ELICITING CRITICAL INFORMATION IN A PRE-STUDY PHASE OF DEVELOPING A DRIVE SYSTEM PLATFORM FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

It is not straightforward to execute a pre-study and elicit all relevant requirements when faced with developing a mechatronic platform, such as a hybrid electric drive system, aimed for reuse in many advanced vehicles. We present analysis of probing critical information areas and how to identify shortcomings by studying an industrial case and compiling textbook recommendations. We present a method, synthesized from literature, for probing critical subjects for a mechatronic platform development initiative and outline related methods to address shortcomings. Recognizing the critical information in an early phase is one key to leverage complexity in an advanced product line effort.

1 INTRODUCTION

Industries that are developing complex systems face challenges related to reuse of development effort in order to offer cost effective systems. One strategy to succeed is to develop a platform product that incorporates a common structure and assets to be adapted and used in a series of applications. It is state of practice for automotive suppliers to provide subsystems [1] such as transmissions, engines, or brakes for many customers by using a variable platform product. The technology content is then structured for reuse in many applications by including variable and reusable assets for efficient instantiation to a large market with numerous applications.

One challenge that companies face when aiming at using a platform as a basis for a family of products, or users of the platform, is to be able to elicit the requirements on the platform. Problems occur because of a possibly complex life-cycle with many stakeholders and varied customer needs. For a platform or product line initiative it is critical [2] to define the requirements and content of the reusable assets and in to setup the development structure to achieve goals in reuse, costs, time-to market. It is known to be a engineering problem to perform early phases of product definitions and requirements definition, but guidance and techniques are available in textbooks [8].

The research we are conducing aim at providing methods for analyzing the needs of a development initiative aimed at developing a complex subsystem intended for many automotive applications. As a first step, we have studied and identified what areas are critical to focus on when forming these methods. This paper present the results of researching a pre-study method. The work will be continued in subsequent phases of the industrial case and more industrial experience will be sought in future studies.

1.1 Case Characteristics

The company that we have studied has developed a customizable hybrid electric drive system intended for only a few similar automotive applications. The goal of the development effort is now to offer customizable hybrid electric drive systems to a large number of customers with a much wider scope of applications.

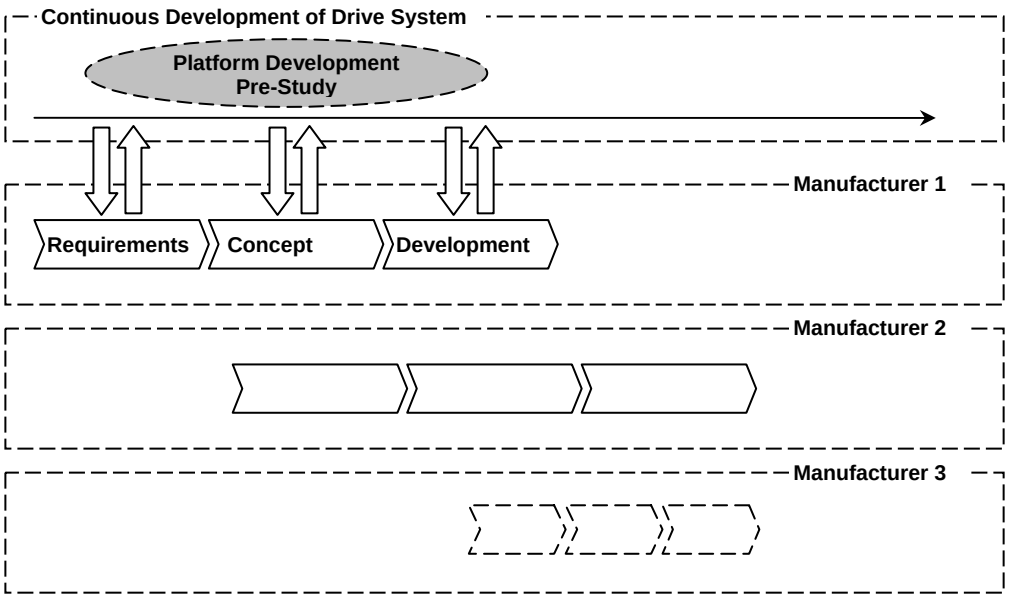

Figure 1. A pre-study of a platform development effort.

Figure 1 show this effort of developing a drive system platform product is to be performed at the same time and coordinated with development of several drive systems for specific applications. Platform development is inter-twined with each individual development project and provides and receives information and assets. As the development progresses, more automotive applications will be considered. It is not fully known which applications are to be developed and thus needs support from the platform. We have conducted research on how to perform a pre-study that, with a small footprint, addresses the various sources of complexity when facing this type of development effort.

1.2 A Pre-study

A pre-study is an early phase of development where requirements, constraint, project setup is elicited and decided. Any development effort benefits from a pre-development phase where requirements and objectives are analysed and made known. A successful pre-study must identify what areas of information are critical to the specific development effort at hand.

1.3 A Platform

Ulrich [15] defines "a platform is a common set of assets that is shared among products". A platform is in this context a product or system comprising all assets whose purpose is to provide a base to develop many applications. A platform may include components, architecture, methods and anything that aids subsequent development projects to meet objectives effectively and efficiently. The life cycle of a platform product is different from that of a 'regular' product. The development of reusable assets may involve different customers, and often company strategy, complex configuration management and quality management is involved. The value and cost of platform assets are often more complex to calculate and depend on projected production volumes, forthcoming customers, strategy, and other dynamic factors. In designing a platform, information on how to relate to the above mentioned sources of complexity need to be addressed.

1.4 An Automotive Subsystem

An automotive subsystem is to be integrated into a vehicle system and perform the specified function that the vehicle system expects. A drive subsystem is likely to be involved in accommodating traction, but may well be involved in auxiliary power outtake, HMI, braking or many other functions depending on the system design. The subsystem to vehicle system interaction is to be addressed and can be complex. Vehicles can be built to different design paradigms. Achieving variability and flexibility enough to accommodate vehicles with radically different architectures, system decomposition and design philosophy can add complexity. Examples of design solutions that may well differ is paradigms for fault handling, diagnostics, and modes of operation. Design of an automotive subsystem will involve these types of complexity.

1.5 An Electric Hybrid Drive System

In order to reduce fuel costs and decrease environmental impact, there is an increasing need to reduce and control the energy consumption in automotive applications. Introducing hybrid electric technology provides means to lessen energy consumption and also to better control energy use and vehicle properties. A hybrid electric drive system can involve electric machines for actuator motion and power generation, electric energy storage, power electronics, combustion engines, gearboxes, other mechanical devices such as hydraulics, and more. There are also concepts with advanced combinations possible for hybrid applications. Hybrid technology is often used to accommodate some of the following

functionalities: Re-generation of motion energy, optimized performance of motion actuators, optimized combustion engine control, productivity enhancement. The increased ability to control electric components compared to conventional automotive components provide the possibility to develop many new functions that improve or optimize performance.

The wide range of possible configurations of a hybrid drive system causes a need for advanced analysis. It can be configured differently depending on the goals of the application and the interaction with the recipient vehicle system. A modern heavy vehicle may typically include a few hundred functions and the drive system may affect many of them. An initiative of developing a hybrid electric drive system will involve such issues of complexity.

For example, a change in configuration can effectively render previously developed control strategies and development activities non-useful. A change of energy storage to meet needs in a new application, can affect ability to regenerate electrical energy. Control strategy, and the process of testing, among other things may have to be rethought, which is precisely what a reuse aims at preventing.

1.6 Objectives of Study

The goal of this study is to find out what must be adressed in a pre-study to enable succesful platform development, and to establish a method to elicit critical information in the context of a platform development initiative. We strive to find this method by identifying what is required in a real case that we have followed and examined.

The problem of developing a platform is more complex in comparison with another product. A method is needed to probe the planned development effort and its setup to identify areas that are not setup to address the effort of platform development.

Problem description:

A platform has a different life cycle than individual products. A pre-study is aimed at finding scope, requirements, constraintes, context before moving on to concept selection and development. Failure to recognize critical subjects specific to product line initiatives can cause future problem in development. Finding critical information needs and guiding its definition is wanted.

In defining this study, we ask ourselves – How to find out what is needed of a specific process/method/procedure for continously developing a platform? What information areas and decisions are critical to address in order to succeed with a platform development effort? Can we prescribe a pre-study method that will identify critical information, reveal neccessary decisions, and also outline methods to address the identified needs?

We structure the study by posing two questions in this study:

Study Question 1: How can a pre-study be performed to identify the critical information needs?

Study Question 2: What methods could guide towards effectively addressing the critical information needs?

We have scanned litterature for guidance on how to do a pre-study, how to elicit the relevant requirements, and how to setup a development effort for a platform.

The contribution of this study is the analysis of how to perform a pre-study when facing a development effort of a platform with reusable assets for series of automotive complex

applications. Our analysis is based on compiling recommendations from the litterature and following an industrial case and practitioners.

We present the identification of critical information areas in the studied case, a method for probing a mechatronic platform development initative which is partly tested in our case, an outline of methods to address identified needs from the probing phase.

1.7 Paper Structure

Section 2 of this paper presents related work that has been used to analyze the problem. Section 3 describes the method used to conduct the study. Section 4 describes the case study together with analysis. Section 5 presents the results; answers to the study questions are presented. Section 5.1 presents the proposed probe method; section 5.2 presents a list of methods that are relevant to solving deficiencies in platform development efforts. Finally, section 6 concludes the paper and section 7 lists references.

2 RELATED WORK

Clements and Northrop [1] describe the problem of coordinating product development with development of reusable assets and provide theory on how to setup such a development effort. The problem of developing reusable assets or platforms is addressed specifically. Systems engineering guidelines typically prescribe valid recommendations to any system development effort, but lack considerations specific for systems with intended platform usage. The theories are mainly focused at describing how software product line initiatives should be setup and function, although many examples describe also complete mechatronic systems as well. The “product line technical probe” is described in section 8 as a diagnostic method for examining an organizations ability to succeed with a software product line approach. Performing the method is a large effort with many meetings and many stakeholders. Interview questions are prescribed for central issues around which the team stakeholders get to discuss and possibly define the setup of the product line initiative.

Our method is much inspired by the SEI Product line technical probe. We have aimed to define a method to probe and find areas of improvement just like the Clements and Northrop probe, but address an early phase of a mechatronic automotive platform development initiative and aim to provide a low footprint.

Bosch [4] proposes a staged adoption of software product families. Adopting a product family approach to development can provide substantial benefits but often requires a major change in organization, process and management. Bosch proposes to implement a product family approach in three stages; early adoption; expanding scope; increasing maturity. Bosch also describes an analysis framework for known problems in development initiatives involving software product lines and describes different choices on how to structure and perform feature selection, architecture harmonization, organization, funding, and shared component scoping.

We aim to provide a method for early assessment of a product family development initiative much like the initial adoption phase described by Bosch. Additional guidance may well be needed in later stages, but we propose a method for an initial iteration to avoid introducing organization-shattering changes and avoid too large study effort in this stage.

Cooper [5] provides the stage gate model for performing the process of going from idea to product. Cooper describes pre-development activities to be performed in order to succeed with development of any product. In order to ‘open’ the gate to development, Cooper prescribes to perform scoping, product and project definition, project justification, and project plan. We use these activities as guidance when we define a pre-study method for a platform product.

The Department of defense prints the text "Systems Engineering Fundamentals" [6] which provides a framework for planning and assessing system development. Supplement 4-A describes procedures for requirements analysis. Sage [7] and Kotonya [8] also provide guidance for how to elicit requirements correctly for any product. We adapt the prescribed method to suit a development effort of a complex mechatronic platform.

The Software Engineering Institute, SEI, provides the Systems Engineering Capability Maturity Model, SE-CMM [9]. Some of the guidance covers our areas of eliciting requirements for a platform development initiative. We use the guidance given in the base practice lists to form our questionnaire for assessing the platform development effort.

Thornell [10] describes theory for logics, structure, and models for business. We use the assessment questions given in chapter 2 to probe the business logics of the platform development initiative.

3 METHOD OF STUDY

Figure 2 shows a process picture of the method we have used to execute this study.

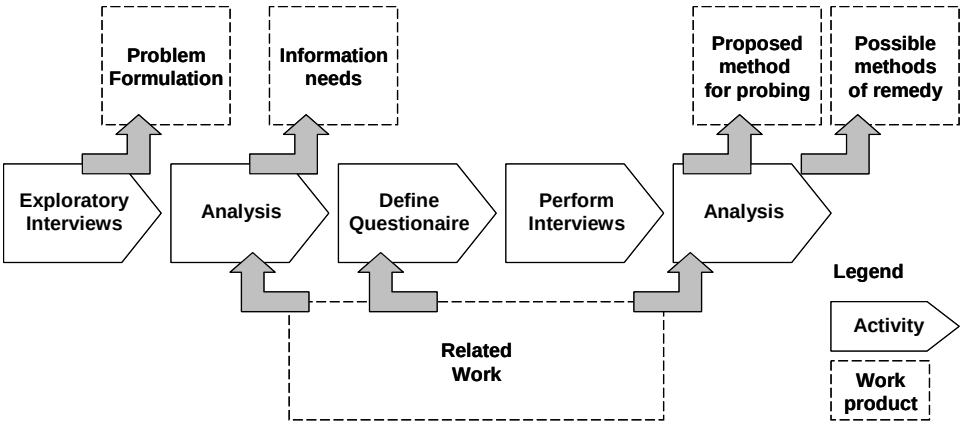

Figure 2. Overview of study method.

1. Exploratory Interviews. First we examined the development effort by exploratory interviews. Interviews were performed with eight line managers and project managers involved in the effort. The interviews were structured as open discussion around what challenges are faced and what the system is to do. The answers were documented and compiled into a problem formulation document that was reviewed by the respondents.

2. Analysis of problem. Secondly, we analyzed the problem formulation and listed the areas where some piece of information is missing in order to effectively develop the platform. Information needs were identified in five information areas around which practitioners expressed some level of concern.

3. Define Questionnaire. We studied recommendations and guidance in appropriate systems engineering literature and synthesized a probe of questions aimed to determine if the guidance is indeed followed.

4. Perform Interviews. To identify shortcomings in the platform development effort, we ask the probing questions to understand the ideas, decisions and strategy for handling each aspect. We note as specifically as possible what seems to be missing in the answers. We also note what different persons understand differently. We list deviations

where there are incomplete answers; vagueness of explanation, clear lack of explanation or a differing explanation among practitioners. Four people were interviewed with overlapping coverage of the five information needs. One line-manager, one program manager, one project manager, and one method strategist.

5. Analysis of the interview method and questions. We analyze the execution of interviews and the feedback given by respondents. We propose some changes to the questionnaire. Finally we compile the advice and recommendations that we found in the literature for how to address the challenges in platform development and discuss possible methods to use for each problem area.

We have not addressed the relative priorities of the needs expressed in the case. Instead we analyze each element of need and try to provide a method to probe for absence of critical information and provide guidance for a remedy. We note that the problem areas are quite general and the guidance we provide would therefore be useful in other cases, but we cannot claim to have addressed all pre-study problems related to platform development. By using guidance in literature, we seek to assure a complete coverage of the specific problem areas reported in the case.

4 A CASE OF DEVELOPING A ELECTRIC DRIVE SYSTEM PLATFORM

In this section we study the challenges and needs in our studied case. Together with theory from textbooks, we synthesize a method to perform a pre-study status measurement (a probe) of a platform development initiative; in order to provide guidance of what to focus on in the pre-study work. We define and test the probe by data from interviewing the practitioners in the case of developing hybrid electric drive systems.

4.1 Exploring the Challenges in Platform Development

First, we explore the challenges perceived by the leading roles of the initiative. We had predefined questions on functionality, components, methods and more but discussions were allowed to roam free. We list the challenges found below:

C1. Elicitation of complex application use requirements. An automotive product can be used in a number of different applications e.g. transporting goods on flat ground, or lifting material in steep slopes in a mine. Each application may require different vehicle properties and drive cycles. These different uses of the vehicle create a variety of demands on the drive system.

C2. Method to coordinate multiple drive system development. The method to systematically manage the development effort is reportedly a challenge. The overall idea is to reuse assets from a common drive system platform. The decisions on what and how to develop reusable assets must be kept on a strategic level outside the individual development projects. There are remaining challenges in creating a structure where decisions are taken outside an application driven development project. The resources on developing the platform should be prioritized so that the efforts that will serve preferably many drive systems and preferable yield benefits to the highest possible number of existing and upcoming customers.

C3. Deciding content and system boundary of the platform. A specific problem is the problem of deciding on a scope and boundary of the drive system platform. What and what not to include in the platform directly affects what application that can be supported and not. Supposedly, it also affects the effort of adapting platform assets to a vehicle system. Respondents do state that the boundary of the drive system platform is not set, neither is the definition of the system boundary.

C4. How to organize? Organizing this effort seems to be difficult within the boundaries of the current structure of the company. A model for deciding on organization seems needed.

C5. Method to estimate scope of applications. One area where developers of the platform will need to get information is an estimated volume, scope and usage profile of the platform product. It is expressed that it would be difficult to take design decisions without these facts as optimization criteria.

C6. Method to estimate the business criteria. The idea with reuse is to minimize development effort for subsequent uses of the same technology. Respondents express that the criteria for how much development effort is allowed in order to be considered business worthy must be made known in order to plan and execute platform development. Work on business model seems needed.

4.2 Analysis – Underlying Information Needs

We are after a low footprint method and we would like to find the essential elements of the platform development in order to probe for potential weaknesses. We go through the challenges C1-C6 found in the explorative study and we try to sum up the information needs that seem to be the underlying problem for the practitioners. We come to the conclusion that there are a number of information areas where the developers need information in order to perform their engineering tasks effectively. We categorize these information needs in the following five needs.

Info need 1. System content / boundary. In order to proceed with development of a platform hybrid electric drive system, information on what the system is to do and include is needed. Functional content and functional interface is requested. For a platform that is to support many development projects the requirements and boundary can be somewhat dynamic.

Info need 2. Application scope. Information on what applications are to be developed and supported by the platform in the future. This can be based on the current customer base and company strategy.

Info need 3. Business model. A business model describes the mode of performing business; what is to be sold; who is the customer. For instance it is possible to sell engineering hours, components, or up-time. Technical decisions are made based on assumptions around what business model is going to be employed.

Info need 4. Business criteria. Information on what constraints are imposed by the business context. There is a limit to what costs and development times can be accepted in order to meet business criteria. This information is dependent on predicted production volumes, investments, level of reuse etc. These business criteria parameters are likely dynamic over time.

Info need 5. Roles & responsibility. Information is needed on roles and responsibilities that will be involved in decision-making in the development effort.

The information needs are thus inferred from the challenges except for the third information need, which is inferred by using theory from textbooks. We see from both Sage [7] and Weilkiens [11] that a phase of business model decisions is a prerequisite to many activities in the requirement definition phase. This seems natural and also relevant for platform development where the business model must not necessarily be simple. Consequently, we draw the conclusion that this is an area of need in our case and add this to our list.

4.3 Compiling a Questionnaire

We have identified a number of information areas that supposedly must be addressed in order to set up the development effectively. To perform a pre-study, it would be necessary to probe the organizations status regarding whether the critical information is set and explicitly known in the team. Finding shortages could then guide activities of remedy.

We have scanned textbooks for guidance in these five areas. Then we synthesized out of recommendations and advice given for normal product development, a set of questions aimed to reveal if enough thought is given to each critical information area (1-5). Many theories provide guidance that is clearly aimed at products for end-users. We did during this step adapt questions to a platform product context.

Systems Engineering textbooks [9] prescribe to perform this activity - "Develop a detailed operational concept of the interaction of the system, the user, and the environment, that satisfies the operational need." Others [7][8] do prescribe activities much like this one. Thus they prescribe sound engineering principles but no precise criteria can determine if this is fulfilled. For a platform, the above problem of defining an operational concept is not straightforward. We want to get questions that can act as a probe and thus get an answer that provide a level of fulfillment. But, we must also get the respondents to describe the situation. Forcing only yes and no type answers would risk a too poorly described situation. As a general principle, we select, from textbooks, only a few questions, and mix measurement type questions with describe type questions. This way we get a list of questions for each area. The questions are listed below.

Info need 1. System content / boundary
1. What is expected by the platform by a development project?
2. What would characterize an effective use of the platform in a development project?
3. Describe a sequence of interaction between drive system and vehicle system.
4. Describe the requirements engineering activities planned for the reusable assets to be developed.
5. How are commonalities and variability identified and modelled?
6. Briefly describe what has been done in; Commonality analysis, Definition of the product line architecture, Definition of an operating concept
Info need 2. Application scope
1. What products are/ are not to be supported? Characterization?
2. Briefly describe what has been done in scoping of the product line
3. What vehicle functions are and are not to be supported?
Info need 3. Business model
1. Is there an established business case? Describe it. Documentation?
2. Describe the business logics.
3. Who is the customer?
4. What is to be sold?
5. Describe a successful customer sale in terms of development cost, price, investment
Info need 4. Business criteria
1. Describe and put numbers on your business goals for adopting a product line approach with reusable assets?
2. What is your timeline for carrying out this effort?
3. Describe a successful development project for a customer in terms of reusable

assets, development effort and time.
Info need 5. Roles and responsibility
1. Please identify the organizational entities responsible for the platform/reusable assets effort; Product line managers, System architects, Requirements specialists, Configuration management, Management steering group

Table 1: Questionnaire for each information area.

4.4 Analysis from Executing the Interview

Practitioners seem to agree that the areas of interest are relevant. Many aspects of the five information areas 1-5 were discussed. We draw the conclusion that at least these areas needed addressing in the studied case.

There were issues and discussions outside the scope of the questions. We believe the issues appear out of peoples' commitment and ideas and may be very hard to produce by having more "correctly" aimed questions. Rather we draw the conclusion that it is important to keep interviews in a relaxed and constructive spirit. Too rigid control of subjects may hinder.

4.5 On Analyzing the Results of the Probe

We do not provide a ready made structure for how to analyze the results. A perfect method would supposedly express quantified needs and, depending on the score, propose methods to identify candidate solutions and selecting the best one according to a criterion. Rather we leave to the investigator to record what shortages exist in a way that is suitable to the case. A better analysis guide seems possible, but for an early phase mapping method, it seems sufficient to pinpoint just the two principles of analysis to get an overview of where shortcomings are. We propose to analyze the answers based on two principles.

Principle 1. Where practitioners fail to convey the critical data, there seems to be a need of engineering or management decisions. These areas of need should be recorded.

Principle 2. We also propose to search for inconsistent understanding of the areas among practitioners. The principle seems to work well at identifying needs. Practitioners did easily see problems with having different understanding and seemed to be able to express what was needed to solve the inconsistencies. Areas of inconsistently perceived information should also be recorded.

In order to negotiate having inconsistent views in the team, a team activity such as a workshop seems necessary. A workshop could also function as a generator of candidate solutions. For instance, if there seems to be different understanding of the functional content of the platform, a workshop could provide means to identify the various thinkable candidates as envisioned by practitioners; possibly finding extreme cases and the reasoning for choosing each one. We draw the conclusion that a workshop is needed to perform the pre-study.

5 ANALYSIS – A PROPOSED PROBE AND LIST OF USABLE METHODS

This section encompass the analysis and attempted answers to the study question posed in section 1.6.

5.1 A Probe Method

Study Question 1. How can a pre-study be performed to address the critical information needs?

We found by interviews five identified areas of information are to be considered critical to the success of a platform development effort. For an arbitrary case there may be more areas to cover, but these five are derived from the study of the industrial case.

We have outlined a pre-study method aimed at identifying the critical needs of information in a platform development context. The pre-study should be led by an investigator and perform the following activities:

- Perform interviews with team members based on the questionnaire in Table 1 covering the five critical information areas.
- The investigator manually determines what elements of information out of the five areas are missing. Information areas that are not addressed or where team members understanding differ are recorded.
- Perform workshop with the key stakeholders of the team to negotiate differences in team understanding and to identify what possible solution candidates do exist.
- The critical information that is not decided and set can possibly be decided by using some of the methods we have compiled from textbook theory.

5.2 Usable Methods to Remedy Shortcomings

Study Question 2. What methods could guide towards effectively addressing the critical information needs?

Here, we provide a compiled list of relevant methods that could be used to aid in addressing the problems in platform development initiatives.

5.2.1 Methods to Aid in Defining Platform Content and Boundary.

The life cycle of a platform product is different from another product. One problem is to understand the systems engineering life-cycle of a platform product. Sage [7] lists typical activities that are involved in the engineering effort of a product.

One important activity is the decisions on the architecture. To handle this, a platform planning method is described by Ulrich and Eppinger [15]. The method is designed for physical products and focus on identifying functions and groupings of these, ending with the identification of geometry and interactions between parts.

Role playing with stakeholders is a way to identify all the critical aspects. Here, scenario based methods (e.g. [12][8]) can aid in identifying all different uses of the reusable assets during their lifecycle.

Deciding on the boundary of a subsystem when considering a single product to be developed can be done using a design structure matrix, DSM, or N2 chart. The separation of subsystems can be decided based on finding a solution that yields a sufficiently simple interaction between subsystems and fulfills a separation criteria. For a platform intended for multiple systems, the criteria are more complex. The subsystem boundary could be chosen so that it provides a low cost or low time for development for the majority of the intended applications. The effort of using the design structure matrix method could prove extensive in a practical case. Also difficulties are expected in getting the estimates of product volumes and costs that will be needed to define the criteria.

Modern methods to solve problems of engineering complexity is often cited to require the use modeling approaches [13][14]. Modeling a system is way to analyze the system and precisely express what entities and mechanisms are relevant, but can be a lengthy process.

5.2.2 Methods to Aid in Defining Business Criteria

In order to provide enough information that development of a platform can be effective, estimates seem necessary. Especially estimates of the scope of coming applications and the business criteria that are constraining the development are important. Estimations are necessary but impose a risk of guiding the development in a non-optimal path. As time progress, more information will likely be available and supposedly a better estimate is possible to obtain. Sage [7] outlines some techniques to assess risk according to several criteria.

5.2.3 Methods to Aid in Defining Application Scope

Clements and Northrop [1] offer a guide as how to perform scoping of the coming applications. In order to get a method for precise estimations it seems likely that a specific method be devised for this company. Company strategy and customers may affect the estimates.

6 CONCLUSION

Generally, the problem of system definition is more complex when considering the development of a platform aimed at supporting many development projects. Sage [7] states that the system definition phase includes activities to understand the problem and requirements. For a platform, the life-cycle can be more complex and cause the need for additional areas of information to be addressed in an early definition phase. We conclude that recognizing critical subjects is a necessary condition to remedy shortcomings in project definition.

In this study we have presented analysis of how to perform a system definition phase, or pre-study, when facing a development effort of a platform with reusable assets for series of automotive complex applications. Our analysis is based on compiling recommendations from the litterature and following an industrial case and practitioners.

Specifically, we have presented areas of critical information in the studied industrial case; presented a method for probing a mechatronic platform development initative which is partly tested in our case; and presented an outline of methods to address identified needs from the probing phase.

Eliciting the requirements is essential in any product development effort. In a development effort for a platform, an increased complexity is faced with more aspects to consider, more stakeholders, and generally a more strategic importance. Recognizing the critical information in an early phase could be one key to leverage complexity in an advanced product line effort.

In the future of this industrial case, we will research more aspects of a complex platform development initiative.

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