient resources, such as masks or gloves, for personal protection of citizens or healthcare personnel. In addition, emergency medical transportation is needed to transfer confirmed cases or severe symptom cases to medical facilities for quarantine or treatment as soon as possible.

For a more effective response to infectious diseases in future smart sustainable cities where the digital twin system is widely adopted, digital twin systems of domains relevant to response to infectious diseases need coordination. The coordination is more than interworking, which comes from interoperability, because each collaborating digital twin system needs to consider the impact of its action on another domain.

Table 7-3 summarizes the response to infectious diseases in smart sustainable cities.

Table 7-3 – Summary of response to infectious diseases

ID	Case number 3
Use case name	Response to infectious diseases
Application field	Smart city

Table 7-3 – Summary of response to infectious diseases

Life cycle stage(s)/phase(s) coverage	Concept, development, production, utilization, support and retirement
Status	Prototype, PoC, In operation
Scope	Support of collaboration among digital twin systems of relevant domains to respond to infectious diseases
Initial (problem) situation	A smart city may face severe infectious diseases that need actions of digital twin systems in multiple domains. However, different digital twin systems are not interoperable and thus they cannot collaborate in response to infectious disease
Objective(s)	Response to infectious diseases in smart sustainable cities
Short description (not more than 150 words)	When a sharp increase of confirmed cases is anticipated, city administrator sets the digital twin for city management to respond appropriately. The digital twin for city management identifies relevant digital twins and it collaborate with the relevant digital twin systems to respond to the infectious diseases. The response may include contact tracing, reserving appropriate medical facilities for accommodating patients, planning required action for managing medical resources such as production or distribution.
Stakeholders	City administrators, medical facilities, manufacturers, government.
Key technologies	Smart city, digital twin system, interoperation among digital twin systems
Relevant standards	[ITU-T Y.4600] specifies requirements and capabilities of a digital twin system for smart cities. [b-ISO 23247-1] establishes a framework to support the creation of digital twins of observable manufacturing elements.
Standardization needs	Definition of the concept and requirements for collaboration among digital twin systems in multiple domains, which are needed to achieve a certain goal.
Remaining issues and items for further study	Establishment of new work item regarding the collaboration among digital twin systems

7.3.2 Process flow

Figure 5 shows the process flow for a response to infectious disease in smart sustainable cities.

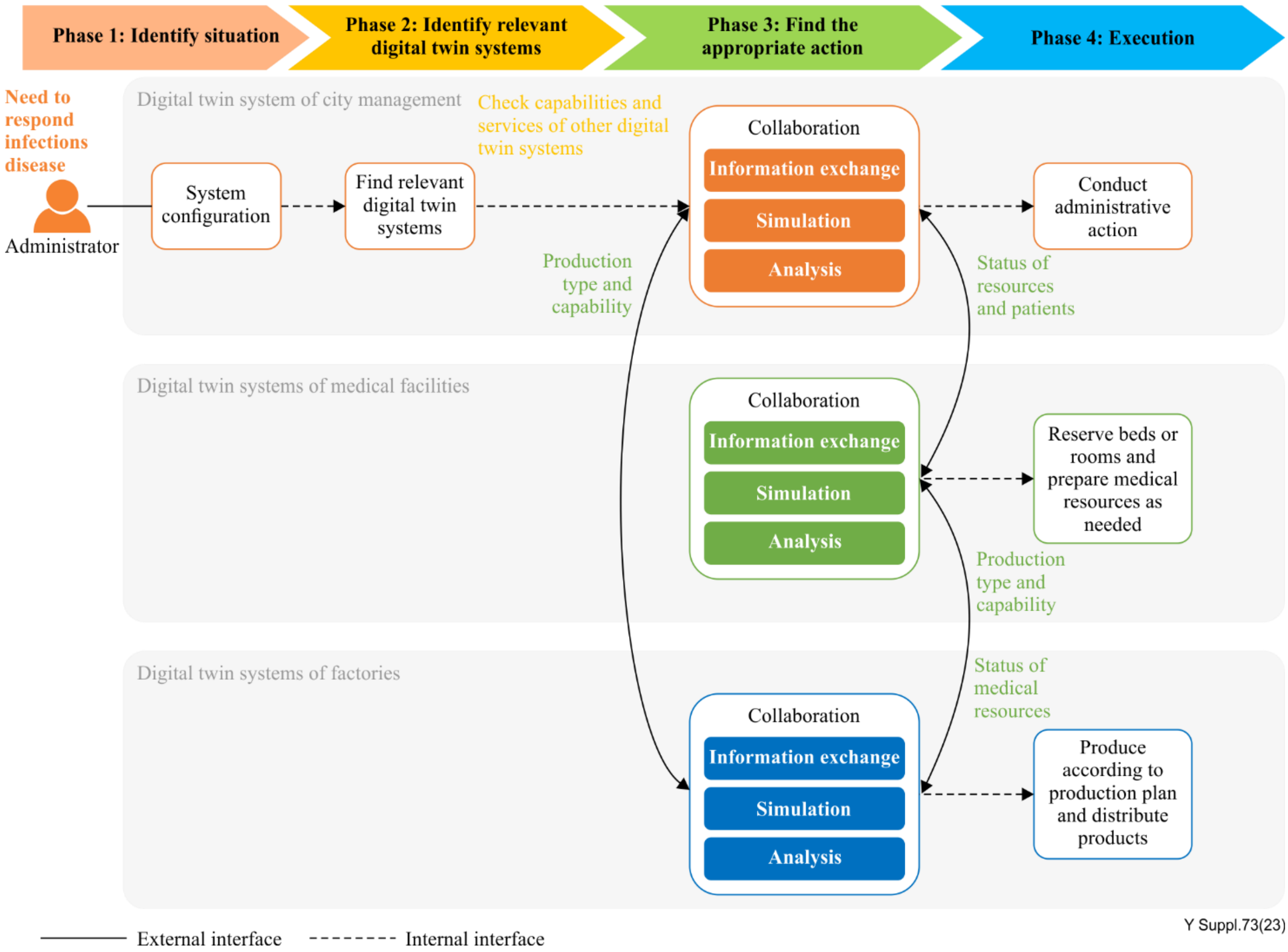

Figure 5 – Process flow of responding infectious diseases in smart sustainable cities

Phase 1: Identify problem

– Step 1

City administrator receives a report that a sharp increase in confirmed cases is anticipated.

– Step 2

City administrator configures digital twin system for city management to respond infectious diseases. The parameters may include the anticipated number of confirmed cases. Configuration may happen without intervention of an administrator, if the city management digital twin system can interact with the disease control and prevention system.

Phase 2: Identify relevant digital twin systems

– Step 1

City management digital twin system finds the digital twin system relevant to respond to infectious diseases. To find relevant systems, service discovery server can be used, where each digital twin systems register their information. In Figure 5, a digital twin system of city management will find other digital twin systems for medical facilities and factories in the city.

Phase 3: Determine the appropriate action

– Step 1

The city management digital twin system initiates collaboration among relevant systems. The collaboration starts with the information exchange. For example, the city management digital twin system provides the anticipated number of confirmed cases. Digital twin systems of medical facilities can provide available numbers of beds, negative pressure rooms, vaccine doses, resources (e.g., masks), in addition to the number of required resources, status of patients, etc. Digital twin systems of factories can provide the production capability (e.g., 50 000 masks/day) and the number of products in stock;

– Step 2

Based on the information provided, digital twin systems collaborate to determine the appropriate response to infectious diseases through simulation and analysis. The results of simulation and analysis are shared among the systems to check the impact of action on other domains. Factories can set the production plan, while medical facilities can reserve beds or rooms and prepare medical resources as needed. City management can determine the administrative action required, e.g., building temporary accommodation or issuing an emergency use authorization.

Phase 4: Execution

– Each digital twin system conducts the action chosen.

8 Challenges and opportunities

Digital twins deployed in smart sustainable cities are likely to be requested to collaborate with other digital twins to cope with complex problems. However, it is likely that differences in level of capabilities will prevent digital twin applications from cooperating with others in smart sustainable cities.

Figure 6 shows an example of digital twin application domains in smart cities, in which each digital twin is isolated from others. Lack of cooperation of digital twins may give rise to the following problems:

– **difficulty** in identifying the causes for an interrelated and composite problem;
– **inability** to simulate and predict an integrated environment over multiple domains;
– **difficulty** in multidisciplinary decision-making between different stakeholders;
– **inability** to identify interrelations and mutual side-effects occurring between industrial domains;
– **inability** to collaborate among stakeholders throughout the industrial ecosystem.

The problems explained in the previous paragraph can be resolved by cooperation among digital twins in smart cities. The capability maturity model of digital twin gives insight into digital twin functionalities, a step-by-step evolution plan of digital twin capabilities and finally the outlook for interoperable digital twins.

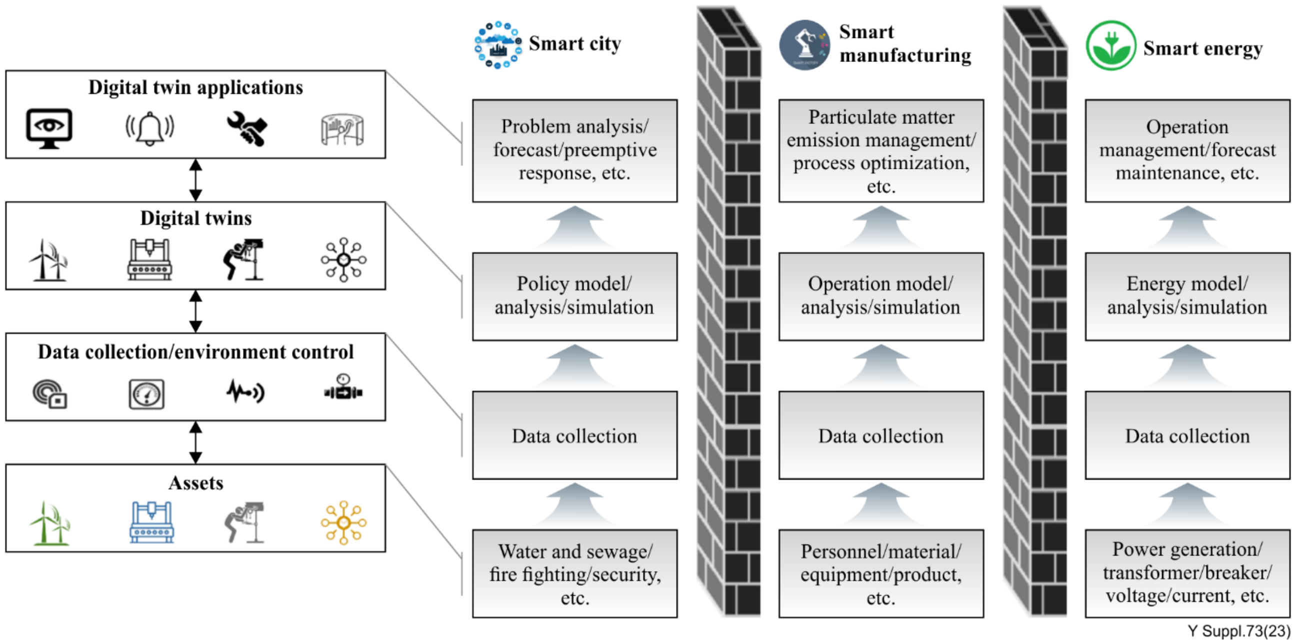

Figure 6 – Example of digital twin application domains in smart cities (each digital twin is isolated from others)

9 Observations and suggestions

Challenges and opportunities in clause 8 show the limitations and boundaries of a digital twin if it is siloed. As the number of applications of digital twins increases, the problem of their interoperability will arise. Smart sustainable cities are a set of application domains for digital twins whose example shows the importance of their interworking.

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