Set-Based Concurrent Engineering Model for Automotive Electronic/Software Systems Development

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Abstract

This paper is presenting a proposal of a novel approach to automotive electronic/software systems development. It is based on the combination of Set-Based Concurrent Engineering, a Toyota approach to product development, with the standard V-Model of software development. Automotive industry currently faces the problem of growing complexity of electronic/software systems. This issue is especially visible at the level of integration of these systems which is difficult and error-prone. The presented conceptual proposal is to establish better processes that could handle the electronic/software systems design and development in a more integrated and consistent manner.

Keywords:

Set-Based Concurrent Engineering, V-model, automotive electronic/software systems development.

1 INTRODUCTION

Development of new products is now considered fundamental for corporate growth and sustained competitive advantage. This is due to increased competition, the rapid development of technology and shortened product life cycles. The success of product development depends on several factors, such as the organisation and team structure as well as the technology employed. The mechanical aspect of the automotive product development has reached an impressive advance in automation and computerisation of the design and manufacturing using CAD/CAE/CAM, Virtual Reality and Rapid Prototyping. Although these technologies are state-of-the-art, they do not guarantee the production of a product that meets or exceeds customers' demands in terms of quality, innovation, cost, customisation features, service and delivery time. This is due to the fact that nowadays cars are software driven which gives it a luxury and modern character. This cannot be achieved unless full integration of electronic/software (E/S) systems is well placed in the vehicle. The task of E/S systems integration should be understood by all departments involved in product development, otherwise consistency problems are going to arise resulting in product and process re-design or even failure in the hands of the customers. This project addresses the challenging issues of the E/S systems development and integration in automotive industry.

Automotive industry currently faces the problem of growing complexity of E/S systems. The development process of these systems is not as mature as other processes within automotive companies, for example the development of purely mechanical systems. This issue is especially visible at the level of integration of E/S systems which is difficult and error-prone. Therefore, there is a need to establish better processes that could handle the development of E/S systems in a more integrated and consistent manner wherein different engineering teams would be able to communicate and collaborate more effectively.

2 AUTOMOTIVE ELECTRONIC/SOFTWARE SYSTEMS

The automotive industry has been facing an increasing complexity of E/S systems in automobiles for 30 years but nowadays this process has become challenging as never before. The reason for the growing complexity is decreasing cost of new technologies, market pressure for new innovative functionalities that can be implemented only by means of software and hardware as well as the need to reduce petrol consumption, gas emissions and improve overall performance. According to a recent study [1] there are 270 functions that run on 70 embedded platforms and it is expected that these numbers will grow. Dealing with the growing complexity is difficult at every stage of the development and at the integration stage it is even more complicated.

Modern cars are filled with a number of E/S systems that support different vehicle functions. According to Schäuffele and Zurawka [2] vehicle function is a set of functional features that the driver is able to control directly or can only perceive indirectly (for example steering is a vehicle function). Nowadays the majority of vehicle functions are electronically controlled and monitored. In every vehicle the complete E/S system can be divided into the following sub-systems:

- Powertrain,
- Chassis,
- Body, (Comfort, Passive/Active Safety)
- Multimedia. (Telematics, Infotainment)

Each sub-system is different, however they are all interconnected and form a network of modules like the one depicted in Figure 1.

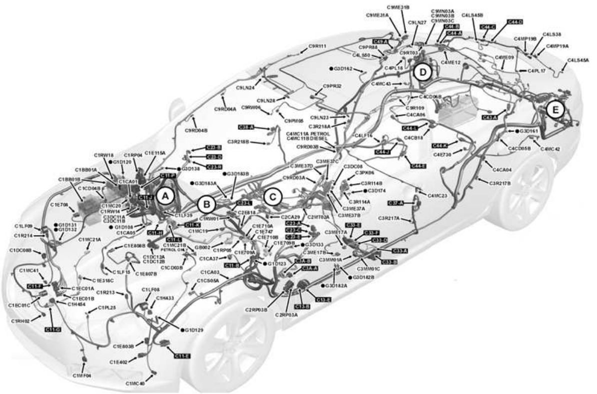

Figure 1. Network of electronic systems in a modern car (courtesy of Jaguar Cars)

2.1 Software Development Models

There are several software development and software process maturity models described in professional literature that could be used in automotive industry, namely: Waterfall model, V-model, Spiral model, various incremental and iterative models and Capability Maturity Model Integration (CMMI). The authors found that the variants of the V-model are most commonly used in the automotive industry. This fact is based on the experience of Jaguar with their supply chain and their formerly relation with Ford and current relation with TATA. In addition other automotive companies such as Visteon and Lotus are also using the V-Model.

The V-model is an extension of the Waterfall model. According to Schäuffele and Zurawka [2] the interactions among vehicle, electronic and software necessitate an integrated development process that covers all steps – from the analysis of user requirements to acceptance tests of the complete system. The V-model is indicated as the one fulfilling these requirements. The shape of the model – the letter "V" – reflects its vital characteristics that make it especially suitable for automotive embedded software engineering: **decomposition of the system** on the left side of the "V" and **integration of the system** on the right side of the "V" accompanied with testing at each level, see Figure 2.

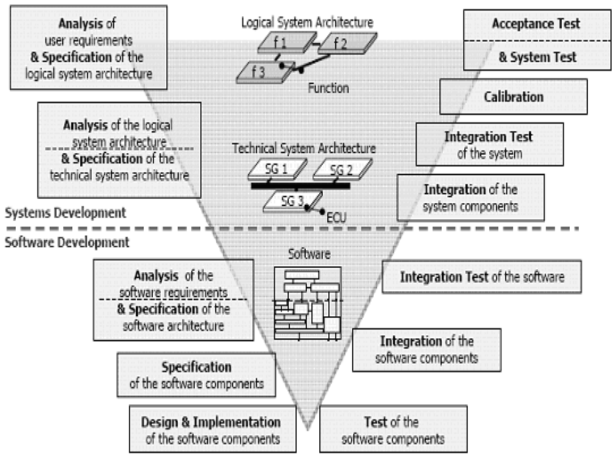

Figure 2. The V-Model [2]

The V-model has similar advantages and disadvantages as the Waterfall model: it clearly distinguishes well-defined stages but its sequential nature makes it inflexible. The process begins with the analysis of user requirements so if these are wrong, late changes are difficult to incorporate and very expensive. On the other hand, if there is significant effort made during early stages of designing logical and technical system architecture, the development of components can be relatively easy and integration is also supported.

3 THE CURRENT PRACTICE OF ELECTRONIC/SOFTWARE SYSTEMS DEVELOPMENT

This paper is a result of the MSc group project undertaken by post-graduate students from Cranfield University with Jaguar Cars. During the project the following areas for improvement were identified:

1. Communication within the department responsible for E/S systems,
2. Lack of ownership of interfaces and component-based approach to E/S systems development,
3. Requirements/Specifications generation, breakdown and management,
4. Supplier selection and relationship,
5. Procedures to support E/S systems integration,
6. Not appropriate or misused IT systems.

In Jaguar searching for the relevant product data is informal – personal relationships are an important facilitator in the information gathering. This is time consuming due to communication problems which affect the quality of the work. One major source of this problem is related to the interaction between the components and sub-systems of the E/S system of the vehicle, which are not well defined or understood from the conceptual design stage. In addition, the engineer responsible for the integration of the electronics and software components is unknown and not involved until the later stages of the product development. This means that the current practice and procedures are inadequate. The proposal presented in this paper is addressing all the areas for improvement above apart from point 6.

4 SET-BASED CONCURRENT ENGINEERING MODEL

Concurrent Engineering (CE) is an approach to product development in which multi-disciplinary teams work together from the requirements stage until production. The idea behind it is to ensure that the requirements of all the stakeholders involved in the product development are met. It reduces the number of late changes, time-to-market and cost as decisions at each stage of the product development are based on the common point of view of people from different disciplines involved.

Set-Based CE (SBCE) is part of Toyota product development system that is different from other manufacturing companies. Design participants practice SBCE by reasoning, developing, and communicating about **sets of solutions in parallel and relatively independently**. As the design progresses, they gradually narrow the sets of solutions based on additional information from development, testing, simulation, trade-off, customer and other participants until they agree on one solution [3].

4.1 The Combined V-model and SBCE

As identified in the literature, the V-model is a typical development approach to automotive E/S systems engineering. Its advantages are clearly visible due to the emphasis placed on decomposition of the system, integration and testing. However, V-model inherits typical weaknesses of the Waterfall model – its sequential nature and the prerequisite for early requirements correctness. The proposed novel model combines the typical "V" approach with SBCE. Set-based approach can overcome the need to specify all the requirements at the beginning, enables late-binding decisions and early verification of them. Concurrent and multi-disciplined team-working on the other hand can help to overcome sequential characteristic of the V-model. The model proposed intends to involve people responsible for E/S systems integration at the level of architecture design, early in the development process. This is based on the analogy found in mechanical domain where manufacturing engineers are involved into the design process early to ensure manufacturability. The overview of the model is shown in Figure 3.

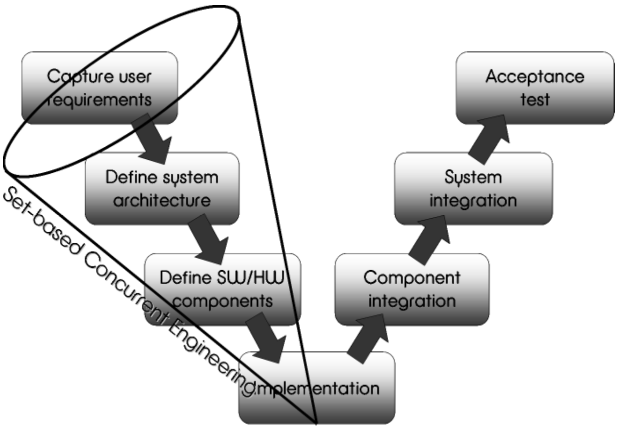

Figure 3. Combined V-Model and SBCE

The cone in Figure 3 represents the fact that the team responsible for the design of the architecture works with the set of conceptual alternatives narrowing the set down with increasing details and results from feasibility studies. In the model presented here the emphasis is put on the system architecture level. Traditional approaches that rely on the component level design are no longer effective. There is a great need to first have clear picture of what the overall architecture is going to be and evaluate different concepts using both quantitative and qualitative evaluation techniques. It is important for Jaguar Cars to know when architectural decisions about hardware and software are committed in order to support bottom levels with unambiguous picture of the system that is going to be developed. The proposal of the combined V-Model with SBCE consists of three stages. These are:-

- Capture user requirements.
- Define system architecture.
- Define sw/hw components and implementations.

The following sub-sections present each stage with some detail.

4.2 CAPTURE USER REQUIREMENTS

At the beginning of any product development process it is crucial to capture and understand customers' requirements. These can be captured and analysed in detail by a multi-disciplinary team consisting of people both from marketing and engineering lead by the *chief programme engineer* (CPE). This will enhance the communications among the team and then address the first opportunity of improvement. Techniques like *Quality Function Deployment* (QFD) can be applied at this level. In the proposed model, customers' requirements are reflected in the CPE's vision. The CPE's vision is a written document that briefly but precisely describes high-level functional and non-functional requirements, such as cost, quality, time-to-market, dependability, scalability of the system etc. This document has input from different participants but its final form is approved by the CPE. This recorded vision is then passed to functional engineers (e.g. electrical distribution, chassis systems, integration, infotainment etc.). The CPE's vision is supposed to be a document of major importance that all further developments have to conform to and has to be expressed properly so that everybody can understand it. Moreover, CPE should be a person with a very strong engineering background with at least several years experience in automotive E/S systems development rather than project management. This stage is depicted in Figure 4 and it is also addressing the third opportunity of improvement of requirement/specifications generation.

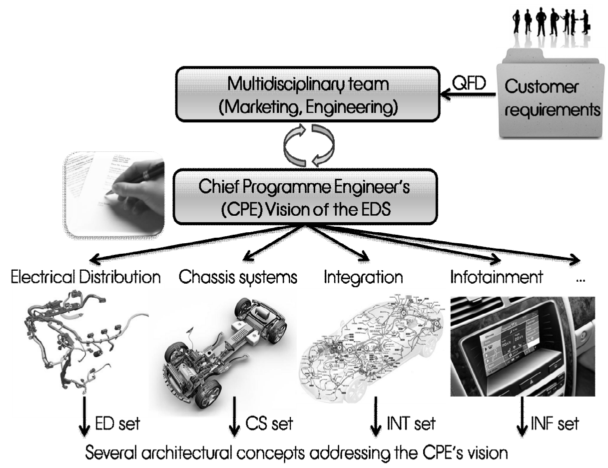

Figure 4. Capture user requirements and pass to functional engineers

4.3 DEFINE SYSTEM ARCHITECTURE

Once the vision is handed over to engineers who represent different functions, they start to develop simultaneously a set of conceptual architectural solutions of their domain that will conform to the CPE's vision, i.e. engineers responsible for communication buses propose a few different layouts. This step is based on the first principle of SBCE: **map the design space** [3]. The set of concepts is then given to the team called *System Design Team* (SDT) composed of engineers responsible for the overall architecture of the system including representatives from the integration function. This concept is called *Early Integration Engineers Involvement* (EIEI) similar to the concept of *Early Manufacturing Involvement* that comes from manufacturing domain. EIEI could also be a basis of *Design for Electrical Integration* (DFEI). SDT evaluates different concepts, combines them and creates a set of several conceptual architectures. The overall functionality of the system, its decomposition into nearly-independent sub-systems (that will allow a fairly independent development at the bottom of the "V") and functions performed by each sub-system are specified. At this level critical characteristics of the architecture must be taken into account, especially the degree to which system will be distributed and how scalable and extensible it is going to be. Engineers during the development should use approved knowledge that comes from previous experience and previous projects rather than personal opinions. Once the set of conceptual architectures is ready, the CPE evaluates them and chooses 2-3 for further development. These steps are depicted in Figure 5.

SDT have 2-3 conceptual architectures to focus on. The document called architecture study, which describes these conceptual architectures, is written and sent to evaluators like the team responsible for available working space, integration engineers, electrical engineers, mechanical engineers and key suppliers. SDT

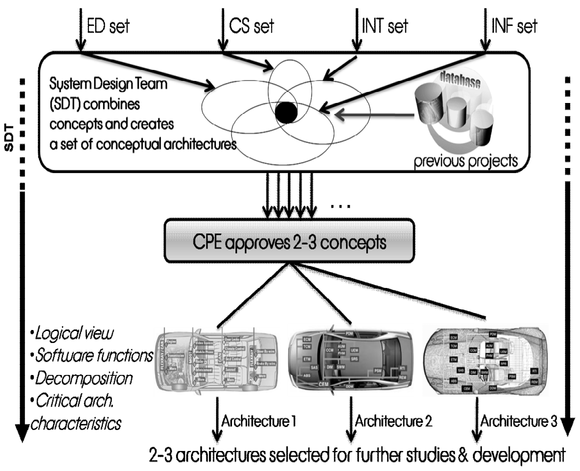

Figure 5. Define system architecture - Level I

starts to increase details of these architectures using feedback from different evaluators. This stage is an iterative and incremental process during which feasible designs are refined and the infeasible designs are eliminated. This step is based on the second principle of SBCE: **integrate by intersection** [3] hence support E/S systems integration that was identified as one of the opportunities of improvement in section 3. The architectures are now specified both at a general functional (logical) level and a physical level, focusing mainly on the interfaces between components and systems. Clear and complete definition of interfaces is of major importance as rigorous encapsulation is a guarantee of relatively independent development and seamless integration. As such this proposal is address the opportunity of improvement of lack of ownership of interfaces and component-based approach to E/S systems development. These remaining architectures are now simulated and evaluated by expert judgement. The results of simulations are analysed by SDT as well as other evaluators and the architecture with best results is chosen as the final one. This step is based on the third principle of SBCE: **establish feasibility before commitment** [3]. At this level the architecture is analysed by integration engineers and a document called *integration study* is elaborated. This document should include information about expected integration procedures, guidelines, possible problems and should be used during the integration stage as a basic guide. The final decision about the architecture is made by the CPE. These steps are depicted in Figure 6.

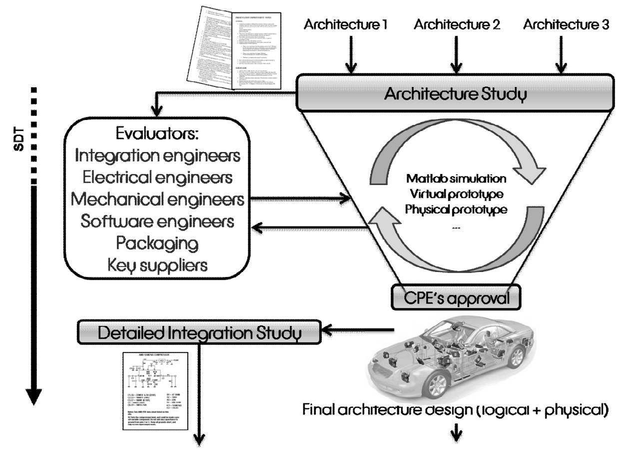

Figure 6. Define system architecture – Level II

4.4 DEFINE SW/HW COMPONENTS & IMPLEMENTATION

Afterwards, full-scale architecture development can be undertaken by different teams so that all software and hardware components are fully specified. It should be unambiguous what configurations the architecture will allow, full topology of the car network, number of time-triggered links, number of ECUs etc. As far as software is concerned, all software components should be defined, the underlying platform with a real-time operating system, real-time requirements of different software functions etc. In addition, decisions about which sw/hw components will be outsourced and which will be built in-house must be made. At this level it is important to have efficient and standardised policy for dealing with component (sw/hw) suppliers. When selecting the supplier, the decision should not be made just on the component cost basis, but also on its capability, conformance to specified quality standards, market position, ability to deliver the component on time as well as a long-term cost model. This model should address the re-education cost of new suppliers and the engineer's effort required in Jaguar to tailor new supplier's component to Jaguar's needs. While considering the change of the supplier that model should be taken into account. Once the component supplier is selected, a gateway process for reviewing the design should be agreed between the supplier, the direct component engineer and also engineers responsible for other interfacing components. In every stage of the gateway process there is a formal meeting between them. In that meeting the supplier explains the current state of the component development and all component engineers (direct + interfacing) provide him with the technical feedback. This approach should ensure that the supplier is aware of the inter-relationships with other components. This is shown in Figure 7.

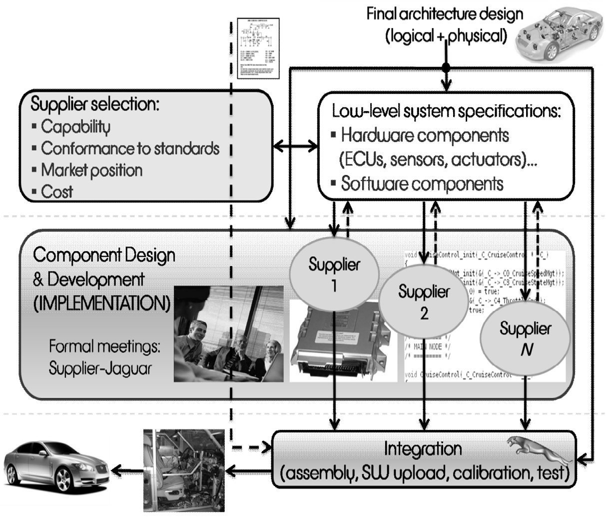

Figure 7. Define HW/SW components and implementation

5 DISCUSSION

It is deemed essential and quite significant to note here that the proposal of the new model for E/S systems development is a completely novel approach. It was ascertained from literatures reviewed that there is no evidence in the electronic/software product development of an approach combining concepts from the standard V-model and Set-Based Concurrent Engineering. The advantage of this combination is the SBCE was developed mainly for mechanical parts with emphasis on the body style [3 and 4]. The combination of the SBCE with the V-Model provided the right guide to consider the detail aspect of electronic/software development.

The electrical development team of Jaguar engineering centre has very positive opinion of the whole project that cover process model developed, opportunities of improvement (issues raised) and the proposed model that is the topic of this paper. The engineers were very impressed with the research approach taken for the study as being practical and realistic as well as the standard of the research team (the MSc students). While the proposal of combined V-Model with SBCE reflects the need of the current development process to meet the new challenges, further study is required to add detail to the proposal. Jaguar would like to look at the implementation of the technique as a priority concerns to improve the current process. Using this technique will improve the ability to design from a systemic approach, which will reduce the development timescales and costs and ultimately reduce our warranty figures. It is hoped to reduce the electrical warranty bill by more than 50%, and likewise the electrical development costs - particularly from a manpower standpoint. This would also offer Jaguar's customers an improved ownership experience.

Jaguar quantifies the impact of the study purely based on how many development issues might have been avoided had the development team better analysed our design integrity. Adopting the presented proposal, Jaguar estimates a reduction in late issue resolution of between 40 and 60%.

This model, if thoroughly defined and implemented, is expected to improve integration and communication alongside the product development process. It is recommended that further studies or projects should be carried out to extend the results from this project. It is believed that this model could be applicable in other automotive companies or even other industrial sectors, such as aerospace or marine.

6 ACKNOWLEDGMENTS

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