Engineering an Electric Drive System Platform for use in Multiple Automotive Applications

A Case Study

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Abstract Industries developing software intensive systems can gain benefits in development effort by using platforms of reusable assets, but challenges exist in effectively reusing engineering efforts. Problems can arise in requirements elicitation, establishing systematic methods around reuse, and estimations of uncertain factors in business and system usage. We present an on-going pre study to define a method to accommodate reuse of hybrid electric drive systems in multiple but similar heavy vehicle applications. We present an explorative interview study on the challenges involved, analyze the needs on a systematic approach, and provide a discussion on solutions. This on-going work shows that establishing a method to systematically reuse assets in development of complex software intensive systems may require solutions from a variety of fields, such as requirements engineering, management, and systems engineering.

1 Introduction

Industries that are developing complex long lived software intensive systems often face challenges related to reuse of development effort in order to offer cost effective systems. One strategy to succeed is to develop a platform that incorporates a common set of features and assets to be instantiated in a product line of automotive products, each used in different applications resulting in different usage scenarios. In automotive industry, it is the state of practice for many suppliers to offer a particular sub-system, such as a transmission system, to many Original Equipment Manufacturers, OEMs. Suppliers then strive to offer solutions to allow efficient instantiation to a many products, applications and usage scenarios, thus serving a large market.

We are currently performing a study to identify a method to systematically reuse the coming development effort of several and somewhat similar drive systems for automotive customers.

In this paper we present an ongoing study of a development initiative with the aim of establishing a hybrid electric drive system product for use in a number of automotive applications. A pre study is being performed with the aim of working out the method for a coordinated development of multiple drive systems. The pre-study is to identify major challenges related to the developing a platform of reusable assets that is to be offered to a wide range of companies that each develop and manufacture various automotive products (machines and vehicles).

This paper present: 1, a description of industrial challenges as described by managers and leading engineers, 2, analysis of the challenges with respect to what is needed to define a systematic method for reuse, 3, a discussion of how to approach and solve challenges related to the systematic reuse of development effort.

1.1 Platform Development

Figure 1 shows a general and simplified outline of a platform development process in relation to the development of several automotive drive system products based upon the platform.

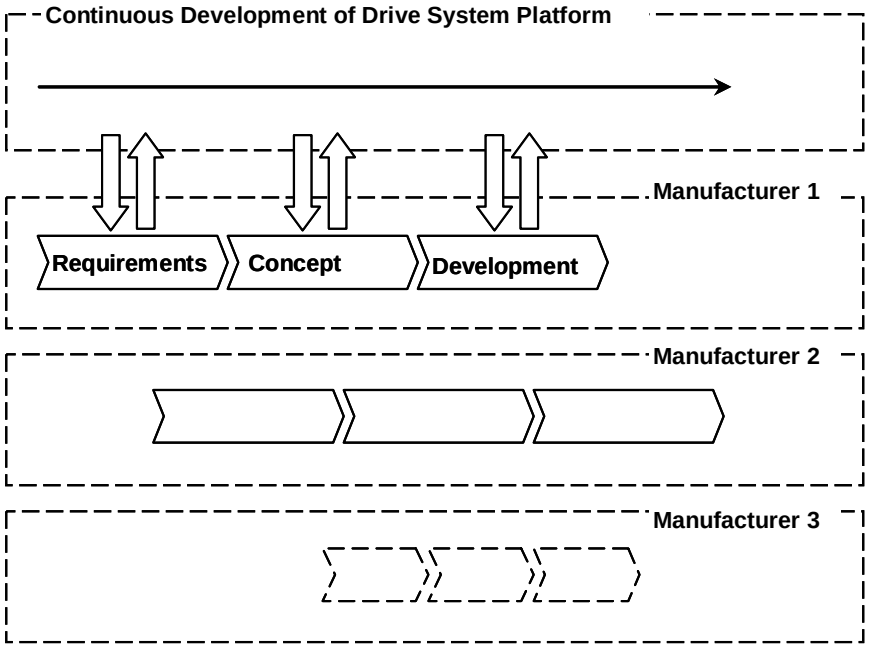

Figure 1. Platform development process

The platform is to be developed and evolved at the same time with development of several drive systems for specific products. Platform development is inter-twined with each individual development project and provides and receives information and assets. As the development progresses, more automotive products and applications will be considered. It is currently not fully known which products are to be developed and thus needs support from the platform.

Typically, a platform for use in many products has a longer life-cycle than the products and there is an ongoing development effort to change and improve the content and to support the development of more applications. The product development efforts are shown in a waterfall type of model while the platform is developed a continuous process to accommodate the current situation of upcoming products development projects.

1.2 A Case of Developing a Hybrid Electric Drive System

The starting point of the development effort at the studied company is an existing customizable drive system intended for only a few different applications. The goal of the development effort is to offer drive systems to a large number of customers with a much wider scope of applications. This effort of developing a drive system product is to be coordinated in parallel with development of several drive systems

for specific applications. It is not fully known which applications are to be developed and thus needs support from the platform.

1.3 Method of study

Interviews have been 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 Problem Formulation

In this section we compile the challenges as described by respondents on defining a systematic method for reuse in developing hybrid electric drive systems. We have sectioned them into three areas of problems. Problems are expressed that are related to the areas; Elicitation of complex application requirements; Method to coordinate multiple drive system development, Estimation of uncertain information on future use.

2.1 Elicit complex application 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 certain vehicle properties and optimum performance for a certain usage profile. These different uses of the vehicle create a variety of demands on the drive system.

- Method to identify required vehicle properties

Requirements on vehicle properties are numerous and many of them directly affect the drive system. There may be precise requirements on acceleration, force, fuel consumption, weight, heat, emissions. Identifying them is a challenge partly because the customer may not be aware of all of them.

Based on the wanted vehicle properties, the properties of the drive system is to be understood. Respondents point out that it is very important to understand the interface to the surrounding vehicle system. For instance, what is required by the drive system is highly dependent on system level decisions such as control strategy.

After understanding the wanted properties, there is still a challenge in predicting how design and concept choices affect the vehicle properties. It is difficult to predict precisely what a certain drive train concept will yield in terms of vehicle properties e.g. fuel consumption.

- Method to identify usage scenarios

A vehicle can be used in different applications, each characterized by a different usage scenario or drive cycle depending on what it is used for. Each application can require different properties of a drive train. Each drive cycle can yield different optimization criteria. For instance, the characteristics of the energy use throughout the cycle together with fuel consumption requirements impose requirements on a drive system. Two different drive cycles of the same vehicle can call for radically different drive system concepts in order to be optimal.

2.2 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.

- Strategy to manage platform development

It is estimated that development effort and developed components must be reused in order to meet the various business criteria. The decisions on what and how to develop reusable assets must be kept on a strategic level outside the individual development projects. Respondents express a difficulty in creating a structure where decisions are taken outside an application driven development project.

There is a need to analyze the platform life-cycle and provide information enough to support decisions on how to further develop the platform. Since it is to be used for many products it is a large risk that a currently important development project affects the focus of platform development.

Respondents state that there will be a difficulty in prioritizing development efforts. Tradeoffs will be made with respect to the estimated benefits of competing proposed efforts. 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.

- 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.

- 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.

2.3 Estimation of uncertain information on future use

There are several elements of information that are important to be able to decide on platform development.

- 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. It is expressed that it would be difficult to take design decisions without these facts as optimization criteria.

- 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.

3 Analysis

In this section we ask the question what is really the challenge and what need must be fulfilled to provide a solution. We are studying a development effort where a complex drive system is to be offered to a wide range of automotive applications. Practitioners express challenges in a number of areas. Here we analyze the challenges and provide analysis on how to understand the challenges.

The pre study that is being performed is to work out the requirements on a development method to support a coordinated development effort for multiple drive systems. Therefore, we elaborate on what elements are needed to be included in such a procedure. We then list what is needed in Table 1 as the list of challenges to be addressed by the overall development method.

3.1 Needs for Application requirement elicitation

Some challenges seem related to the difficulty of understanding requirements in a complex application. Each application has a usage scenario with a typical vehicle drive cycle that corresponds to the activities that are performed, e.g., a short loading cycle, which define the application requirements. A common method to analyze and tradeoff multiple application requirements would be desired as part of the overall method for development of reusable assets. The complete set of requirements could then be used for making decisions on the platform or product line level. What is needed to solve the challenge seems to be a method to elicit and compare application requirements and to understand how to select a drive system concept and reusable assets that meets and is adaptable to many of the requirements.

Another need here is to understand what requirements apply to the drive system as opposed to what is required of the complete vehicle properties. Respondents state the experience that the relation between drive system and vehicle system is complex and that customers do not always understand it. We draw the conclusion that the needed method may involve understanding vehicle properties as well. The challenges related to application requirements elicitation is listed C1-C3 in Table 1.

3.2 Overall Method to coordinate development efforts

There seems to be a need for a structure to manage and prioritize a coordinated development effort for product lines. A platform of assets can be seen as a product in itself where the customers are the development projects to use the drive system. Identifying the scope of the life cycle seems a key to understanding and defining the managing principles of its development. Support for trade-off decisions on development effort is requested by the respondents and this would require a method to estimate value that can be applied to competing suggestions on development goals. Deciding on system boundary and organization are also expressed as important challenges. Deciding on the content and system boundary seems viable only if there are estimates of the future use of the platform such as production volumes and some notion of customer value. These challenges are listed in Table 1 C4-C7.

3.3 Estimation of uncertain information on future usage

Estimations of information that is not yet known is expressed as a major challenge by the respondents. It seems natural that knowing or estimating the usage and

production volume is a prerequisite for designing any product. For a platform product, not knowing the usage in multiple development projects can prove paralyzing.

Respondents state a number of parameters that are needed in order to make effective design decisions. This includes the scope of coming applications and the business criteria for the effort. Engineers need to know which applications are targeted and what usage these involve. Also, constraints such as product cost and other business criteria are needed.

It is obvious from the interviews that development projects intended for one application cannot estimate the scope and business criteria. These needs are listed in Table 1, C8-C9.

C1	Elicit complex application requirements
C2	Method to understand required vehicle properties
C3	Method to identify usage scenarios
C4	Method to coordinate multiple drive system development
C5	Strategy to manage platform development efforts
C6	Deciding content and system boundary of the platform
C7	How to organize?
C8	Estimation of uncertain information on future use
C9	Method to estimate scope of applications
C10	Method to estimate the business criteria

Table 1. Challenges Compiled

4 Discussion on Solutions

Here, we provide discussion around available models and tools that could aid in defining a solution. It is possible that a development method can be defined by using existing techniques or adapted variants of existing techniques. It may be that specific problems in this case require a completely new or heavily adapted existing method.

4.1 Eliciting complex application requirements

Solution to C1-C3. The challenges C1-C3 relates to a difficulty in eliciting requirements from a complex application. These challenges seem related mainly to a requirement engineering process. Kotonya [1] proposes techniques to elicit and analyze requirements.

Goal-oriented techniques for eliciting requirements have been proposed to aid in attaining completeness of requirements and also to avoid irrelevant requirements [6].

Scenario-based requirements elicitation methods have been proposed [5] as a viable way of reasoning about the different uses of a system. Scenario based methods could be applied to identify the complete usage profile of the drive system including service and fault tolerance schemes that may not be obvious from strict operational viewpoint. The interaction between vehicle system and drive system seems possible to map and understand using a scenario based method. There could be possible to find system actors that require the drive system to support various scenarios related to vehicle system functionality such as braking, boost, recharging.

In summary, combining the above methods for requirements elicitation and applying it to the case of drive systems may solve the problems C1-C3.

4.2 Overall Method to coordinate development efforts

Solution to C5. One part of the problem is to establish a systematic way to manage development of both reusable assets and products based on the assets. Clements et. al propose a method [2] to distinguish such development in three actitivities; Core asset development, product development and management.

Clements model is by name intended for software product lines, but practices and examples are often taken from software intensive systems rather than pure software systems. There may be a need to adapt this method to the specifics of drive system development. However, the method seems promising since it addresses precisely the problem that is expressed by the respondents.

Solution to C5. 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 [3] lists typical activities that are involved in the engineering effort of a product.

Role playing with stakeholders is a way to identify all the critical aspects. Here, scenario based methods [1,5] can aid in identifying all different uses of the reusable assets during their lifecycle.

Solution to C6. 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 is 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. Likely estimates of product volumes and costs will be needed to define the criteria. The challenge of estimations is discussed in the next section.

The use of DSM or N2 charts may be difficult if the drive system is complex and cannot be simplified, because of the resulting matrix size.

Solution to C7. We have not addressed the challenge of how to organize the developers. We need to retrieve more data on the current state of the organization in order to prescribe a useful and non revolutionary reorganization.

4.3 Estimation of uncertain information

Solution to C8-C10. 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 is constraining the development. 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 [3] outlines some techniques to assess risk according to several criteria. Clements and Northrop [2] 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.

5 Conclusion

In this paper, we have presented results from an interview study, analysis and discussion on possible solutions for establishing a method to coordinate development effort and reuse drive system assets in multiple development projects.

We believe this problem is general to industry companies working with complex long lived software intensive systems. A supplier company especially perhaps in the automotive industry will recognize and face similar challenges. Cost drives the attempt to reuse which may conflict with the business goal of providing a product flexible enough to fit many applications.

This on-going work shows that establishing a method to systematically reuse assets in development of complex software intensive systems may require solutions from a variety of fields, such as requirements engineering, management, and systems engineering.

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References

1. G. Kotonya, I. Sommerville, Requirements Engineering – Processes and Techniques, Wiley, 1998.
2. P. Clements, L. Northrop, Software Product Lines – Practices and Patterns, SEI Series in Software Engineering, 2002.
3. A. Sage, Systems Engineering, Wiley Series in Systems Engineering, 1992.
4. F. Van der Linden, Software Product Family Evaluation, Software Product Lines (2004), Volume: 3154/2004, Publisher: Springer, Pages: 107–109.
5. A. Sutcliffe, Scenario-based requirements engineering, RE '03 Proceedings of the 11th IEEE International Conference on Requirements Engineering, IEEE Computer Society Washington, DC, USA 2003.
6. A:V: Lamsweerde, Goal-oriented Requirements engineering: A guided tour, 5th International Symposium of Requirements Engineering, Toronto, 2001.