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AN INTEGRATED APPROACH TO MANAGE NEW PRODUCT DEVELOPMENT PROCESSES IN THE SPACE INDUSTRY

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ABSTRACT

The New Product Development (NPD) process is characterized by numerous elements of complexity and firms face varied challenges in managing it. Because of the close link with innovative processes and its inter-functional and multidisciplinary features, the NPD process needs new tools and methodologies to acquire and structure the its essential knowledge elements.
These issues require an extra attention to be paid to the design and development of high technological products (like in the space sector) and call for new approaches to update and adapt methods and tools from different disciplines (Engineering Design and System Engineering, Operations Research and Management Science) to the new industrial context and to analyze the impact of these solutions on the NPD process.
This paper investigates how companies can integrate different perspectives into the management of the New Product Development process when using modeling and simulation techniques as a basis. The idea is that this activity can be facilitated using a structured approach that considers modeling of product, process and organization together to support NPD process mapping, analysis and control activities.

Keywords: Engineering Design process, New Product Development management, Modeling and Simulation

1 INTRODUCTION

Modern space industry is getting more and more involved in the development of more profitable products and services [1]. The consequent innovation approaches focalize on the impacts of decisions on the whole product lifecycle [2] (i.e. from the early program definition among the stakeholders to the mission close-out and spacecraft disposal) and call for solutions that can derive from marketing strategies, process reengineering, new technologies (on the product and the process) or by the combination of these elements. The theoretical elements that result and the software tools for engineering design (e.g. product modeling tools) can give significant contribution to the activities of process improvement but they also induce a further adaptation of methodologies, activities and tools in order to manage the impact on the iterative behavior of New Product Development (NPD) processes typically characterized by trial&error approach.
Several authors have discussed how to evaluate NPD process behavior when dealing with uncertainty, for example focusing on the robustness of the engineering design processes and on robustness analysis [3], [4]. The existent research contributions about NPD processes behavior fall into two main streams (“macro-perspective” and “micro-perspective”). In the management of the engineering design, the micro and the macro perspectives are often keep separated and the application of the relative tools is limited to its specific focus (e.g. NPD strategic decision making, “planning, monitoring and control”, etc.). This specificity is despite the fact that engineering design encompasses many elements of complexity and the need of a systemic approach is clearly shown in those sectors where the NPD has unique features (as in the space industry). The integration of the two perspectives can significantly reduce the perceived uncertainty and then the overall approach can gain a considerable robustness.
Many aspects must be taken into account for a consistent evaluation of NPD processes. First, processes are strictly connected with the product architecture. If the approach used for the analysis considers this relation, it will be more realistic and will be able to study the impact of the

technological uncertainty on the different phases of the NPD process [5]. Second, substantial changes are entailed in the NPD processes structure by innovative implementation tools [6] or innovative applications of tools already used in the NPD process (e.g. integrated product development modeling, [7]). In this sense, an integrated analysis model that considers the product, the process and the relative organizational elements (e.g. actors, decisions, etc.) can define a valid informative basis for a better management and control of these aspects and of the complete product development environment.

Three forms of process improvement can be provided approaching the design of complex systems applying such informative basis: knowledge capturing, management support and analysis and control of the system (process but even product). The relations among these different perspectives on the NPD process and the relative approaches (e.g. descriptive and analytical approaches) will be explicated basing on the common model of information.

Innovation in implementation tools has also other benefits. The possible applications of a tool strictly depend on the context of the technical action, as well on the finalities it was created for and on its operative functions. The integration of tools for reasoning on the whole context, from decisional and operative points of views (tools from the field of OR/MS, [8]), with others that can analytically study and simulate processing operations, is an essential condition for the creation of a consistent and complete NPD model and the definition of an appropriate methodological framework.

The first objective of the paper is to define a model that integrate and analyze knowledge on the product, the process, the organization and the relationships among these. Then, the study proposes an evaluation of how the use of an integrated model for NPD management can influence the iterative behavior of processes and its robustness in comparison with the effects due to exogenous elements (e.g. technology and market).

The paper presents a 12-month case study on spacecraft development approaches conducted with a major Franco-Italian manufacturer of space products. Section 1 introduces the problems we set out to address. Section 2 gives an overview of the existing researches about the arguments involved in the study. Section 3 outlines how the research objectives have been tackled basing on the modeling activity. Section 4 describes the application of the integrated methodologies to the test case in order to evaluate the effects on the overall NPD environment. Finally, Section 5 highlights the emerged reflections on the introduction of modeling to support NPD process, discusses the collateral implications of its involvement and suggests areas for further work.

2 BACKGROUND

The New Product Development (NPD) process is characterized by numerous elements of complexity and firms face varied challenges in managing NPD [9], [10], [11]. New competition mechanisms have modified products and processes. Nowadays, products are technologically more complex, they must have a shorter lifecycle, inter-industrial features, a lower time-to-market and higher reliability levels. Processes must be more flexible, should be reengineered and be composed of the minimum number of operations. The new features of products and processes have caused profound changes in organizations and have led to new forms of cooperation and coordination among the communities with highly specialized technologies, and have defined complex networks of the firms involved in common innovative processes.

Because of the close link with innovation processes and its inter-functional and multidisciplinary features, the NPD process needs new tools and methodologies to acquire and structure the essential product knowledge elements. These can become new representations of technological knowledge, new shared operative models, as property of the whole organization.

All these problems require extra attention to be paid to the design and development of high technological products (like in the aerospace sector) and call for new research to update and adapt methods and tools from different disciplines (Engineering Design and System Engineering, Operations Research and Management Science) to the new industrial demand.

On the one hand, numerous models have been developed to define a paradigm of NPD process, and numerous contributions have studied the effective management of NPD projects in the Engineering Design ambit. In particular, concurrent engineering [12], design coordination [13], product development models and strategies [14], [15] have been considered. Process modeling and simulation in engineering design [16] and Design Structure Matrices [17] have also been studied to consider specific methodologies and tools for design management. Last, the objective of evaluating the NPD process robustness induced the review of the present literature over this topic [18]. On the other hand, all these theoretical elements have been confirmed from the industrial practice point of view, through management perspectives on new product development processes, such as System Engineering (e.g. in the space industry standards [19]) where particular practitioner-oriented contributions empathizes the importance of the management of multidisciplinary domains and re-iterations in the development of complex systems ([20]).

Focusing on the robustness characteristics of the engineering design processes and on process robustness analysis, several contributions are present in literature [3], [4]. A higher robustness means a better capability to deliver projects on time and on budget, despite of the uncertainty elements derived from the novelty and the complexity of the products, the processes and the organization. The existent contributions about robustness analyze the problem from two main perspectives. In the first stream, the studies with a "macro-perspective" [21], [22] focus on analyzing the behavior of a system in its typical environment (e.g. product, process and organization complexity vs. available technologies and market). For this purpose, high level descriptions of the whole system are necessary. In the second stream, other authors [23], [24] use numerical/analytical methods to study design process robustness by focusing on the simulation of particular models related to different case studies (micro-perspective). The macro-perspective does not capture in detail the effects of specific elements on the NPD. On the other hand, the micro-perspective is more limited to a specific case and needs to be properly set-up to meet its peculiar details. The micro-perspective is strictly related to the models used for the analysis and the resulting meaning closely depends on the perspective used on the process.

This separation of the micro and the macro perspectives does not support the engineering design, where a systemic approach is needed and an integrated analysis model that considers the product, the process and the relative organizational elements (e.g. actors, decisions, etc.) can define an informative basis for a better management and control of the product development.

Many efforts have been made in academic literature to integrate different tools. On the one hand, the literature present researches about the integration through STEP models for concurrent engineering or simultaneous engineering [25], [26], or for software applications (e.g. Service-Oriented Architecture, [27]). On the other hand, methods that support concept generation considering diverse disciplines and business practices exist [28]. Nevertheless, to tackle the need of reasoning on context of the technical action and on the decisional and operative circumstance for the integration problem, models and tools for decision making in the NPD process [29] must be investigated.

3 RESEARCH METHODOLOGY

The study objectives are tackled by applying a six steps methodology, which is subsequently revisited in a process of iterative refinement (Figure 1). This approach has its foundation in the model proposed in Information System literature [30] and is then applied in an industrial test-case as described in Section 4.

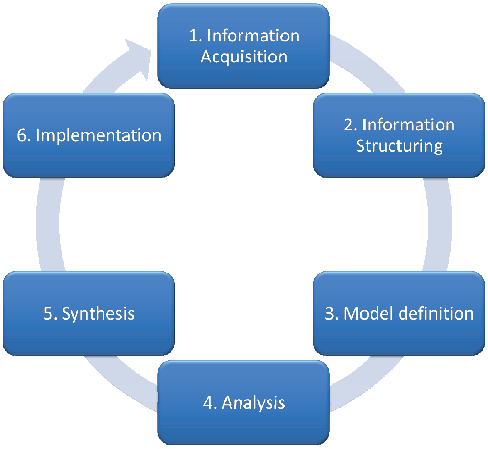

Figure 1. General framework applied for the identification, development and implementation of problem solutions.

The study framework starts with the collection of information about the investigated problem (i.e. NPD process definition and management) and its constitutive elements (i.e. the product and the design process) in order to have a deep understanding of the problem's foundation. Then, the investigated information covers the product, the NPD process models ('as-is' and 'to-be'), the organization and the description of management methodologies and tools as they are currently applied and which are proposed by the academic researches. The data about the reference models and approaches can be gathered by literature review on the current state-of-art (e.g. NPD process models, NPD management) or considering the relative best-practice prescriptions. On the other hand, information about the current practice are collected from the experts operating in the industry or by the analysis of typical documents, reports (e.g. system technical descriptions, product specifications, design and development plans) typically used by experts during the development of a system. About the tools, the research is based on the proposed solutions from research and market and on the availability and constraints in the industry.

The collected data provide a huge amount of information which needs to be structured and formalized by e.g. classifying, understanding multiplicity and getting rid of wrong duplications, defining cross-relations among the elements and describing them. In order to do this, first of all, it is important to define the objective of the model by determining the boundaries of the analyzed system,(e.g. the product, the process, the enterprise) which aspects needs more attention and which can be the missing information for the accomplishment of the research objective. Then, the relevant macro-concepts extracted from the gathered information need to be structured (step 2 of Figure 1). The structuring activity requires many iterations among the definition of the classes and their verification through the allocation of the data. A possible approach could be to start from the relationships among single couples of elements and growing towards a global meta-model. This process of knowledge elicitation, localization, model development and validation can be conducted through the application of structuring tools by single experts and the discussion of the results during workshops.

The meta-model, or conceptual data model, besides representing the frame for the allocation of the collected data and addressing the research question about the integration of NPD elements, is also the basis for the definition of the 'to-be' model (step 3 of Figure 1). Once all the relevant collected data about the current practice are instantiated (i.e. allocated in the 'as-is' data-model), the prescribed data of the 'to-be' solution are included in the new data-model and the missing aspects required by the research objective are defined (e.g. tailoring of the model-based NPD process, integration of the tools). This structuring and modeling activity can be tackled by the use of different tools depending on the level of definition. Common spreadsheets can be the starting point for separating data into main classes but the cross-relations among the data are difficult to be modeled. Then, some formal tools like the Design Structure Matrices, the Domain-Mapping Matrices and IDEF0 can be applied depending on the specific type of relationship on which the modeling activity is focused. The global model, on the other hand, needs to define all the possible relationship and possibly also the attributes, the hierarchies, the multiplicity and the sequences. Two different tools typologies can help in this effort: tools for ontology definition (e.g. Protégé) and the object-oriented languages (e.g. Unified Modeling Language – UML). The former is more oriented on helping the instantiation of element in the data-model at a high level of detail, while the latter can be used to formally define the meta-model in such a way understandable by the human user and the machine. A good connection between the object-oriented diagram representation and the detailed instantiation of the data-model could be the notification by SysML. Last, the storage and access to the data can be managed by common commercial databases which already integrate exchange services (e.g. XML tools).

Once the overall structure of the 'as-is' and 'to-be' models (in particular for the process) are agreed they have to be verified and evaluated (steps 4 and 5 in Figure 1). The validation of the models (step 4) can be carried out by two approaches: the analysis by simulation (by the use of e.g. Applied Signposting Method, System Dynamics), which gives a quantitative evaluation of the behavior of the system, and the testing by demonstration test-case, which provides a qualitative description of the overall system (or part of it) and a measure of some specific aspects on focus (e.g. task durations, probabilities of rework, resources behavior). The two approaches should interact and exchange the results (in parallel or by iterations) in order to cross-check and tune the variable parameters.

The results of the activities are then post-processed for the definition of synthetic parameters able to describe some characteristic aspects of interest (step 5). An important aspect of this synthesis activity is to highlight the connection among the causes, both internal and external, and the effects. This is fundamental for the feed-back mechanism which permits the refinement of the verification activity and the tailoring to the specific cases during the final implementation and the daily utilization of the system. The obtained results can then be integrated in the descriptive model and shared among the stakeholders for further validation and discussion.

The sixth and final step of the framework is represented by the implementation of the integrated system by the application and management of the engineering design process in the industry. In this step more attention is paid on the organization aspect reconsidering the roles of the stakeholders and their perspectives (e.g. develop the product, finance the development, and satisfy the market). In this sense, the project management and control processes can be reviewed and adapted to the proposed model-based engineering design approach.

An iterative behavior occurs in the proposed framework (e.g. for the structuring and modeling activity or for the verification activities) before the final 'steady' implementation is reached. On the other hand, the framework needs to be re-trailed any time the NPD process and its management are applied to a new case in order to include the historical-data in the reference model and properly settle the 'to-be' model.

The possible expansion of the framework to new NPD aspects (e.g. innovation strategies with respect to the market) or problems needs further implementations. Nowadays, the application of the described methodology provides a test-case for the examination of the impacts on the process behavior (iteration and robustness) due to the adoption of the modeling approach.

4 TEST-CASE IN THE SPACE INDUSTRY

The present paragraph reports the demonstration activity carried out for the validation of the described methodology and of a proposed NPD integrated approach.

The test-case meta-models and methodology application are jointly developed with a industrial study which focuses on modeling and virtualization activities in a spacecraft design process, where product information elements (e.g. architecture, requirements, operations, functionalities), the NPD process, the tools enabling the development process (i.e. Model-Based System Engineering software), are considered together. This industrial experience highlights the characteristics of the process models, the reciprocal influences among the above mentioned elements and the applicability of the proposed methodology.

The description of the developed approach has been structured according to the essential implementation levels of the methodology as represented in Figure 2. At first, the industrial context (paragraph 4.1) and the data gathering activity for the example applications (paragraph 4.2) are introduced. Then, the 'as-is' and the 'to-be' product and process modeling activities are explained (paragraph 4.3) and the resulting integration of tools and perspectives is presented (paragraph 4.4). Finally, the reflections about the implementation in the industrial organization and the deduction of the effects on the process of the integrated modeling and management approach are discussed in paragraph 5 together with the overall conclusions.

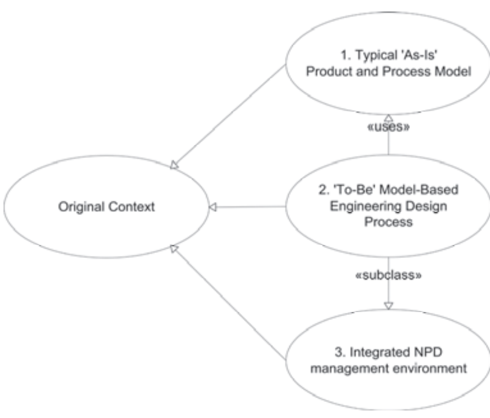

Figure 2. Levels of implementation of the industrial test-case for the research methodology and the problem solution.

4.1 Original context

This section describes from a macro perspective the original context in which the test-case is applied. The description is obtained by the application of a reference model [7] that defines the elements of complexity (of the NPD process) of a problematic situation for the analyst in a decision aiding contribution. The evaluations are derived from direct observation of the context and interviews to experts in the company.

The typical customers of the company are national and international space agencies which depend from ministries of the participants nations and then the reference market is influenced to a great extent by political events. On the other hand, the NPD process is oriented to long-term objectives, because of innovation aspects of the space projects. For these reasons, it is possible to assume that the reference market is characterized by a turbulent behavior along the NPD process and many strategic changes are required. Market novelty should also be taken into account even if in this sector the possibility of expanding to new markets is limited by the close collaboration among the space agencies and their local industries (e.g. the USA, Russia and China). Moreover, even if a customer were new, it would not mean a real change in the market, because the needs are quite similar for each space agency. Instead, from a technological point of view, several innovations are implemented in this field and usually deal with new materials, mechanical structures, ergonomics, development and production processes and IT tools. The severe reliability levels which require long and deep verification periods are not practicable in an uncertain context and then, turbulent technological changes are not admitted.

As far as the innovation of the products is concerned, the situation of the considered products is controversial. Commercial and military satellites (typically for telecommunication and observation), except for some specific cases usually have incremental innovations with improvements to processors and to antennas. Scientific satellites require radical innovation due to their experimental nature. Innovations concerning the manned modules for the International Space Station, because of the consolidated system concepts, are modular and typically adapt specific subsystems to fit the payload needs. Launchers typically are subjected to incremental innovations while re-entry vehicles require high levels of research, since few consolidated reference models exist and new solutions are under examination. Last, the architectures for space exploration missions and the relative systems for their realization need mainly architectural or even radical, innovations. According to these considerations, at this moment the situation in the analyzed company stands between modular and architectural innovation but the specific test-case can be considered a radical innovation case.

The organizational context of the analyzed NPD case is characterized by teams internal and external to the company. The human resources are quite homogeneous in the organization, and are mainly composed of aerospace, nuclear and mechanical engineers who already had a common knowledge and language. Moreover, the long term collaborations, due to the high average seniority within the company further increase the internal communication. The organization is characterized by several coordinators for each function (both concerning engineering and management) and discipline so that communication and collaboration are facilitated. In particular, the analyzed organization is slightly more oriented on the engineering perspective than on the project management side. Project teams are created for projects which are considered strategic or critical since technically complex. Concerning the external environment, the company cooperate in the product development with other stakeholders (partners in the development of a system, subcontractors and suppliers) and with the customer. In this context some difficulties could exist for the realization of an optimal collaboration because of organizational differences, different objectives, and, in some cases, difficulties in the communication (e.g. physical distance, different language). In general, the management of knowledge is structured, but not always formalized. The uniqueness of the projects with a continuous tailoring of the NPD process does not allow a detailed mapping of the activities, therefore only a coarse map is possible and only the individual experts know the details. The seniority of resources helps dealing with the problem of poor codified knowledge, but this situation could become critical if some resource' changes or if unexpected individual workloads occur. This is more critical if the long duration of the space projects in relation to the turn-over of the resources is considered. The whole product development is therefore characterized by a cooperating organization with some attempts at collaboration. In fact, the test-case used for the present research is related with an industrial study made by the company jointly with the customer and other stakeholders to enhance collaboration in the design process. In this research the proposed methodology intends to widen the collaboration among different functions in the NPD process.

4.2 Data gathering

The initial point for defining an integrated NPD process is to model the existing ('as-is') environment. During the carried out case-study, interviews have been conducted with experts operating in the industry from different NPD disciplines (i.e. system engineering, project management, product assurance, architectural /configuration design, mechanical design, thermal design, functional modeling and simulation, propulsion design and assembly-integration-test) who work in various roles and levels of seniority. This has been supplemented by studying product and process documents. Then, specific information about the product needs to be gathered in order to understand the reasons to perform the prescribed activities and the links among product and process. For this purpose, some general documentation (e.g. system technical descriptions, product specifications, design and development plans) has been analyzed. Typically, the collected information are diagrams, tables and other schematic representations of the system which are generically identified as 'views' by the case-study team.

Once the data for the 'as-is' process are obtained, the remaining steps, including iterations, took just over 12 months. Most of the information needed for the later steps has been elicited from other key stakeholders in the process (e.g. typical costumer, competitors, research centers), each with their own domain of expertise.

After this investigation on the present practice, the case-study for the demonstration of the proposed 'to-be' process has been developed on the basis of a reference project. Although it has been recognized that all projects would be different, as a starting point a specific reference project, for which the conceptual design phase was complete, was chosen. The selected project is a scientific satellite to measure high-accuracy gravity gradients and provide global models of the Earth's gravity field and the geode. The project has a prime contractor for the development of the whole system (project management and system integration), a sub contractor for the development of the platform, and another sub contractor for the scientific payload. This permits the availability of reference data in both sides of the industrial consortium involved in the study about model-based engineering-design. Satellite's phase B design activities were originally conducted from 2000 to 2002 which allows people that worked and are working on the project to be available to support the demonstration.

The data collected from the demonstration activities and from other ongoing project during the study can be used for enriching the database of the 'as-is' model. This iterative data-gathering activity will originate a structured historical-data collection which permits further analysis and set-up of the NPD process.

About the integrated 'to-be' NPD management, the model is investigated considering the standards and the available researches on this subject. Finally, the NPD management elements (i.e. tools, methodologies, organization) of the industrial practice are collected and compared with the perspectives available in the research ambits.

4.3 Design process modeling

The test-case modeling activity starts with the definition of the typical product and process model as they are (points 1. of Figure 2), and with the definition of the 'to-be' model-based system engineering process (points 2. of Figure 2). The result of the first point is a populated data model with a consistent conceptual structure and some reference data and attributes. On the other hand, the modeling of the 'to-be' process provides the basis for the analysis by test and simulation of the innovation elements investigated (i.e. introduction of virtualization for enhancing collaboration in the design process).

Figure 3 represents, through the use of a UML Use Case diagram, the analyzed environment as derived from the collected data. The picture shows the initial formulation of the problem and the extension to a wider case that include also the tools and the related development activities. The current definition of the system is composed by the product, its operations, the design process, the production and test process, and the activities to manage the development processes (e.g. design of the design process, process monitoring and control, etc.). The proposed extension to the modeling of the development of tools and methodologies for the design and management of the NPD is described on the next paragraph. At the moment, the model does not include the organization but it could be necessary to insert all the actors involved to improve the process control activity and integrate the whole NPD environment.

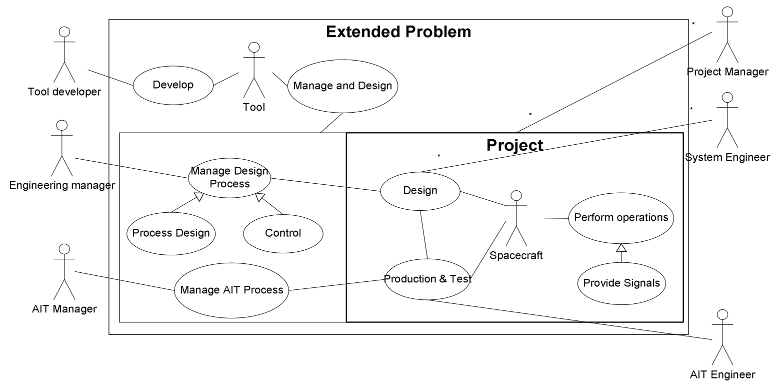

Figure 3. Sample of a UML Use Case model relative to the application of the research activity in an industrial case.

In order to model the NPD process, a draft of the conceptual structure has to be defined which identifies the main classes and the type of relations. The analysis suggests a further detailing of the meta-model and then the elements and the classes derived from the case model and from the conceptual analysis are modeled by the preliminary class diagram reported in Figure 4, with the possibility to improve the description with a SysML notification. Here, the connections are represented by an association between the elements occurrence and the activities occurrence (line circled by the blue dash-dotted oval) which could also be described with Domain-Mapping Matrices. On the other hand, the red dashed circles highlight the connections among the elements of a single package, which permit the definition of the elements and the description of the interfaces between the single instances (analogous to the type of description provided by the Design Structure Matrices). At present, a more detailed model of the instances is also available which represents and describes the overall complexity of the system and refine the representation of the iterations in the process, but the structure and the characteristics of the above depicted framework already permit a hierarchical decomposition of the problem.
The product and process data collected from documents and databases of current space projects are then included in the meta-model by the use of a tool for the ontological analysis (Protégé, Stanford Medical Informatics) for the validation of the basic categories. This activity permits to set-up the meta-model, to describe the instances and the relative interdependencies and to start filling the database.

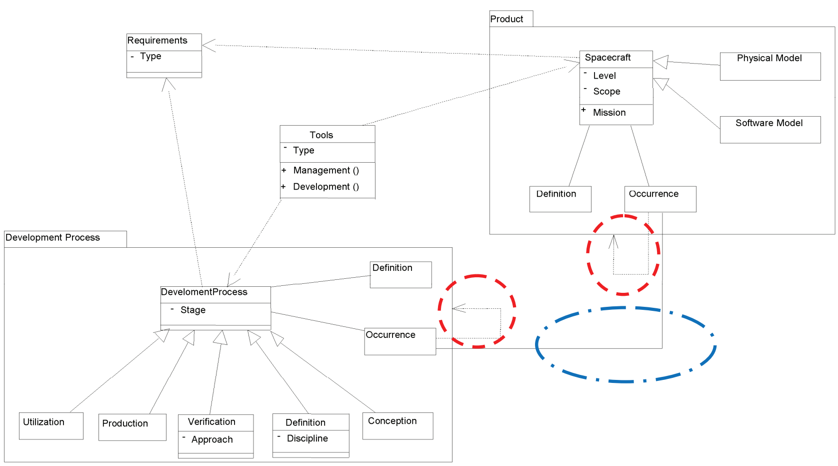

Figure 4. Preliminary meta-model of the investigated system.

In order to analyze some specific aspects of the processes like the application of a trial&error approach, the Design Structure Matrices are applied to refine the modeling. The DSMs help in modeling and explicating the iterative behavior of the analyzed NPD process. In further investigations, the DSM model could be integrated with analytical approaches which permit a simulation of the system behavior (e.g. Applied Signposting Model, [24].) and the evaluation of characteristic parameters such as costs, robustness and complexity useful for setting the 'to-be' process models or controlling the current process.
The developed meta-model and methodology are then applied and compared to a specific industrial test-case. This test case, in particular focuses on the definition of a 'to-be' model for the Engineering Design process with the introduction of modeling and virtualization activities (i.e. realization of Model-Based System Engineering). This spacecraft design process model considers the relations with product information elements (e.g. requirements, operations, functionalities), the overall NPD process, the tools enabling the development process (e.g. repository, analysis tools, visualization tool, forms and reports for design definition), but also the reciprocal influences.
At the moment, the process model is focalized on the definition of a simplified flow of activities to be carried to accomplish the conceptual design phase of a scientific satellite (already mentioned in paragraph 4.2). The proposed process is constituted by three design activities (for different solutions, levels of detail and disciplines), three verification activities (i.e. two analysis of design and one virtual test of the integration) and several system-engineering activities for the integration of the different design information elements. This process is set-up in order to demonstrate the focal points for the introduction of modeling in engineering-design and it is simplified enough to be carried out in a relatively short test activity. This is the reason why it does not cover all the NPD activities. A more detailed model could be developed for the simulation of the complete process.

4.4 Integrated NPD environment model

The current effort is focalized on detailing how specific methods (e.g. UML, DSM, Databases, Ontology, Gantt Charts, etc…) applied for the definition of the Conceptual data-model can provide a consistent basis for the integration of approaches, organization and tools. The resulting model of the NPD process is then applied to explore the effects of strategic decisions (e.g. system architecture, the application of system virtualization, project control philosophy, etc.) on overall NPD process characteristics.
The proposed meta-model structure is already the result of the joint application of ordinary structuring tools. Figure 5 shows a sample of how some basic elements of the NPD environment have been associated integrating generic spreadsheets with Design Structure Matrices and Domain-Mapping Matrices. First, a draft of the conceptual structure is used to discuss and identify the type of relations. The suggested further detailing of the meta-model is tackled by the application of DSM and DMM (contextualized in the orange, yellow and green frames) in order to track the interconnections of the single elements. The light-blue area in Figure 5 represents the proposed extension of the current research, where the role of the tools for NPD process development is included inside the overall modeling.

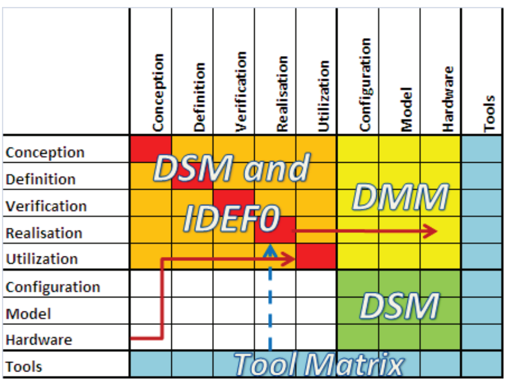

Figure 5. Sample of Integration Structuring of spreadsheets, DSMs, DMMs and IDEF0.

This framework already satisfy the need of model conceptualization, but in order to deal with the hierarchical decomposition, the definition of the elements and the different types of relation some other tools could help. Then, the IDEF0 approach can also be integrated. This integration can be seen identifying the diagonal cells about process activities in Figure 5 with the boxes of a IDEF0 diagram. The product instances are linked to the activities as input and output (coming from the left and right side of an activity box in the IDEF notification) while the mechanism arrows coming from the bottom side link the tool with the activities.

On the other hand, the UML model can be considered as a further detailing of this framework with the addition of attributes and operational aspects to the elements definition. This approach still maintain the visualization immediacy but it can be applied only for high level description, that means for the definition of the database structure (i.e. the meta-model). The detailed allocation of the data requires a more appropriate tool like ontology or a database. The passage between these tools and a UML model is quite simple by the use of exchange languages like XML.

The above described integrated framework has demonstrated a twofold advantage since it is rigorous enough to force a detailed analysis of the overall system but it is also flexible enough to be adapted at different processes of development. It provides a common vocabulary for the stakeholders who need to share information in the engineering design domain and it can be easily extended to the overall NPD environment. Some of the reasons to apply such a methodology are:

- To share common understanding of the structure of information among people or software agents
- To analyze domain knowledge
- To make domain assumptions explicit
- To separate domain knowledge from operational knowledge
- To enable reuse of domain knowledge

Such an approach can provide immediate interface tools for the extraction of specific data which are of interest of different disciplines. This is the case, for example, of the connection between the engineering operations and the project management needs. If the informative model is complete and properly updated the single tools for the analysis of the project can consistently access the right data and the uncertainties in the decision process are reduced. An example of integration of perspectives which emerged during the test-case is in the assessment of the status of a project which is typically settled by the PM on the basis of the engineers' reports and which influences the future planning of the engineering task. When a common clear description of the technology status and a shared process model are provided early in the conceptual definition of the project, all the stakeholders are able to actively collaborate providing more precise evaluations and focused comments. This means an earlier exploitation of the uncertainties and then the possibility to approach the design with the proper decisions on the required robustness and flexibility of the project.

5 CONCLUSIONS

Nowadays companies approach the NPD with new forms of cooperation and coordination which need new solutions from tools and methodologies from different disciplines (Engineering Design and System Engineering, Operations Research and Management Science) to manage the essential product knowledge.

In this paper a methodological approach was proposed to investigate how companies can integrate different perspectives into the management of the New Product Development process when using modeling and simulation techniques as a basis. The idea is that this activity can be facilitated using a structured approach that considers modeling of product, process and organization together to support NPD process mapping, analysis and control activities.

A test-case was proposed to analyze the applicability of the integrated approach in the industry and in particular in the space sector since it represents an interesting case for its features of innovation and technological complexity which also impact the organizational and marketing behavior. Nevertheless, the method demonstrated to work also on other complex development processes due to its scalable levels of application and to the derivation from the origins of information management and problem solving approaches [30].

Nowadays, the modeling effort has already detailed the integration of the product and the design process models providing some preliminary benefits in terms of process robustness. It has been observed, for example, that a shared and common modeling philosophy of the product between the

configuration engineer (e.g. for the configuration of a structural element of the spacecraft) and the expert of a specific discipline (e.g. thermal design, but also integration and testing) in all the development activities can reduce the time to rebuild the models when design changes occur but can also avoid design reiterations due to lack of an overall vision on the problem.
The results obtained in the design activities can be extended to the whole NPD environment since this solid information basis is able to manage the data for different actors realizing the integration of perspective and a consequent improvement in the collaboration status described in paragraph 4.1. This means an improvement in the design characteristics (e.g. product and process robustness) but also an higher project flexibility since the whole history of requirements, models and decision is tracked, a better equilibrium of the different functions in the NPD organization (e.g. engineering vs. project management) and a consistent support to the decisional process in all its phases (e.g. marketing strategies based on innovative but also available technology solutions).
The study presented many links with other research areas and can be both extended and detailed. For instance, connections were found in the study of robustness of the NPD process with respect to the production, considering the modeling, analysis and tracking along the process of the effects of errors and margin between designed items and realized items.

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