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Enhancing knowledge management into systems engineering through new models in SysML

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Abstract

This paper aims at exploring cooperative work and knowledge implication into Systems Engineering approach in order to study organisational impact. Furthermore, the study aims at providing conceptual models that enhance a Model-Based Systems Engineering (MBSE) with the purpose of taking into account knowledge management (KM). The research formulates a decision model that complements the existing methods through Systems Modeling Language (SysML). The methodology is based on current SysML diagrams and proposes a KM solution focused on an organizational approach. The requirements satisfaction is built on this conceptual approach to help on the decisional process. Systems Engineering (SE) integrates all the disciplines and specialty groups into a team effort forming a structured development process from design to production. SE shows that cooperative work and management increase with the complexity of systems. Thus far, the current models do not present enough cooperative and knowledge management supports. The study proposes to add a new model to imply KM and organizational aspect through SysML in order to develop a cooperative work process with a first conceptual approach. This paper tackles several possibilities based on modeling language SysML extension and discusses the interest of implementing the model while providing a complementary decision-making tool.

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Keywords: Model-Based Systems Engineering; Systems Engineering; Knowledge Management; Cooperative work; SysML; Decision-making; Organizational; Product LifeCycle Management; PLM;

1. Introduction

The increasing complexity of systems makes requirements engineering activities both more important and more difficult. Therefore, Systems Engineering (SE) proposes a methodological approach developed to control the design and integration of complex systems throughout a system development process based on systemic approach. SE allows the integration of related technical parameters and assures compatibility of functional, logical and physical system in a way that optimizes the total system definition and design with the management of the reliability, maintainability, logistic, safety, producibility, structural integrity, human factors, and other related specialties [1].

From requirements definition to achievement, the models presented in SE method do not take into account the cooperative aspect although SE is a cooperative activity which involves different actors in diverse disciplines with organizations contributing to system development. However, Knowledge Management is essential to handle decision-making because it is not conducted in the current SE methodologies. In recent years, by increasing the importance of knowledge as a source of wealth creation and economic development [2], the activities have become more complex. It seems important to consider those aspects into Systems Engineering models through their integration in an organizational model.

First of all, the study is positioned in Systems Engineering methodology, cooperative work and Knowledge Management (KM) through a review to demonstrate the requirement of

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using them and the gap in knowledge aspects into SE. Secondly, conceptual approach proposes to tackle the cooperative aspects into a SE model in order to define a first overview of cooperative work process. The conceptual research shows how knowledge management should be a decision-making support to link different SE aspects and to keep track of knowledge produced thanks to Model-Based Systems Engineering (MBSE) tool by adding new management models. Finally, the paper will show the possibilities to develop a model and a decision-making tool based on Systems Modeling Language (SysML) which is currently in the making.

The paper goal is to provide an organizational solution that integrates cooperative work and KM in Systems Engineering to manage the industrial environment by including the aspect of project, team' management and their intellectual production. The main intention of the suggested models, based on cooperative process, is to open reflexions and hypotheses for a new research work. The different models are reflexions toward the desired solution and the paper proposes a new extended conceptual model that addresses management of cooperative work and decision-making in SE projects.

1. System Engineering review and KM literature

For some decades, Systems Engineering (SE) works on development and identification of new methods and modeling techniques to deal with complex systems. A professional society for systems engineering, the *International National Council on Systems Engineering* (INCOSE), has been founded to answer the need for enhancement in systems engineering practices and education. This organization defines SE as an engineering discipline which manages and executes an interdisciplinary and holistic approach to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. This process is usually composed of the following seven tasks: state the problem, Investigate alternatives, model the system, integrate, launch the system, assess performance, and Re-evaluate [3]. The ISO/IEC 15288 is a Systems Engineering standard covering processes and life cycle stages [4]. This methodology is centered on the system regardless of the intangible elements like decisions, conflicts or knowledge capitalization even if it includes a recursive process through other systems. Some papers expose a new conceptual model that merges with KM, intellectual capital and project management to propose a model which aims at being used as a valuable theoretical basis for future empirical research of modern knowledge organizations [5,6]. These researches deal mainly with the capitalization of project organization knowledge. Broadening the scope of system engineering, authors observe that cooperative work and KM have a significant role in the conduct of complex systems, especially to consider negotiation and cooperative problem solving. The approach is illustrated on a scheme (Fig. 1) that shows the cross-over of KM through the system. The scheme follows a known process from requirements to features, which handles an operational scenario containing limits, functionalities, enabling system and project management.

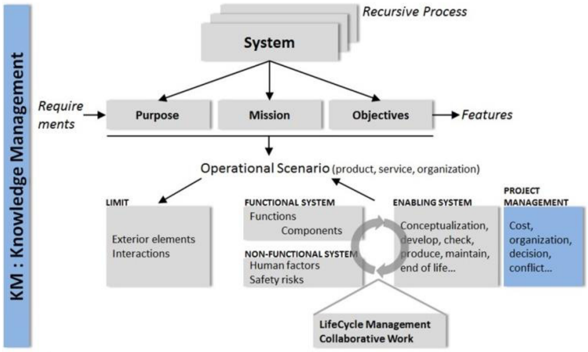


Fig. 1 Research approach into the Systems Engineering methodology

Following the research construction in the overview process, the approach adds a lifecycle management between the enabling system and the functional and non-functional elements which require an iteration and cooperation process with stakeholders. This position is justified by the cycle location where the most structural exchanges occurred. Before establishing a solution and defining a model from this approach, the study presents some principles and SE models, Knowledge Management process and collaborative activity studies.

2.1 Systems Engineering Models

SE methodology is based on different processes that provide guidance on the project steps and carry out the major tasks (Fig. 2). The paper will show thereafter that some software tools have been developed to manage complex systems. The first model is the *waterfall model (a)* which was a refinement of the stage-wise model in the 1970s. It is a sequential process which defines and applies each action to go back through the process. This model stipulated that software has been developed in successive stages [7]. Then, the *spiral model (b)* has been based on experience with various refinements of waterfall model as applied to large software projects [8]. The *"vee" model (c)* represents the systems engineering design and development process.

The left side of "vee" depicts the decomposition and definition of the system requirements and specifications at the beginning of the system's life cycle in top-down approach. After the individual physical components developed in bottom-up approach and the responsibility passes back to the systems engineer who integrates and assess the system to the right side [9]. All processes have been focused on creating a discipline of software risk management often dissociated from engineering and management by profession and skills.

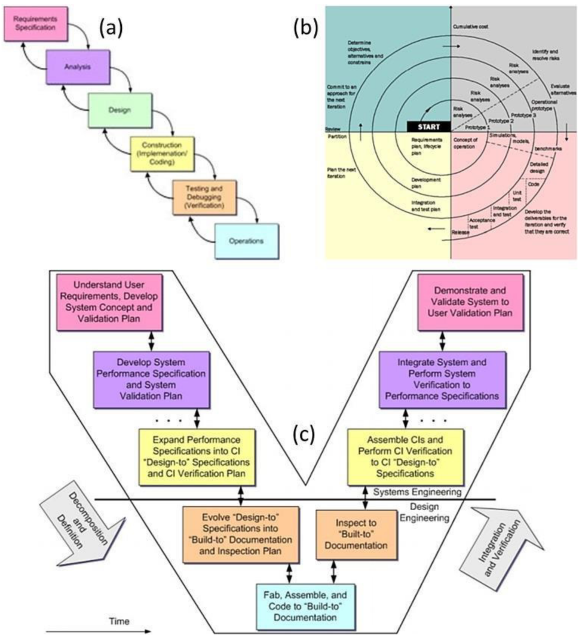


Fig. 2 Seminal Lifecycle Development Models: (a) Waterfall, (b) Spiral, (c) "Vee" [10]

Model-Based System Engineering (MBSE) can help to manage the complexity, while improving design quality and cycle time, enhancing communication among a diverse development team, and facilitating knowledge capture and design evolution [11]. Systems Modeling Language (SysML^{TM}) (Fig. 3) is a general-purpose modeling language based on Unified Modeling Language (UML) which supports the specification, analysis, design, verification and validation of a broad range of systems.

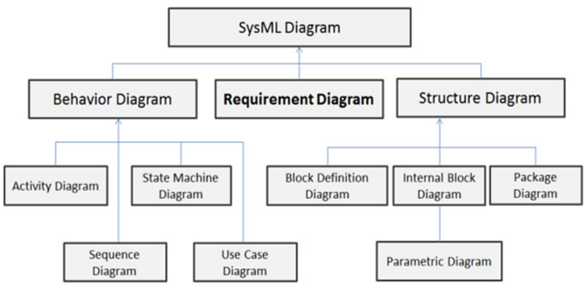


Fig. 3 SysML diagrams types

The structured objects knowledge representation has provided a conceptual foundation for SysML parameters [12]. During the development process of any system it is necessary to support interoperability with the specifications that address integration through the whole system lifetime. This representation is open enough to add other components as objects or models containing action blocks. For example, the requirement model captures requirements hierarchies and the derivation, satisfaction, verification and refinement relationships. The relationships provide the capability to relate requirements to one another and to system design models and to test cases [13]. The requirement model provides a bridge between typical requirements, management tools and the system models. There are other MBSE like Dymola (Modelica) developed by Dassault System and based on object-oriented language for modeling of technical systems in order to reuse and exchange dynamic system models in a standardized format. Dymola is a software solution for modeling to simulate the dynamic behaviors and complex interactions between systems. In this paper, the authors are mainly interested by systemic approach proposed by SysML to implement cooperation and KM. The next section tackles cooperative work and KM in order to apply them in the suggested conceptual model.

2.2 Cooperative work and KM implication

Cooperative activity is studied specially in *Computer Supported Cooperative Work* (CSCW) [14], where it is defined through three dimensions: communication, coordination and cooperative decision-making. The actors have a common objective and they need to interact in order to reach this goal. Thus, the study needs to review techniques in order to tackle these three dimensions and to extract the knowledge.

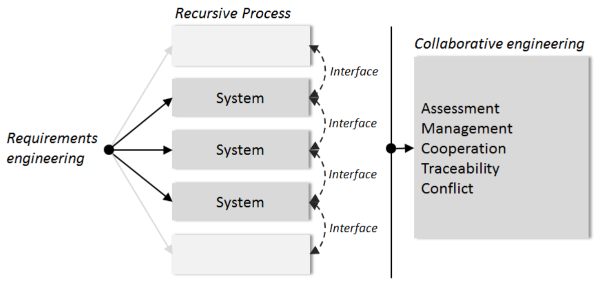
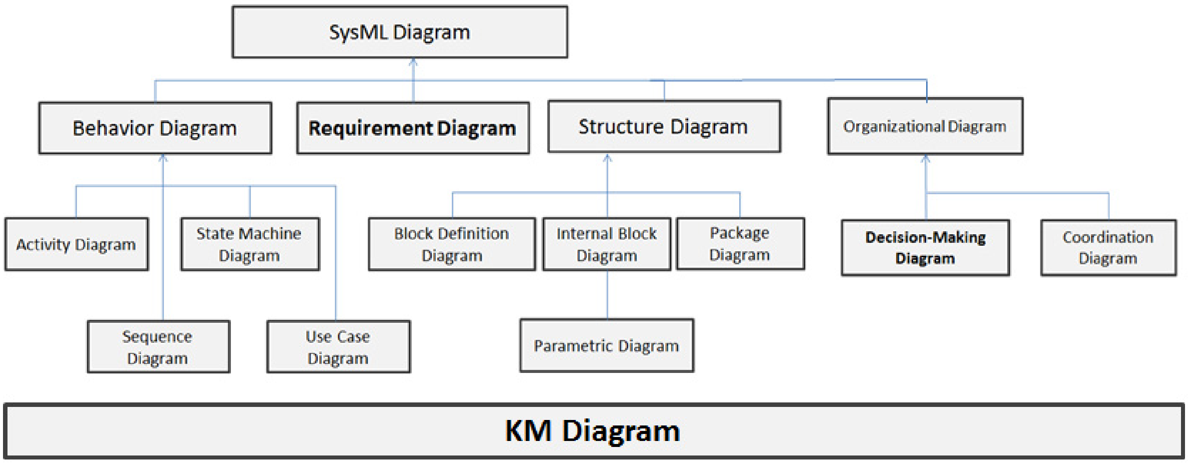


Fig. 4 Concurrent engineering in complex system

Studied systems engineering must not only consider the system representation development (structures, functions, etc.) but they also have to provide tools to support cooperative activity, like conflict management [15], coordination and communication. For instance concurrent engineering [16] approaches tend to study this type of supporting techniques. In the research approach, the sub-systems are led simultaneously while being embraced in the recursive process (Fig. 4).

This configuration leads to multiple systems and gets in a complex collaborative management and a generation of several exchanges, knowledge, decisions and conflicts. The evolution of actors' organization (their skills, roles) is not developed in these new systems engineering techniques.

This paper found two main differences between knowledge related to a given domain and collaborative one [17] :



- The nature of knowledge is different: The business knowledge is related to a field and contains routines and strategies developed individually from experiences which involve a number of experiments. Cooperative knowledge is related to several fields, i.e. several teams (of several companies) and in several disciplines collaborates to carry out a project. Otherwise, knowledge observed in a corporative constitutes one experiment to be structured.

- Capturing of knowledge is different: The realization of a project in a company implies several actors, if not also other groups and companies. For example, in concurrent engineering, several teams of several companies and in several disciplines collaborate to carry out a project of design. In this type of organization, the knowledge produced during the realization of the project has a collective dimension, which is in general volatile. Traceability and direct knowledge capturing are needed to acquire knowledge from this type of organization.

So, the integration knowledge representation on SE leads to consider the collaborative aspect of knowledge (organization and cooperation). The following section develops the suggested solution through SysML diagrams to help the organization to manage the knowledge aspects in the complex system.

2. KM development into SE model

The main asset of SysML diagram is the interoperability and the specialized management based on specific models. The four pillars of SysML are modeling of requirements, behavior, structure, and parametric. Following the previous analyses, the knowledge management and the cooperative work are hardly reflected in MBSE including SysML diagram. The authors propose to add new models to improve process' management and consider team intervention through their skills, roles and decision making into an organization part (Fig. 5).

The approach puts forward knowledge management model which has a transversal action on all models.

Fig. 5 New model into SysML: Organizational diagram, Decision-making diagram, Coordination diagram.

These models are considered as enabling systems to get a project managed more efficiently in take in account the cooperative aspect. The organizational diagram depends on decision-making model and coordination model which organize the cooperation part and the broadcasted information like decisions or roles with other criteria based on the theoretical background research. Thus, this new model proposes to add an interaction between system description and collaboration information's. This paper shows that KM impacts this system strongly while acting on all subsystems. In the next section, the paper presents the models decomposition and their interactions through a KM model.

3.1 KM Model

Users have accessed at an intern process described by a blocks arrangement through SysML model. A block definition model describes the system hierarchy and system/component classifications.

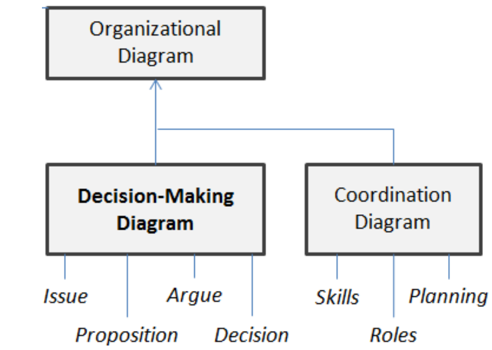


Fig. 6 Positioning of knowledge management model and organizational package

Thus, the internal block model describes the internal structure of a system in terms of its parts, ports, and connectors [13]. The new package model is used to organize the complex system. KM is transverse to all the models to take into account roles, skills and tasks of each stakeholder. This KM position supports the interoperability amongst models to exchange the knowledge and tend to an organizational package (Fig. 6). The challenge is to act on exchanges and their semantic to capitalize the skills actors through factors in order to link them with each model. This conceptual proposal opens the way for a better knowledge organization within the workgroup and the components management (decision-making, coordination, conflicts, roles ...).

The development of new models requires the study of coordination and decision-making process. The feedback loops amongst the steps of analysis, modeling and decision-making are in the context of systems engineering; they are used to refine each of these steps [18].

As seen previously, the satisfaction of requirements all along the lifecycle is primordial to manage a complex system.

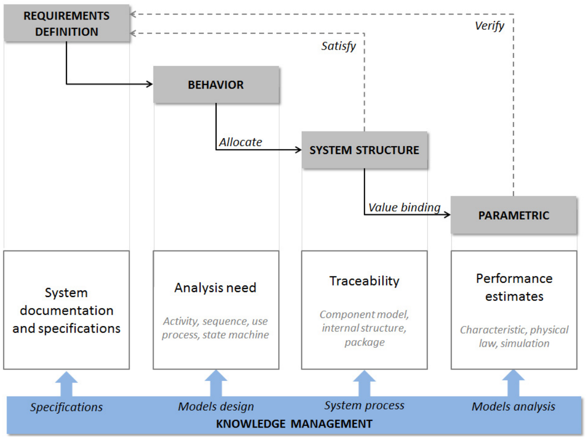


Fig. 7 Requirements satisfaction

In figure 7, the study explores the requirement process which has to satisfy the original specifications. This cycle is based on different structural models which follow a temporal but concurrent process. A block influences the following while satisfying the requirements; this leads to define relations into the system:

- *Requirements definition* develops the specifications supported by the knowledge of complex system which is implemented. This stage is primordial because it can impact all the system and the cost whether it is poorly defined;
- *Behavior* analyzes the interactions and the activity of complex system through sub-systems which are allocated to the system structure. The knowledge is used to design these specific models (activity, tasks sequence, use process…) thanks to skills;
- S*ystem structure* organizes the components to transmit the physical values to parametric stage. It leads the overall system in order to trace the components and learn about be sure of their physical specifications and their technical roles;
- *Parametric* part checks the system constraints to realize a performance and quantitative analysis. It checks if each requirement is satisfied.

An action into activity can be used to invoke any behaviors. The parametric part supports engineering analyses with performance, reliability, availability, mass, and cost...

The requirements satisfaction is driven by four steps in knowledge management: specifications, models design, system process and models analysis. They depend on project organization and the semantic of work environment. The roles and skills are assigned through the knowledge management and remains transverse to the whole system. The general operation based on Multi-agent System Engineering (MaSE) methodology can follow the progression of steps [19] and check if the specifications are reached. The semantic has a great importance in the project management and in the understanding of exchanges inside teams. In the same way, the cooperative decision-making representation must also integrate not only the product evolution such as the PLM, but the decision relation with the actors' parameters (roles and skills), as well as the negotiation that leads to decisions. Coordination traceability can show the influence of actors' organization on the decision making; i.e. by mixing competences in workgroup and meeting frequencies, etc.

3. Empirical study

This paper proposes an iterative and incremental process on the figure 1 through a lifecycle management and the research checks some orientation thanks to an experimental and empirical study. An implementation of results through a demonstrator is necessary to show whether a SysML model could bring a better configuration management. A workgroup has triggered the realization of tools required to support the previous concept. A body of research [20–22] define a flexible managing product development strategy in order to develop the team work as a unit to reach the requirements. The workgroup has taken into account this last element in their design management. Based on the previous concept, the empirical study has led to demonstrator below (Fig. 8). This demonstrator is currently in the making and presents some tracks on the internal block diagram which respond to previous models. Thus, the technical details are being studied and can't be described in this article. Internal block diagram (or ibd) describes the internal structure of the system and the design or process management:

- *Decision-making management* structures the workgroup and defines the skill and role of each person. Stakeholders represent the customer and they have to be accountable for follow-up of team that delivers value to the business. The project master is responsible for removing impediments and for the reliability of the team to deliver the product goals and deliverables;

- *Completed tasks chart* keeps track of the advanced of teams in their assignment.

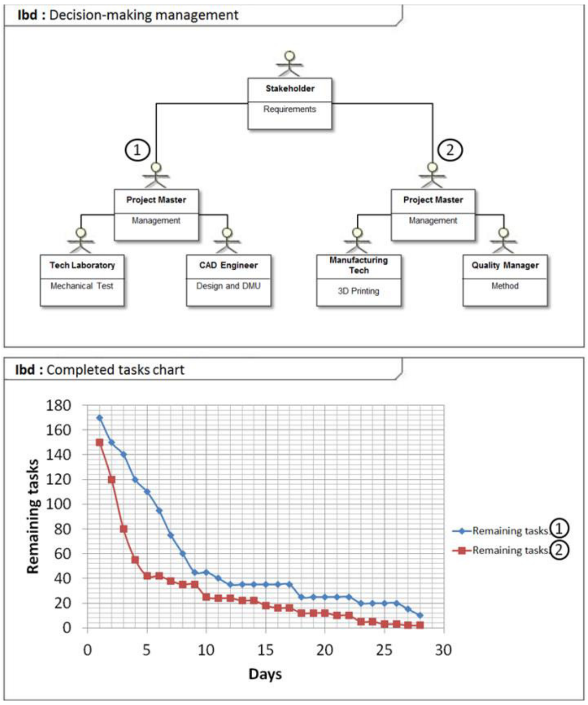


Fig. 8 Demonstrator with the ibd (internal block diagram) proposed

The internal block diagrams correspond succinctly to organizational, decision-making and coordination diagrams based on SysML configuration with the purpose of taking into account the knowledge management. An interface close to SysML diagram is proposed to manage the requirements from the stakeholder and the coordination process with different tasks allocated to teams. It shows a measurable process with a traceable decision-making monitoring over time. The actors' parameters (roles and skills) are difficult to measure in order to evaluate the negotiation impact that leads to decisions. This demonstrator is being developed into computer application to check use and interactions in order to study the technical data.

4. Conclusion

Developed Systems Engineering controls the complex systems which resulted in the creation of methodological models. Originally developed to design software or hardware, the traditional description of Model-Based System Engineering (MBSE) shows that the knowledge management and the team organization are poorly integrated in the systemic approach like into Systems Modeling Language (SysML) model. SysML model supports the specification, analysis, design, check and validate a broad range of complex systems. The study observed that knowledge management is rarely addressed through MBSE in order to improve the workgroup management and their intellectual production. Thus, authors propose to develop new models into a SysML diagram to answer requirements. This article is the first proposition of a new research work mainly concentrated on cooperative process. The study developed the requirements satisfaction and decision-making process to get a model necessary to models definition (organizational, decision-making, and coordination models). The research project is oriented towards the definition of specific models to manage the cooperative activity of the complex system. Suggested conceptual models tackle reflexions and hypothesis through a cooperative process in order to impulse the research work and the next implementation phase. Some fundamental factors still have to be studied to finalize this conceptual proposition in order to study the workgroup exchanges and to refine aspects. This conceptual novelty will be implemented into SysML software and a demonstrator is assessed with others factors.

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