



HAL
open science

A systemic, model and data-based method for depollution projects engineering and management

mayssa Chebbi, Vincent Chapurlat, Jean-Samuel Wienin, Laurent Aprin, Philippe Girones

► **To cite this version:**

mayssa Chebbi, Vincent Chapurlat, Jean-Samuel Wienin, Laurent Aprin, Philippe Girones. A systemic, model and data-based method for depollution projects engineering and management. WM2023 Conference - “Planning for the Future: Innovation, Transformation, Sustainability.”, Feb 2023, Phoenix, United States. ⟨hal-04168094⟩

HAL Id: hal-04168094

<https://imt-mines-ales.hal.science/hal-04168094v1>

Submitted on 22 Aug 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

A systemic, model and data-based method for depollution projects engineering and management

Mayssa Chebbi, Vincent Chapurlat*, Jean-Samuel Wienin*, Laurent Aprin*, Philippe Girones***

** Laboratory for Science of Risks (LSR), IMT Mines Alès, Alès, France*

*** CEA, DES/DDSD/UARP/CMT, Site de Marcoule bât. 02, Pièce COM13, France*

ABSTRACT

Decision-makers are struggling to design and manage depollution projects all along their duration, facing various events and challenges. So, they need approaches allowing them to act. In general, existing approaches focus on costs optimization and deadlines management but remain not entirely adapted for depollution context and objectives. In particular, multiple, heterogeneous and independent enterprises are generally involved in such projects. Indeed, they provide each particular capabilities (e.g. mastering depollution techniques), resources and means to perform some depollution activities that are requested as a whole and during various time period. However, they need to interact with each other, having and sharing in confidence a good understanding. They need a common point of view and vocabulary about the whole project itself, of concerns of all its stakeholders, about its current state of development, of the first obtained results and so on. There is then a need to assist and support actors who are in charge of depollution projects to engineer and manage such projects and address all these challenges: complexity, heterogeneity, multiplicity of interactions and actors. This paper proposes and argues the value of a collaborative and model-based method aiming to specify, check then control and adapt dynamically depollution projects. As a consequence, this method intends to move from an artisanal depollution approach to a standardized vision of the depollution.

INTRODUCTION

In recent years, the French industrial landscape has undergone major changes. Many operations have ceased their activities and the sites are either reused for industrial purposes or shut down permanently. These transfers or cessations of activity represent the moment to take stock of the environmental quality of the sites, in connection with the obligation to restore the site which is incumbent on the actors who will carry out this rehabilitation. On the other hand, as real estate pressure is increasing in urban areas, there is a growing demand for land on industrial wasteland or other sites that have been abandoned for many years. The necessity of setting-up depollution projects of these sites is increasing.

Depollution requires organizing and managing various activities that involve different business actors and companies and crossing various skills, for instance, geology, hydrogeology, toxicology, or metrology[1]. Different locks (technical but also methodological) and various unpredictable events could emerge all along during depollution. For instance, launching common activities, and involving several business actors could make appear difficulties (e.g., synchronization when sharing common resources or delays). At the same time, it is mandatory to reach an equilibrium both by respecting regulatory rules (e.g., operators' security and safety, or environmental) and by assuming competitiveness objectives and limiting time constraints. The same race concerns underway the quality of the proposed depollution strategy, especially when risks for human life or significant financial risks must be managed [2]. Last, each depollution project is generally considered a special case, even though there are several common points that enable the provision of feedback and standards.

The purpose of the work described in this article is to increase the reproducibility and automation of the procedures implemented during future depollution projects. It seeks to develop, provide appropriate tools, and validate a method to describe, analyze and help in the piloting of a depollution project. In order to move efficiently towards the application of this method. Within this frame work the support tool includes the development of modeling and analysis tools which will then be integrated around a single interoperable

database working with the information systems of the stakeholder companies involved in each of the projects. The objectives included improving the performances of future depollution operations in terms of scheduling, cost, and performance, for the operational aspects as well as the management and piloting of such operations. At the same time, all the requirements imposed on depollution, formalized or not, must be respected, while targeting this purpose.

The paper is organized as follows. The next section describes the real case study used to illustrate the method. Section III identifies the main depollution issues and existing approaches to face these problems. Section IV presents the contributions of the R&D works, under the form of a method, before concluding, Section V describes how the method has been applied to the case study.

MOTIVATING USE CASE

A use case allows first to show some problems encountered in a project of depollution, and second, how the proposed research contribution may support managers to face these problems. To this end, this use case focuses on an industrial site located in a French territory which has undergone depollution projects considering then French regulation rules. The industrial site and the installation to be depolluted will be no more detailed in this article for confidential reasons. The installation was specialized in the production of chemical products, here gelcoats, including the formulation and mixing of resins, solvents and additives which are considered toxic, pollutants and risky for the environmental health. The activities of this industry started in the early 1970s on virgin ground and gradually developed over the years. From the end of 2010, the activity of the site decreased significantly and then stopped around 2014. Since this site produces several polluting products, it is subject to authorization under the regulations of Classified Installations for the Protection of the Environment (ICPE)¹. For this reason, a depollution is necessary to preserve the environmental health and to allow the rehabilitation of the land.

The industrial site covers a total area of approximately 60,000 m² which includes various areas at significant risk of contamination. In these areas several samples were taken from soil, groundwater and surface water. The results of these analyses show the existence of several toxic elements (styrene, Total hydrocarbon (HCT), arsenic, chromium, volatile organic compounds, Isopropanol ...) with different concentrations and different impacts on environmental health. For instance, let precise that exposures to styrene have been associated with nausea, dizziness, inebriation, headache, loss of balance, coordination disorders, prolonged reaction time, prolonged nerve conduction velocity, peripheral neuropathy, and visual disturbances (especially color vision impairment). In epidemiological studies, a decrease in memory, motor speed and visual perception have also been demonstrated. So, depollution is quite delicate, as it is not limited to the elimination of the pollutant from the site but it is more extensive and includes several classically requested activities like:

- The evacuation or elimination of dangerous products and waste present on the site;
- The elimination of fire and explosion risks;
- Prohibitions or limitations on access to the site;
- The measures planned to control risks related to the soil and groundwater, as well as the monitoring of the effects of the facility on its environment;
- Demolition of all structures on the site, including resin and paint manufacturing buildings, warehouses and infrastructures.
- Consignment of residual connections (gas, water, electricity, etc.);
- Asbestos removal (roofs, joints, equipment, etc.);

¹ In France, a classified facility for environmental protection (ICPE) is a facility operated or owned by any natural or legal person, public or private, which may present dangers or nuisances for the convenience of local residents, health, safety, public hygiene, agriculture, the protection of nature and the environment, and the conservation of sites and monuments.

- The carrying out of additional environmental investigations in order to complete the characterization of the quality of the subsoil and the water table of the site.

In consequence, depollution project needs the presence of several skills, means and to perform various actions that must be provided by various business fields actors i.e. enterprises, forming then a subset of all stakeholders that are involved, concerned or impacted by this depollution project. These stakeholders must be able to interact and cooperate with each other in order to fulfill a global depollution objective they cannot reach and address individually and respecting several needs, constraints and values for all other stakeholders i.e. client, authorities, public, etc. Here are the main stakeholders involved in this use case:

- Companies that have carried out investigations following pollution accidents on the site
- Companies that present Analysis Laboratory which analyzes soil or groundwater samples to identify pollutant type and concentrations;
- Companies specializing in topography, which allow the measurement and representation on a plan or a map of the shapes and details of the site
- Companies providing services in piezometer levelling which ensure the measurement of the depth of the groundwater;
- Companies provide soil probing;
- Companies offering Soil Excavation;
- Companies dedicated to biological treatment on site by the ventilated «Biotertre» method;
- Companies that ensure safety and Environment prevention for the site monitoring;
- Companies that manage waste storage facilities;
- Companies aiding the project manager and specialized in the follow-up of asbestos removal/demolition works of industrial sites;
- Companies dedicated to technical studies, ...

In this use case the technique chosen to do the depollution is the «Biotertre» which consists in putting polluted soils in a heap for a biological treatment. To do this, the polluted soils are usually amended and the conditions in the «Biotertre» are controlled (aeration, nutrient additions ...). The process requires prior excavation then the polluted soils are mixed with an amendment (structuring agent) and are then directed to a treatment area containing at least a leachate collection system and aeration units (air extraction or insufflation) in order to optimize the oxygen transfer and the stimulation of biodegradation. Biodegradation is controlled (temperature, moisture content, nutrients, oxygen, pH).

DEPOLLUTION ISSUES

In the remainder of this section, it will be focus on specific depollution issues, giving examples of the use case presented above:

Complexity

The depollution project will be hereafter considered as a complex system [3] i.e. a set of many interacting entities whose integration achieves a common goal, which in our case is the depollution of the site. Indeed, a large number of entities (actors, means, companies) are to be considered all along depollution project. A large amount and diversity of requested interactions between these entities stand for one of the most critical hardships for depollution. The results are often emergent properties and even non-predictable behavior that occurs at the project level and cannot be simply observed and managed at the level of these entities[4]. For instance, in the middle of the depollution project of the use case, the decision makers encountered an unpredictable event inducing increasing in planned costs. The company in charge of the soil excavation went bankrupt and could not complete its mission[5]. This led to the entry of a new company that had to cooperate and interact differently with the other entities, which slowed down the depollution process. This highlights the evolutionary and non-predictable character of a depollution project and the difficulty for managers to first detect, and second deal with unexpected behaviors that stem from interactions between the entities and the project's environment as a whole.

Heterogeneity

As said before, depollution activities request to establish and manage a collaboration between several independent organizations and other stakeholders [6]. By definition, each of these organizations i.e. entity has its own structuring, rules, culture and strategy which is different, even sometimes in contradiction, from each other. This requested heterogeneity of companies makes appear a multiplicity of languages and practices. The problem is then the potential ambiguity, even difficulties, in the dialogue between stakeholders. In the same way, polysemic notions and concepts may be subject to different interpretations by these stakeholders. Some words may have several meanings depending on the area of activity or context in which they are used. This makes it more difficult to understand and track project elements over time. This probable semantic distortion must be considered during the dialogue with stakeholders. The conditions for requested interactions and communication exchanges between all these stakeholders must therefore be established and sustained. This is a real consultation strategy, the results of which reinforce the legitimacy of the actions carried out and their operational relevance [7].

Depollution boundary

When a depollution project is under design, its border is generally blurred in the sense that identifying the stakeholders, activities to be done, needs and so on is not trivial. The use case illustrates this issue with the example of spare parts. The technique chosen to do the depollution on this use case is the “«Biotertre»”. The processing time duration when applying this technique is between 18 and 24 months. In the meantime, it can happen to change some spare parts. The company that managed it bought these spare parts from a second supplier in China. However, the export of these parts did not take place because of the crisis of COVID 19 which impact processing times. In this case, if a second-level supplier is not identified in advance, reliability analyses of the depollution project fail to report the weakness. The problem is then to become able to identify all stakeholders which are impacted, implied, concerned all along depollution project from its design stage to its complete end[8].

Dynamic requirements

Requirements are defined as a need, a necessity, an expectation that a depollution project must meet or a constraint that it must satisfy. The requirement may be expressed by a stakeholder (user, customer, market analyst, manager, etc.) or determined by engineering processes and in particular by design activities. Successful depollution projects require understanding the needs of all stakeholders; comprehending the contexts in which the project will be conducted. Depollution project are undergoing continuing changes and rapid revolution during its conception and implementation. As consequence, requirements that were satisfied may no longer be satisfied or new requirements may be introduced. The environment of depollution project evolves and it can be different from the initial thought[2]. For example, in the use case, during the project a new legal expectation has imposed to change condition of access to the storage facilities of dangerous waste. This lead to impact the course of the processes of the depollution, and oblige the decision makers to adapt with the new legal requirements. The depollution project needs to evolve accordingly. Thus, a challenging aspect is to develop a methodology and tools to model, manage, and analyze the evolution of requirements.

Positioning of our work

There are several related works, means, and methods that are proposed in the depollution field. However, most focus on improving depollution techniques by arbitrating between technical solutions, economic constraints, and environmental objectives [9][10], [11]. These solutions deal with the depollution on a case-by-case basis. The major drawback is that there is no field of study that enables that address the multiple and main issues presented before in a systematic way. So, the research work and contribution intents to improve the engineering and management of such depollution projects by considering the depollution in its globality and its complexity, and then paying particular attention to various kinds of systemic concepts and principles.

A SYSTEMIC ORIENTED, MODEL BASED AND DATA-BASED METHOD

Indeed, this method aims to improve current depollution projects' engineering and management approaches to a depollution more reproducible, mastered, and efficient:

- Through the adoption of a systematic and holistic view and through a model-based approach (modeling all the depollution from several points of view or “dimensions”). This enhances the overall consideration of the parameters involved in a depollution project, particularly by facilitating both the understanding of the initial state and the traceability of the input data, a precise upstream specification of the final state targeted, and the description of all the stakeholders' needs, and all the processes and interfaces involved during the project through the different stages of its life cycle;
- By assisting the decision-makers and giving a wider view of strategic management of projects, through particularly the whole set of requirements applicable to depollution projects;
- By supplying modeling patterns to assist each project design and carrying out and guide the design and the creation of an information system which will be shared within the complex system– i.e. all the project stakeholders sharing and further ensuring the availability of all the data, information, and knowledge.

This method must in same time allow any person in charge of depollution projects and activities to:

- To head and request these stakeholders to converge and particularly to support them in preparing, managing, and performing activities related to reach depollution objectives (e.g. in terms of resources, means, etc.);
- Check the wholeness and the relevance of those activities in a global and holistic way;
- Improve the coordination and the articulation of the different activities of all stakeholders involved both in the design and implementation phases of a depollution projects;
- Establish, formalize, and optimize the planning of these activities in terms of costs, duration, and performance;
- Last, organize and complete the REX of the pointed-out depollution, to facilitate its reuse by other projects.

So, the proposed method is largely inspired by both systemic principles, Model Based System Engineering (MBSE [12]) and Model Based System of Systems Engineering approaches (MBSOSE [13]). MBSE and MBSOSE are ways of performing System Engineering [14] focusing on specific kind of systems typology, that promotes particularly modelling and models use. This is first opposed to traditional document-based engineering approaches. This allows second to gain in terms of delays and efficiency in engineering. This is attested by offering also, among other recognized qualities, the possibilities to improve collaboration and iterative work between depollution practitioners and other concerned actors. It allows too to ameliorate actors' confidence and performance levels by permitting the use of various techniques of verification, validation (e.g. model simulation [15]) and evaluation. Then any model could be then rapidly modified and adapted, obtaining more easily actors' consensus in case of error, omission or default.

To develop this method, two research methodologies have been crossed as synthetized in *Fig. 1*:

- A top-down approach, essentially bibliographical, from reference works on systems theory and MBSE principles to the field (how to make these principles understandable, useful and usable? So, how to formalize, validate and tool them?);
- A bottom-up approach which starts from the study of a panel of use cases allowing us to refine the needs, uses, habits and thus confirm or question the top-down approach (how is the depollution carried out on the field?).

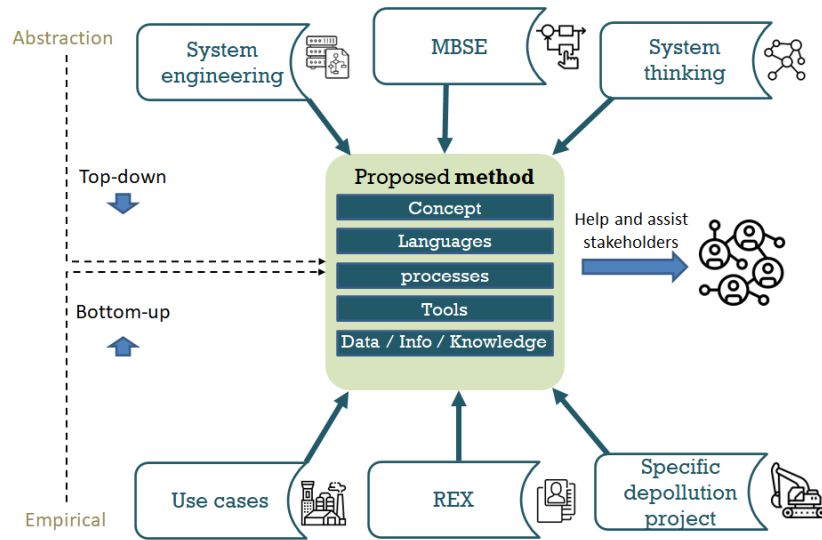


Fig. 1: Description of research methodology

The resulting method is then composed of 5 elements that are mandatory to be defined in any method:

- The **concepts** that are requested in order to establish a shared and common stakeholders' vocabulary or the means to ensure sufficient semantic interoperability between these stakeholders according to their domain, business, usages, etc. These concepts are then specialized for describing depollution operations, projects, rules and so on.
- The **languages** that are then necessary to allow these stakeholders, according to their uses and needs, to manipulate these concepts then to create models, to test hypotheses, to run model i.e. to simulate them, to evaluate then optimize some alternatives of project organization, etc.
- The **operational approach** that formalizes how the method must be deployed then used, i.e., how the stakeholders must proceed when considering depollution problematic.
- The **method's support tool** which allows the implementation of the operating approach, i.e. to carry out modelling and analysis (simulation, evaluation, search for blocking points, etc.) or to federate and make interoperable the own tools used by the stakeholders who often have preferred tools they wish to remain attached to.
- **The knowledge and expertise repository** are a data management system that gather all data, information and knowledge generated and used during the project, from internal sources (e.g. models, surveys, field analyses, stakeholders' interviews, best patterns, feedbacks and REX, best practices, recognized and proven causes of failure or success, etc.) or external sources (e.g. applicable norms or standards giving regulatory requirements, knowledge on the harmfulness of a pollutant, etc.). By evidence, this repository has to be shared by all stakeholders and then must be conform to both concepts, attributes and relations definition, languages and operational approach.

RESULTS AND DESCRIPTION OF THE METHOD ELEMENTS

This section presents the main contribution proposed to define the elements that compose the method. It intends to show benefits by developing the application on the use case presented above. This article will develop only the two first elements of the method concepts and languages.

Concepts

The first expected contribution must give a solution to the absence of standardized concepts of depollution. This makes it indeed difficult to represent particular aspects such as interoperability requirements and interactions. This allows the genericity of the elements of depollution projects: generic structuring elements. For this, formalization and theorization work are necessary to structure a coherent, exhaustive, and reproducible elements, and specific elements. In this method with an industrial vision. Three important concepts are presented in this article we will present just three concepts:

SoS: We consider that any depollution project requests the interventions of multiple and heterogenous companies, interacting continuously and being present at various moments of the project. So, depollution project is to be considered as a Depollution System that is a *System of Systems (SoS)*[16], *i.e. integration of a finite number of constituent systems which are independent and operational, and which are networked together for a period of time to achieve a certain higher goal* [17]. To argue and illustrate this hypothesis, it is important to specify that this depollution system satisfies the expected characteristics of an SoS: operational and managerial independence of companies involved, evolutionary development, the possibility of various emergent behaviors and characteristics that could change or affect the global expected behavior of the depollution system, and geographic distribution of its components inducing often logistic problems [18]. The concept of SoS will allow us to better understand the design and implementation phases of depollution, in particular by identifying the need to adopt agile validation approaches with the existence of various stakeholders.

Life cycle: The method highlights also two classic and generic time steps, called Design time and Run time. These two steps allow us to distinguish:

- 1) Activities aiming to design, check and optimize the depollution system achieving a sufficient maturity level of the depollution system specification;
- 2) Activities aiming to execute depollution system on site, *i.e.* running, adapting and managing depollution activities as specified and optimized in a first attempt. It is indeed indispensable to identify the depollution system evolutions (e.g. in terms of new requested operations, or at the level of new control and monitoring activities, even in terms of requested new stakeholders that could replace existing stakeholders for instance in case of disruption) as soon as the preliminary solution has been validated.

Fig. 2 schematizes the lifecycle of the use case presented above. It makes appear an ideal operational approach inducing both static and dynamic points of view and interactions with the whole set of depollution processes. It illustrates also several entities join and leave the scope of the system depending on phases:

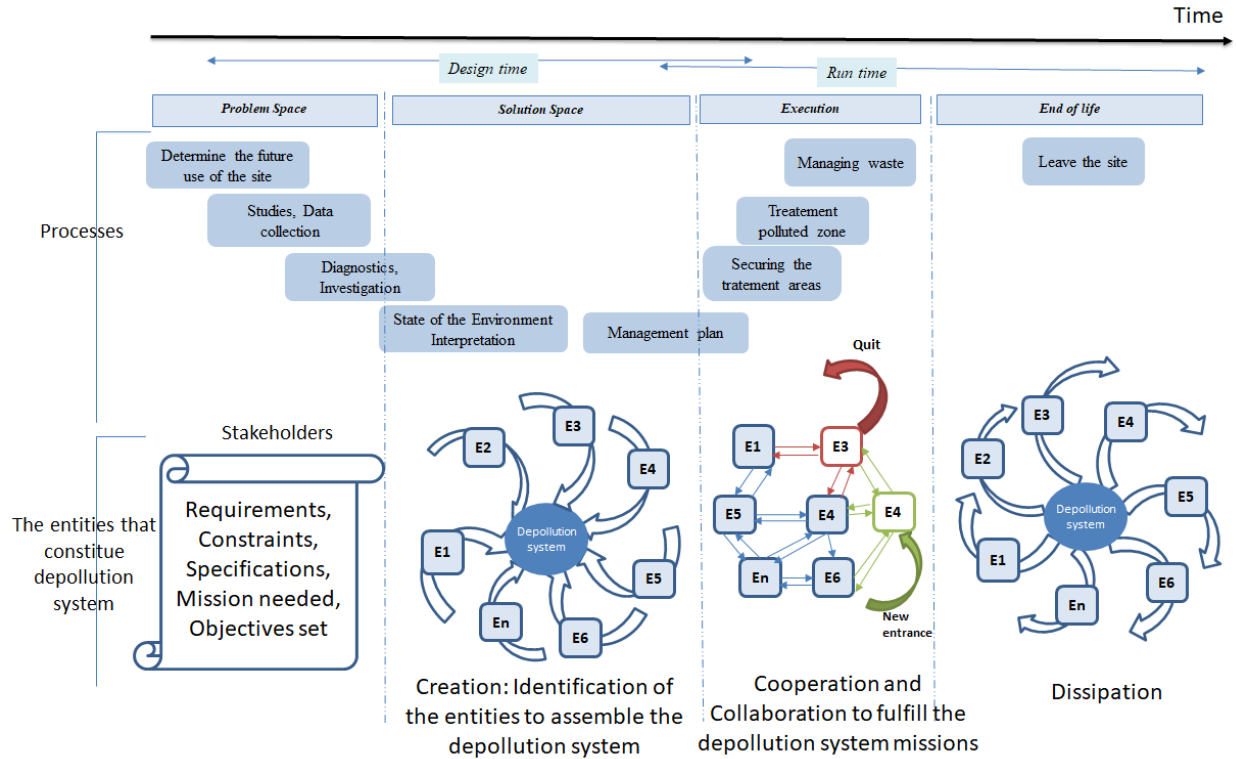


Fig. 2: Representation of processes and elements of depollution system during its lifecycle

In early design time, a complex system boils down to a set of thoughts, objectives, and values in which few if not only stakeholder is involved. These stakeholders can be the owner of the site or the government that aims at realizing rehabilitation projects in order to fulfill some specific objectives. The feasibility and viability of the idea are then analyzed using limited resources.

During design phases, entities having interests in the system progressively join the project such as sponsors, operators, project teams, etc. Other entities are also involved in the design as they represent the laws that should be respected and the norms that should be followed such as legislators, safety authorities, etc. End-users or consumer representatives can also be part of the design.

During the run time, entities such as end-users, suppliers, and subsystem operators including multiple teams from different possible stakeholders can be involved. Also, the arrangement of entities can widely vary as a new entity can be handed responsibilities, the scopes of the existing entities can be substantially modified, and some of these existing stakeholders can leave the scope of the system for reasons such as the non-fulfillment of their interests, their inability to perform some required tasks, or even the rise of concurrent stakeholders. The life cycle finishes with the dismantling phase, in which the components of the depollution system dissociate after achieving the global purpose. In this phase, a final version of REX is determined which may help in the development and deployment of future depollution systems.

Requirements

The proposed method gives the concept of requirements high importance. It must consider the need to identify all concerns i.e. expectations, constraints, and values expressed by the stakeholders involved in depollution system. These stakeholders remain of course actively or passively impacted by whatever is taken decision. It must also consider all the data specific to the facility to its environment which could also induce risks, misunderstanding, and impact on depollution system behavior and organization. Also, it is important to refine all these concerns into a requirements repository that gathers then all the requirements

applicable to the depollution system of interest. These requirements are of various types e.g. functional, organizational, technical, operational, logistical, regulatory, financial, or more classically focus on safety and security, human, ethical, or environmental aspects. To develop a well-organized requirements repository, requirements can be structured in a hierarchical manner. These packages can have their own internal structure that offers some relief from the complexity of the requirements. An example is illustrated in *Fig. 3*.

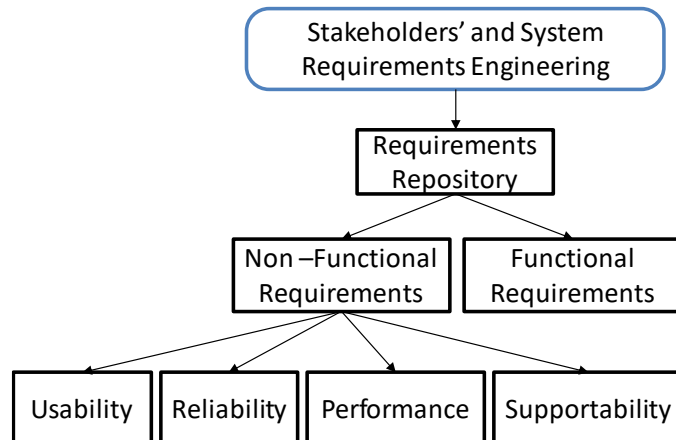


Fig. 3:An example of requirement classification

Languages

The large number of participants in the pollution control system implies a large volume of data. As mentioned above, their diversity and the heterogeneity of their sources prevent any manual operation to extract this knowledge. The need has arisen to propose new methodologies and efficient tools to achieve this. The visualization method must therefore make it possible to image the data, as well as the results of their analysis, while maintaining the important relationships between the information and illustrating the behaviors of the processes considered. In particular, following the principles of systemic and modelling, representing depollution projects as univocally as possible requires modelling the defined concepts of the depollution system. It is thus a question of formalizing a generic meta-model putting forward the crucial concepts, in terms of vocabulary and meaning, of their attributes and of the relations between concepts allowing to perceive and represent, to characterize and finally to model any depollution project in spite of the specificity of each one. It therefore allows abstraction, reasoning, as well as the structuring of data, information and knowledge related to complex depollution projects, by putting forward more general concepts from System Engineering and modeling (requirements, scenarios, organization, activity, task, phase, milestone, etc.).

It is then proposed to face the complexity of such system of system by developing a multi-views and viewpoints modelling approach, that it to say to define various languages aiming to model, to evaluate, to simulate, to check and validate the resulting behavior and organization of the depollution system thanks to the requirements repository.

[19] defines:

- A view as “*a representation of a whole system from the perspective of a related set of concerns*”.
- A viewpoint as “*a specification of the conventions for constructing and using a view. A pattern or template from which to develop individual views by establishing the purposes and audience for a view and the techniques for its creation and analysis*”. Each viewpoint highlights certain details of

the pointing depollution system, neglecting other details that are defined in other viewpoints. A viewpoint is hereafter considered as a type of model or even equivalent to the definition of Domain Specific Modeling Languages (DSMLs) [20] to express one or more models in each view. In other words, a DSML simplifies the modeling of complex systems by providing domain-specific abstractions and expressive notations that focus on a particular problem domain in a precise and concise manner.

Then, as commonly defined, a model M of a system S, for instance a depollution system, refers to the data obtained after using a given and appropriate DSML for the purpose of a given view. It is then defined as “*a perception of (maybe imaginary) reality*” considering the filter and details appropriate to this view. Indeed, by hypotheses, M reproduces how the depollution system functions, or have to be structured, or behaves and evolves, or interacts with its environment, etc. So, M formalizes and trace all data, information and knowledge related to S considered observed and specified in a given view. So, many models are requested to represent more precisely and realism the depollution system. As an evidence, by using views and DSML, the proposed method promotes the creation and employment of models from various natures, respecting principles and reaching the numerous advantages of models use as described in the previous sections. Particularly, modeling and then models provides an unambiguous and precise way of description and representation of the depollution system that can be evaluated for consistency, correctness, and completeness. In addition, they enhance knowledge capture and the reuse of the information by capturing information in more standardized ways and leveraging built in abstraction mechanisms inherent in models driven approaches. Last, they offer a way to improve communication and exchanges between multidisciplinary stakeholders (e.g. the future user of the site, the owner, hardware and software developers, legislators, and specialty engineering disciplines). Last [21] defines a system model as “*an interconnected set of model elements which represent key system aspects including its structure, behavior, parametric, and requirements*”. In the purpose of promoting such depollution system model, seven views and various DSML are proposed to satisfy the needs of the stakeholders on the one hand, and to manage the depollution projects on the other.

Considering a logical sequence of construction of this depollution system model, these views are:

- **Context view:** to model the environment of the depollution system in a given situation. It answers the question: "What are the actors and elements that interact with the depollution system?".
- **Concerns view:** to model and verify the set of requirements of the different stakeholders for the depollution system.
- **Life cycle view:** to model the description of the evolution of a depollution system over time.
- **Functional view:** to model the activities, processes, resources and capabilities required;
- **Physical view:** to model the means, tools and techniques, and their interactions during the depollution operation;
- **Data view:** to model the different data/information/knowledge that can flow and be exchanged in the depollution system;
- **Risk management view:** to model the different events and hazards to occur and to evaluate their impact on the project, on the resources involved, etc.;

As an example, *Fig. 4* shows an extract of the meta model that defines the proposed DSML for functional view. This DSML is explained in the next by highlighting the concepts used in **Bolt** font. Indeed, to properly describe the functionalities of a depollution system, it is crucial to define its **Processes, Functions, and Activities**, which are classified in a single meta class named **Processor**. This Processor transforms inputs that are presented by **Flows** to produce outputs that fulfill the **Objectives** of **Stakeholder**. These transformations require **Resources** with specific **Capabilities**.

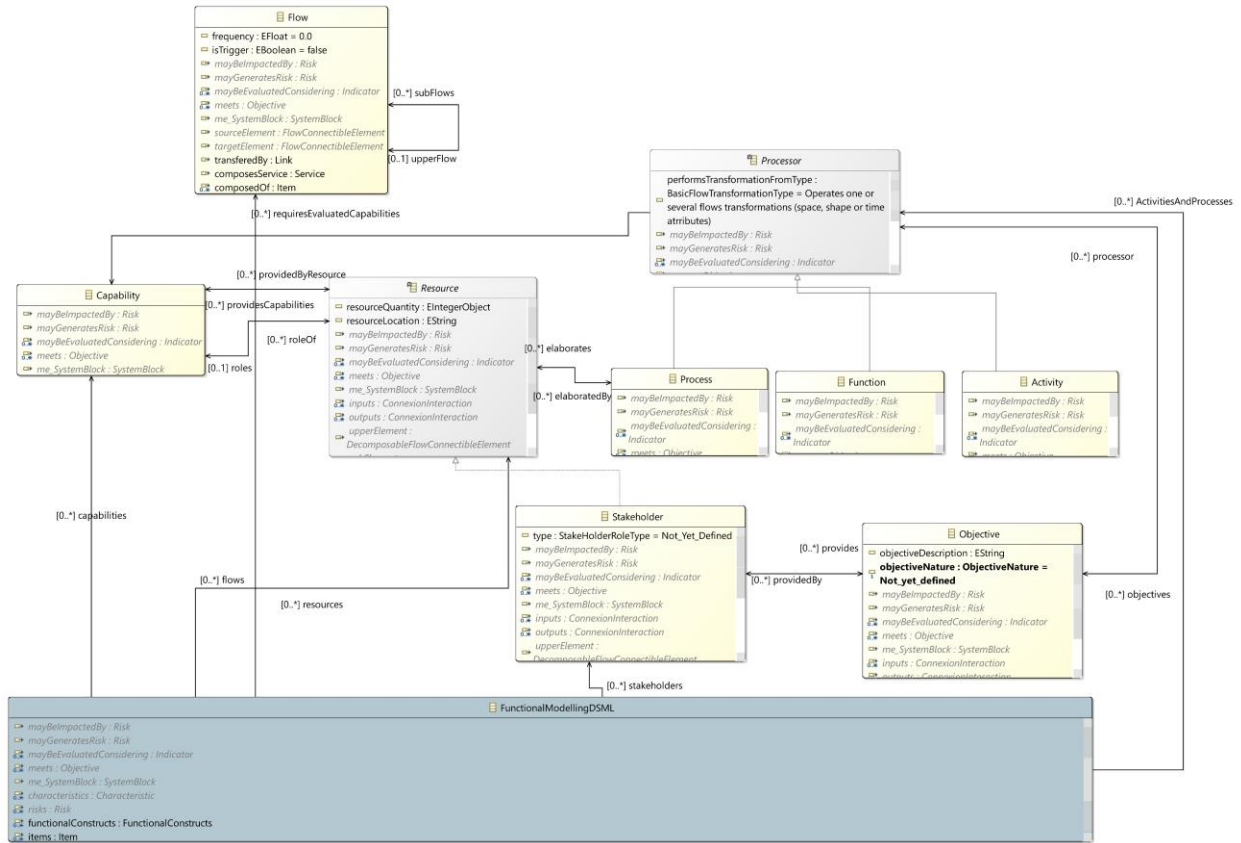


Fig. 4: Functional Modeling DSML

Modelling: Models must be created by manipulating concepts seen before and their relationships i.e. in accordance with proposed DSML [15].

For instance, the functional view requests to build one or more functional models of the depollution system. Each model is established allowing the discussion of the functions and the activities that are run by the different subsystems and actors. Conform to the functional DSML shown in Fig. 4, a model is elaborated to illustrate the functions of the use case using the BPMN (Business Process Modeling Notation [22]) language which provides a process description language with a visual notation that is easy to understand, at least at a basic level, by all stakeholders including domain experts. Fig. 5 describes the treatment of certain sources which is done first by excavation and then by biological treatment on site in order to obtain a diminution of the concentrations. This on-site treatment can be completed, if necessary, by additional off-site treatment at the end of the work for materials whose chemical quality is incompatible with the backfill. The excavations will then be backfilled with treated materials from the site with concentrations in compliance with the quality objectives set out in this management plan. Fig. 5 represents the sequence of events by representing them with pools that represent the entities and participants in a process. These pools contain activities that represent the decomposition of the process. The sequence between these elements is represented by the sequence flows. These flows can be converged or split by gates. Also, there are message flows to materialize the exchanges. This BPMN model allows functional managers to define their objectives, in a simple way, but with a high degree of precision. It optimizes communication with decision-makers on nature and performance of a process. It allows the identification of improvements and their implementation, all in a collaborative manner.

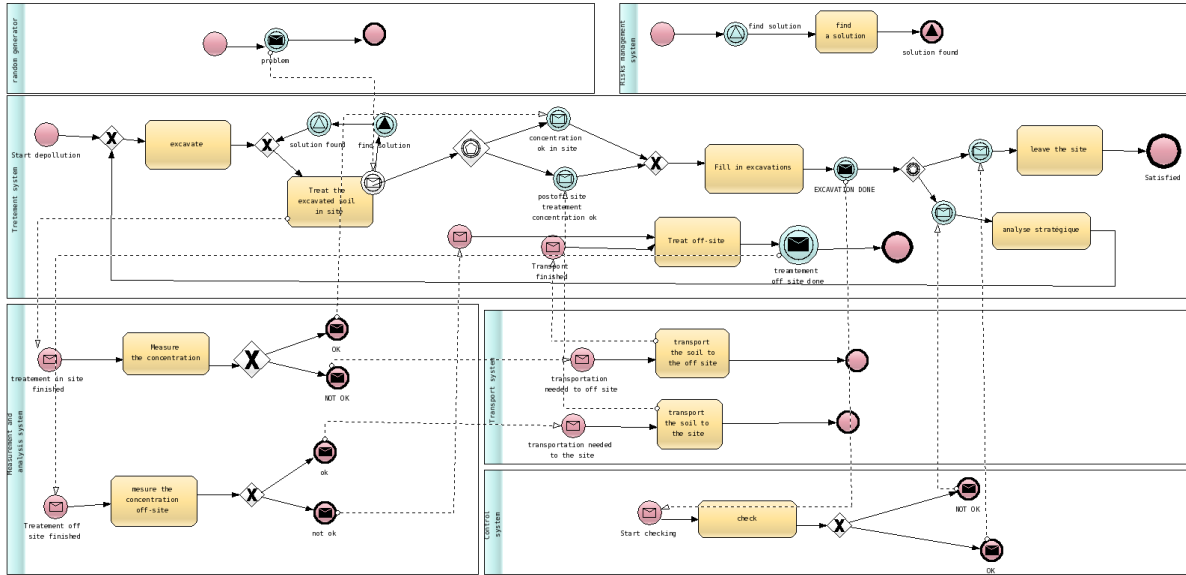


Fig. 5: BPMN describing a depollution process of a specific use case

Thanks to this BPMN modeling a simulation of scenarios is possible using appropriate information technology (IT) tools. These Scenarios can assist in all phases of the depollution life cycle. The scenario-based approach goes in good agreement with the aim of conceiving possible futures and exploring the pathways that lead to each stakeholder in order to clarify the proposed requirements. In the form of scenarios, there is the ability to describe the evolution of the depollution system, and to identify, from a present situation as well as the prevailing trends, a series of events leading in a logical (necessary) way to a possible future. For example, we can simulate the impact of unexpected events on the depollution system. Three types of scenarios are thus retained, which will provide results on the cost and delay of the treatment activity. The scenarios vary in the number and frequency of the incidents during the treatment operation. Thus, for each scenario, X incidents are integrated, and these incidents are separated by Y days each;

- **"Standard" scenario** represents the nominal functioning of a treatment operation. In this scenario, the number of incidents is fixed at 5, they are spaced of 10 days.
- **"Degraded" scenario**, simulate an operation in a situation of moderate degradation of the operation. x takes the value of 20, and y takes the value of 10.
- **"Highly degraded" scenario**, simulate an operation in situation of severe degradation. x takes the value of 40, and y takes the value of 15.

These scenarios have allowed the description and the formalization of the behavior of the depollution system when passing through certain situations. Through the simulation of these three scenarios, the tool makes it possible to highlight possible additional costs or delays. Tests on an application case have allowed us to measure an additional cost of 5.6% for a degraded scenario, and 15.24% for a very degraded scenario, as well as an increase in delays of 12.5% and 30.9% respectively.

By applying these techniques, here of simulation, to the models of the depollution system, it was possible to validate the future system of depollution by working only on models which are not very expensive, easier to handle. Thus, we perceive here that a method based on models takes all its importance and is really innovative in this field of the depollution.

CONCLUSION

This paper presents a depollution method based on an MBSE approach coupled with systemic thinking applied on a use case feedback. This method not only facilitates the design and conduct of the depollution but also aims to anticipate potential problems that might be encountered during depollution projects. The modeling orientation of the proposed method adopts a multi-view modeling approach that promotes a system of systems engineering and helps to simplify complex depollution projects. This method provides interesting benefits when deployed in the presented use case. Overall, this paper discusses the use and promotion of a model-based method to prepare (model, verify, improve, evaluate and validate) and conduct (control, evaluate, modify and adapt, manage changes) depollution management.

Based on the identified concepts of depollution and the set of modeling languages presented in this article, as a perspective, an operational approach to implement the method is currently under development. Thus, tools to support the method will be proposed, and at the end a Repository Knowledge will be established and enriched throughout future work. The proposed method must be enriched and validated on more complex projects and be deployed on the scale of depollution companies. To do this, it is first essential to describe the method's operating procedure in order to optimize its use. Next, it is essential to identify the most suitable IT tools in terms of functionality and interoperability within the network of companies involved in depollution projects. Then, the work of the decision-makers must be supported to improve the use of resources and to reinforce the confidence of all the stakeholders.

REFERENCES

- [1] R. Gilbert, "27 An overview of statistical issues related to environmental cleanup," *Elsevier*, Accessed: Oct. 14, 2022. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S016971610580029X>
- [2] L. Michele, "Case studies and lessons learned from decontamination, demolition, and managing the produced wastes," *Elsevier*, Accessed: Oct. 15, 2022. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/B9780128183281000095>
- [3] J. Ladyman, J. Lambert, and K. Wiesner, "What is a complex system?," *Eur J Philos Sci*, vol. 3, no. 1, pp. 33–67, 2013, doi: 10.1007/S13194-012-0056-8.
- [4] E. Raber, A. Jin, K. Noonan, R. McGuire, and R. D. Kirvel, "Decontamination issues for chemical and biological warfare agents: How clean is clean enough?," *Int J Environ Health Res*, vol. 11, no. 2, pp. 128–148, 2001, doi: 10.1080/09603120020047519.
- [5] N. Ulibarri, Cameron, L. Tracy, and R. J. Mccarty, "Cleanup and Complexity: Nuclear and Industrial Contamination at The Santa Susana Field Laboratory, California," *Environ Manage*, vol. 65, pp. 257–271, 2020, doi: 10.1007/s00267-019-01239-7.
- [6] A. Gaignebet, V. Chapurlat, G. Zacharewicz, V. Richet, R. Plana, and G. Zacharewicz, "A contribution to Commissioning as enabler of nuclear infrastructure delivery: Tests and trials program elaboration and management," *ieeexplore.ieee.org*, 2020, doi: 10.1109/ISSE49799.2020.9272027i.
- [7] O. Adjir, V. Kouamé, C. K. Niangoran, G. Soro, and J. Biémi, "Toxic waste spills in Côte d'Ivoire : Follow-up of the effectiveness of the cleanup operation according to residual pollution indicators," *Environnement, Risques et Sante*, vol. 17, no. 2, pp. 147–154, Mar. 2018, doi: 10.1684/ers.2018.1145.
- [8] B. John, "What to do when stakeholders matter: stakeholder identification and analysis techniques," *Taylor & Francis*, vol. 6, no. 1, pp. 21–53, Mar. 2004, doi: 10.1080/14719030410001675722.
- [9] S. Long, M. Cook, "Rehabilitation of the former nuclear test site at Maralinga," *iopscience.iop.org*, Accessed: Nov. 14, 2022. [Online]. Available: <https://iopscience.iop.org/article/10.1088/1361-6498/abf15b/meta>
- [10] K. Wee, "Decommissioning and rehabilitation: funding models," *The APPEA Journal*, vol. 61, no. 2, pp. 526–529, Jun. 2021, doi: 10.1071/AJ20180.
- [11] S. Dubchak and O. Bondar, "Bioremediation and phytoremediation: Best approach for rehabilitation of soils for future use," *Remediation Measures for Radioactively Contaminated Areas*, pp. 201–221, Jun. 2018, doi: 10.1007/978-3-319-73398-2_9.
- [12] K. Henderson and A. Salado, "Value and benefits of model-based systems engineering (MBSE): Evidence from the literature," *Systems Engineering*, vol. 24, no. 1, pp. 51–66, Jan. 2021, doi: 10.1002/SYS.21566.
- [13] Y. Baek, Z. Mihret, "A Modeling Method for Model-based Analysis and Design of a System-of-Systems," *ieeexplore.ieee.org*, doi: 10.1109/APSEC51365.2020.00036.

- [14] L. Hallo, B. Payne, and A. Gorod, “Model-based approach to system of systems engineering: Reevaluating the role of simulation,” *2019 14th Annual Conference System of Systems Engineering, SoSE 2019*, no. July, pp. 266–271, 2019, doi: 10.1109/SYSOSE.2019.8753868.
- [15] B. Nastov, F. Pfister, V. Chapurlat, C. Dony, and F. Pfister, “Model Verification & Validation and Model Based Systems Engineering,” 2014, doi: 10.13140/2.1.3557.9684.
- [16] D. Kozma and P. Varga, “applied sciences System of Systems Lifecycle Management; A New Concept Based on Process Engineering Methodologies,” 2021.
- [17] S. Cook, “Evaluating a framework for visualizing system of systems engineering research coverage,” *ieeexplore.ieee.org*, Accessed: Nov. 15, 2022. [Online]. Available: <https://ieeexplore.ieee.org/abstract/document/6892455/>
- [18] M. W. Maier, “Architecting Principles for,” 1999.
- [19] IEEE-SA Standards Board, “IEEE Recommended Practice for Architectural Description of Software-Intensive Systems,” *IEEE Std*, vol. 1471–2000, no. November, pp. 1–23, 2000, [Online]. Available: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.102.9904>
- [20] B. Combemale, J. Deantoni, B. Baudry, R. B. France, J.-M. Jézéquel, and J. Gray, “Globalizing modeling languages,” *ieeexplore.ieee.org*, 2014, Accessed: Nov. 15, 2022. [Online]. Available: <https://ieeexplore.ieee.org/abstract/document/6839148/>
- [21] “[ISO/IEC CD 24641:2020(E), Systems and software engineering, Methods and tools for Model-based systems and software engineering]
- [22] F. Corradini, “A Guidelines framework for understandable BPMN models,” *Data Knowl Eng*, vol. 113, pp. 129–154, 2018, doi: 10.1016/j.datak.2017.11.003.