An approach based upon Model-Based System Engineering and Value Analysis for Sustainable Systems

Alexis Lalevée[1], Vincent Hilaire[2]
[1] Université de Technologie de Troyes, UR InSyTE, Troyes, France
[2] CIAD UR 7533, Univ. Bourgogne Franche-Comté, UTBM, 90010 Belfort, France
Vincent.hilaire@utbm.fr

Abstract - Nowadays, one of the key challenges is to design and maintain sustainable systems. This challenge is even more difficult for system of systems or complex systems. A possible contribution is to provide approaches that allow to take into account requirements in the earlier phases of the projects and the interests and benefits of stakeholders. These requirements should take into consideration the notion of "safe and just space" that define planetary boundaries and social foundations. The approach proposed in this paper is based upon Value Analysis methodology and more specifically Stakeholder Value Networks (SVN) that are represented through a SysML profile which defines an extension of the SysML standard. This extension is an added value for the early requirements phases of system engineering.

Keywords: Sustainable systems, model-based system engineering, value analysis, SVN, SysML.

I. INTRODUCTION

Nowadays, one of the key challenges is to design and maintain livable, sustainable systems. Indeed, the stability of the planet's environment known as Holocene is now under threat. In [Rockström et al, 2009], the authors propose a framework for defining preconditions of human development: planetary boundaries. Raworth in [Raworth, 2013] define a visual framework – shaped like a doughnut – which brings planetary boundaries together with social boundaries, creating a safe and just space between the two, in which humanity can thrive.

This "safe and just space" is a tough challenge for humanity to attain and maintain. Indeed, the possibly numerous components of this framework are contradictory, thus imposing considerable challenges.

There are very few approaches nowadays that try to fill the gap in order to address these challenges. It is more the case for complex systems. Complex systems, frequently denoted as system of systems, frequently involve a great number of parts composed of several technologies co-existing in order to deliver services. The technical point of view on these systems has been studied through different approaches. However, technical success alone cannot ensure sustainability [Cameron et al, 2008]. Indeed, the stakeholders, and their respective interests and benefits, are frequently ignored during the design of these systems. The system stakeholders may be numerous with different goals to be taken into account and the overall system has to fulfill different requirements that may be contradictory. We will call this key element of the design of the system-to-be as early requirements.

It is admitted for any design approach that early requirements have a critical importance for the rest of the process. If some requirements are not elicited or ill-defined the risk is great that the resulting system does not satisfy the stakeholders.

In a previous work [Lalevée et al, 2021a], the authors propose the use of a Value Analysis methodology to perform the analysis of the needs of stakeholders in an SA approach.

The approach proposed in this paper is based upon Value Analysis methodology and more specifically Stakeholder Value Networks (SVN) that are represented through a SysML profile which defines an extension of the SysML standard. This extension is an added value for the early requirements phases of system engineering. Moreover, the integration within SysML allows to benefit from an industrial standard in System Engineering. SysML was chosen for it extension capabilities and the fact that it allows Model Based System Engineering (MBSE). The latter type of SE proposes the use of models and models elements as principal engineering artifacts. All viewpoints and models are thus part of an integrated process that allows traceability, separation of concerns and productivity of models by their many possible manipulations by the corresponding software tools.

This paper is organized as follows: section II details necessary background, section III presents the contribution, section IV presents related works and section V concludes.

II. Background

A. Sustainability

The Sustainability is a key element today. Before explaining why it is important, this concept have to be defined. Indeed, the most popular frame of the concept is Brundtland report that said ". Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [Brundtland, 1987]. Moreover, it is mainly represented as the "three pillars" as described by [Purvis et al, 2019]. However, is has to be noticed that the Sustainability can be split into two approaches: the first one admits that capitals are able to be replaced by others: it is a weak Sustainability approach. One the contrary, a strong Sustainability approach does not permit to replace a capital by another [Pelenc et al, 2015]. To illustrate this, within a weak sustainability paradigm, we can say that money can replace biodiversity loss or the life of a Human. At the contrary, strong Sustainability says that biodiversity cannot be replaced by anything, and a Human life also.
Sustainability is a key element and it seems that the Stakeholders could be a lever to introduce the Sustainability dimensions [Sánchez, 2015]. To make it possible to make decisions, the sustainable design have to be supported by methodologies and tools. While many exist (as Life Cycle Assessment (LCA), the most known [Millet *et al.*, 2004], it is complicated to design with clear targets.

In this article, we have chosen the Doughnut to frame the Sustainability. In fact, we hypothesized that the indicators used to frame planetary boundaries and social foundations were able to serve to constrain the choices made during the design and design monitoring of complex systems.

B. The Doughnut as a support

Living in a "safe and just space" is the goal of the creation of the Doughnut. Indeed, [Raworh, 2012] and [Raworth, 2017] proposed some criterions to frame the planetary boundaries in regard to social foundations in that permit to live well. Some researches tried to explore and apply the Doughnut: [O'Neill *et al.*, 2018] proposed to downscale the criterions and proposed some indicators, based on Raworth, to determine the "Doughnut" for more of a hundred countries. Thus, the proposed paper aims at propose a frame based on the Doughnut to design sustainable systems.

C. Value Analysis and the SVN: a Stakeholder-based approach

Value is a polysemous concept [Ben Ahmed et al, 2003]. We will take here the axis developed following Miles in 1947. Initially described as a ratio between the response to needs and costs [EC, 1995] and [Fernandes, 2015], value must reinvent itself by integrating sustainability. Initially described as a ration of [Fernandes, 2015] shows that the Value Analysis could be used within many conditions to be adapted to a context as the social one [Fernandes, 2012] The article proposed by [Lalevée et al., 2020] goes in this direction since it shows methodology able to integrate Sustainability issues. Not only VA is able to integrate Sustainability issues, but also it could improve Stakeholders integration in a project design, as described by [Lalevée et al., 2021a]. The measurement of the Value is a challenge today: each Stakeholder of a complex project has its own view of the project. It is why we tried to know what are existing methodologies that allow to link value, design and management of a project.
We have made the hypothesis that the Stakeholder Value Network, proposed by [Cameron, 2007; Cameron et al., 2008] could help us to determine the value perceived by each Stakeholder, concerning a project. This concept were used by [Feng et al, 2008] to determine the most important Stakeholders of the project. [Pereira et al, 2018] applied it to determine key Stakeholders in a project also. The hypothesis we made is that could help us not only to determine the link between the Stakeholders of a project (based on the exchange of resources) but also the expected value of each of them and in fact, the influence of each of them.

D. Model Based System Engineering

For this paper we have adopted the SysML notation [SYSML, 12]. This choice was motivated by the fact that SysML is a general purpose graphical systems modeling language that supports System Engineering (SE) approaches (analysis, specification, validation, verification, trade-off analysis, supported by many tools, …) with the following modelling capabilities taken into account: differents aspects/points of view of the system, different levels of abstraction, fitted for systems of systems. This language is one of the main used standard for SE and more specifically Model Based System Engineering (MBSE). The latter type of SE proposes the use of models and models elements as principal engineering artifacts. All viewpoints and models are thus part of an integrated process that allows traceability, separation of concerns and productivity of models by their many possible manipulations by the corresponding software tools. Moreover, SysML allows the extension of existing concepts and creation of new diagrams known as Domain Modeling Specific Language (DMSL). As such, SysML is mainly a notation and an extensible infrastructure.

SysML is built using another well-known modeling language: UML [UML, 12] which is another OMG standard. The principle used to define SysML with UML is called profile and allow to add custom model elements to UML to suit system modeling needs. A profile is thus a generic, in the sense that it can be used for any usage, extension mechanism for customizing UML concepts and diagrams. Indeed, it is widely acknowledged that there is no one-size-fit-all modeling language that can satisfy every possible need and usage. “safe and just space”

Profiles are defined using stereotypes, tag definitions, and constraints which are applied to specific model elements, such as classes, attributes, operations, and activities. A profile is a collection of such extensions grouped according to a specific logic. SysML specific (respectively to UML) concepts are defined by using UML's profile mechanism.

More precisely, any UML profile is developed by extending the UML metamodel [UML, 12] and introducing domain specific concepts into it, under the form of stereotypes. A stereotype represents an extension to the UML metaclasses and may be parametrized with properties known as tagged values.

As the UML metamodel contains all model elements that can be used in UML diagrams and the different diagrams themselves it is then possible to define specific language, frequently called Domain Modeling Specific Language (DMSL). Examples of such DMSL are: DoDAF [Giachetti, 2015], Marte [Graf et al, 2005].

III. Model-Based Approach

A. *Case study*

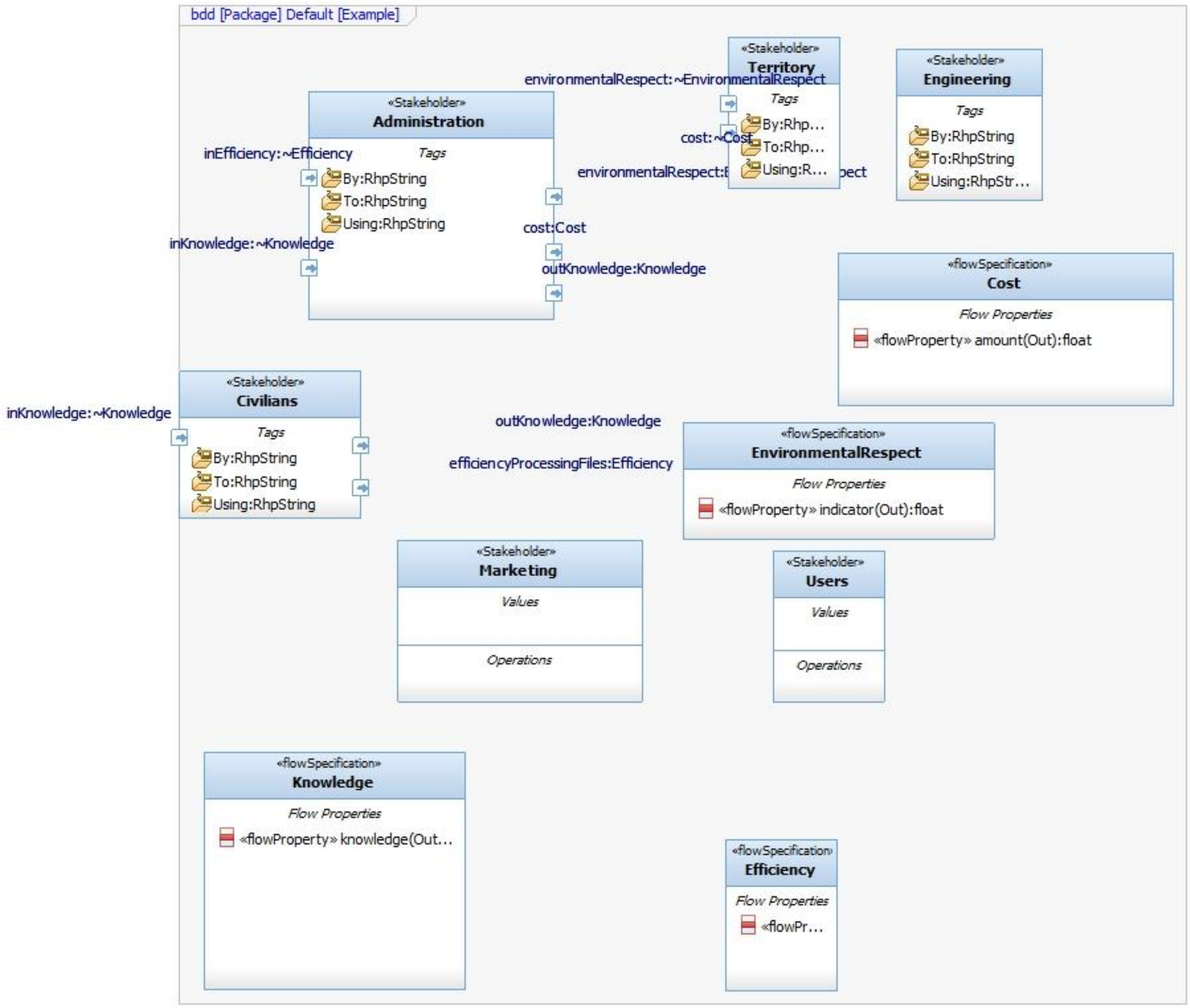

Figure 1 Example of definition of stakeholders

In order to illustrate the approach presented in this paper we have chosen to reuse the work presented in [Lalevée et al, 2021b]. The system-to-be concerns the design of transportation solutions between two cities A and B far from about twenty kilometers each other. The project's aim is to find some technical solutions to link up A to B globally more efficiently. Existing small roads between A and B are overloaded and a highway exists near to B from North to South without any exit to lay out B. Furthermore, some residential subdivisions were built on the outskirts of both cities; a river is situated at few hundred meters of A and B South's limits, and there is a mountain to the North. These topological constraints do not let us think about an "easy" solution. The consulting company is asked by the government to determine what technical solutions could answer this problem and how to compare them.

B. *The SVN Profile*

The SVNProfile for SysML defined in this paper is based upon the Block Definition Diagram (BDD) and the Internal Block Diagram (IBD) that are part of the SysML standard. The choice of the BDD and IBD allows wide modelling capabilities and is particularly fitted for the SVN concepts representation.

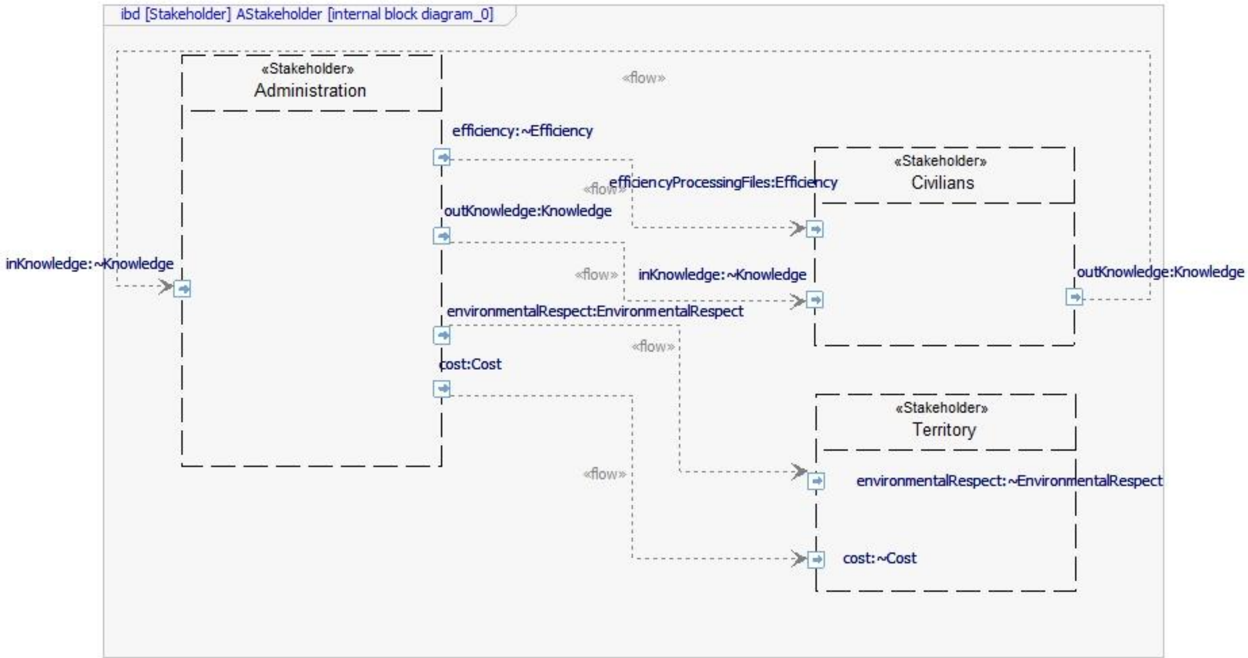

Figure 2 Example of connection of stakeholders

The table I resume the SVN concepts, their corresponding stereotype within the SVNProfile and the base stereotype that is extended by the SVNProfile.
The BDD allows the definition of stakeholders, their characteristics and potential relationship between stakeholders such as composition or sub-typing.
The first model element is the stakeholder. The stakeholder stereotype is based upon the Block metaclass. In order to describe a stakeholder five attributes are proposed. These attributes are tagged values that are added as a definition of the Stakeholder stereotype. These attributes are listed below:

- **To**: specifies the goal or objective of the stakeholder
- **By**: specifies by what means the goal (described in **To**) is satisfied
- **Using**: the inputs that are necessary for the means identified in **By**
- **Inputs**: which inputs are required by the stakeholder
- **Outputs**: what are the outputs of the value creating organization

Each input and output are specified by a FlowSpecification. This concept defines all the elements (names and types) that compose the flow.
For example, as illustrated in the figure 1, Civilians is one of the defined stakeholder. This stakeholder is characterized by two inputs and one output. The inputs are: inKnowledge, representing the knowledge received and efficiencyProcessingFiles that represents the need for efficiency concerning any file processing. The ouput is outKnowledge that represents the knowledge shared by Civilians. The cited inputs and output are defined by several FlowSpecification, respectively: Knowledge, Efficiency and Knowledge.

Once defined, the stakeholders may be linked through value chains that relate outputs to inputs. These connections are made through an Internal Block Diagram. On this diagram the stakeholders definitions of corresponding BDD are used to create specific SVN. In order to connect flow ports another model element is created : the value flow from A to B that defines a connection between an output of a stakeholder A and an input of a stakeholder B. It is obviously an oriented

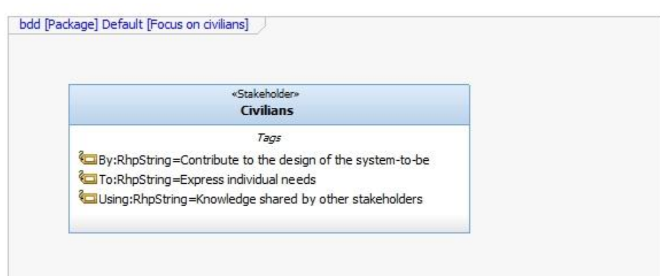

Figure 3 Focus on the civilian stakeholder

relationship from A to B. Such a relationship may be further defined through a flow specification which is the third stereotype of the SVNProfile.

TABLE I

concept	stereotype	Base stereotype
stakeholder	Stakeholder	Block
value flow	flow	connection
Input	Input	FlowPort
Output	Output	FlowPort
Value flow type	Flow specification	Flow specification

As illustrated in the figure 2, some stakeholders are positioned and connected through flows. These connections define the graph underlying the SVN. Each IBD thus represents a possible SVN based upon the stakeholders defined within BDD.

C. *Profile usage*

A first possibility offered by the presented profile is, obviously, the possibility to create graphical diagrams that model SVN. Each of these diagrams is composed of model elements as defined in the previous subsection. All these model elements constitute the backbone of Model-Based System Engineering approaches and can be used through specific softwares.
One of the principles of SysML and MBSE approaches is to allow to define relationship between model elements whatever their type and diagrams that handle them. These relationships can specify a refinement, a derivation, a realization, a dependance, a traceability or any semantics the system designer intends to express. An example of such relationships is given in figure 4.

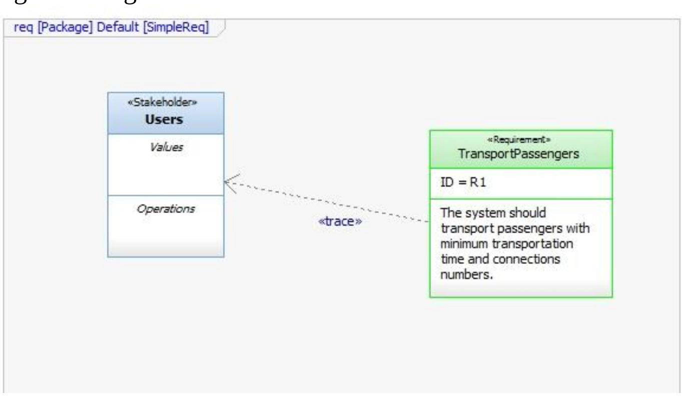

Figure 4 Example of traceability relationship

In the previous example, a Requirement model element is defined. This requirement, named TransportPassengers, specifies the principal purpose of the system-to-be that is transport passengers while minimizing transportation time and number of connections. This requirement obviously depends upon the future users of the different transportation modes. These users were already identified as stakeholders (see figure 1).
Starting from requirements, other model elements, either structural or behavioral, can be linked step by step to define a sequence of elements related in the first place to stakeholders. The future parts of the system-to-be for example or the system as a whole may be in such configuration as described in figure 5.

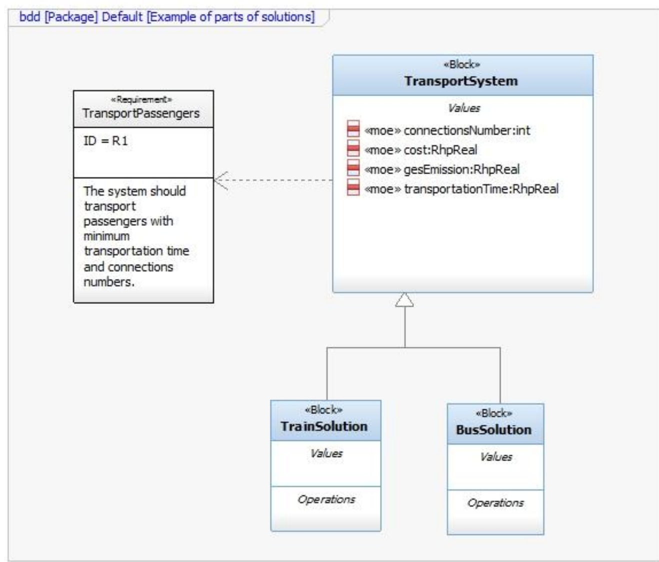

Figure 5 Example of solutions representation

Another possibility offered by the representation of model elements is their manipulations and transformations according to the needs at hand. For example, report can be generated and formatted automatically following some given template. Simulations can also be produced from executable parts of the models. Eventually, parametric design such as sensitivity or trade-off analysis can be realized. Several approaches based upon MBSE and SysML use parameterized models to evaluate by quantitative means the defined models. These approaches are discussed in the next section. For the SVN specific needs, transformations techniques from model elements are a possible mean to compute the different algorithms related to the SVN.

The computation is based upon graph theory and determine pathways of interest for the system-to-be. For example, the value chains induced by the flows between stakeholders can be studied. Value chains are collections of value flows. A value chain that returns to the starting stakeholder is called a value loop. Value loops constitute feedback loops and are a first important result of SVN manipulations. The identification of needs that are not well satisfied is a second result that may also be done automatically.

Some validation and verification techniques can be applied to the produced models (and model elements) automatically. Using the SVN profile defined the designer can verify if all inputs and outputs are connected. If the modeler discovers inputs that have no corresponding outputs or outputs that are not connected to an input there may be a forgotten situation or some inputs/outputs need to be deleted as they are not useful. This verification can be done through the IBD. Using the BDD one can verify the coherence of inputs with using attributes of the stakeholder and outputs with to attributes.

IV. Related works

The use of SysML to support sustainability is not new. There are several existing works with different approaches and perspectives.

In [Bougaina, 2017] the authors propose a methodology in order to specify environmental impacts of mechatronics systems and evaluate these impacts in order to guide the design. This kind of approach can be useful during the design phase. Our contribution lies in earlier phase of analysis and can be combined with the one described in [Bougaina, 2017].

SysML has also been used for specific domains such as construction industry [Matar et al, 2017]. In this paper the authors define a model of environmental impacts of construction projects and study the different flows between the identified sub-systems. This approach is interesting but specific for construction projects and do not tackle the earlier phases of analysis.

In [Lamjahdi et al, 2020] the authors integrated the value chain principles and propose models based upon block definition diagrams that represent the main activities of a firm. These models are then refined in terms of flows and interactions. However, the hypothesis of the authors is that the firm already exist or that it architecture is already defined which is not our case.

The approach proposed in [Eigner et al, 2014] takes inspiration from the V lifecycle and focus on product modeling with the help of parametric models allows simulation and evaluation of GHG emissions. The approach we propose is not dependant on a specific lifecyle and address analysis before the product requirements.

V. Conclusion and Perspectives

This paper presents an approach based upon Model Based Systems Engineering and Value Analysis in order to support sustainability. More specifically, the SysML standard is used for MBSE and SVN as a value analysis component.

The contribution lies in the extension of the SysML modeling language with a profile that allows the definition new diagrams dedicated to SVN modeling. This profile is composed of model elements necessary for the definition of a SVN that may constitute the earlier part of the analysis process of a system.

Once defined a SVN is part of the models produced and can be linked to any other pertinent model elements such as requirements, blocks (logical or physical components of the system), behaviours, … The SVN can also be used through different services and softwares to be analysed, refined, simulated, …

The definition of these new diagrams and related concepts allows to take into account the SVN concepts within a MBSE approach and analyze and design systems with value analysis elements and more specifically stakeholders and their relationships. Sustainability is integrated within the System analysis and design in the earlier phases and can be refined all along the chosen process downto the chosen solutions.

Future works will enrich the expressiveness of the presented profile and define some tools to analyze and exploit the SVN. We also plan to integrate Artificial Intelligence and ore specifically Smart systems that may contribute to the challenge discussed in this paper by helping humans not to get out of the doughnut. An example of application of smart system (not taking into account the doughnut) can be found in [Zhu et al, 2019].

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