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A case analysis for PEArL: Software on wheels

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ABSTRACT

In recent years, the automotive industry has moved from building mechanical systems to creating complex 'system of systems' products, where functionality is controlled through multiple embedded software systems. These products are the result of increasingly complex design methods that require cross-disciplinary collaborations involving many different teams, each of whom work with diverse sets of expertise and working practices. This case describes an application of the PEArL framework, to connect different collaborative activity across a large automotive Original Equipment Manufacturer (OEM) in support of systems design practices. In the case presented here, the application of the PEArL framework also resulted in new organisational governance structures being adopted to embed collaborative design practices and to integrate the work of multiple design teams, both in the OEM, and along its global supply chains.

1. Introduction

Over the past 40 years, the car has changed in character from being primarily a mechanical entity with simple electrical systems, to the point where a car is now essentially a complex set of computer systems controlled by networked software intensive applications, or 'software on wheels'. The recent pace of development has been driven by the need to meet customer demands, offer distinct market differentiation and also by the need to satisfy increasing legislative demands. One of the implications of this increased complexity, is that the underpinning organisational mind-set of how to build a car also needs to change.

Car manufacturing has grown from a being a mechanical challenge, where a relatively small, often close-knit team of experts, worked on designs, to the systems of today, where creating these complex products requires the collaboration of many hundreds of experts with different domain expertise and varied professional backgrounds, often spread across a global supply chain. This case study sets out an example of the application of the PEArL[1] framework, (Champion, 2016; Champion & Wilson, 2010; Champion & Stowell, 2003, 2001), to support a team in the automotive sector managing the 'soft' challenges around improving the integration of different technologies and systems for complex products. The case describes how PEArL was applied to facilitate the design of new networks, relationships and innovative working practices. The PEArL framework was also used to monitor collaborative practice as the new design practices became embedded across the enterprise. Section 2 sets out the context and challenges at the beginning of the field study, with Section 3 briefly explaining the PEArL framework and Section 4 describing the work that was undertaken. The last section offers some reflections on practice, lessons learnt and makes some suggestions for future research.

2. The challenges of designing complex products

The growing trend for complex products to incorporate semi-autonomous operation or self-diagnosis within the product (making them potentially much safer and easier to use) is creating new levels of complexity for manufacturers. For example, self-parking systems or collision avoidance systems are appearing in vehicles as must-have features, but these new capabilities also raise important questions of legality, safety and societal trust issues as well as an assumed role and skill set of the operator. Additionally, the way in which these different systems and new technologies are integrated into product lines requires new approaches to information and knowledge exchange. This is particularly the case for large OEMs where design teams, manufacturing teams, service and dealership teams, can all extend across a global supply chain network.

Within manufacturing contexts, design processes for complex products are often based on the NASA 'Vee model', as this framework is the basis for the International Standard for Systems Engineering: ISO 15288. This 'Vee model' is a development of the traditional waterfall model of systems development, which facilitates a component-based view of the systems under development, and helps to manage the integration, verification and validation processes as a complex system, or product is designed, tested and built. Such systems development

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[1] PEArL: Participants; Engagement; Authority; relationships and Learning. The 'r' is deliberately small to draw attention to the most subjective element of the framework, and also the most important.

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frameworks make systems design on a large scale manageable, but there are also significant practical challenges to overcome. For example, using a component based approach to design of a complex system, often means that any integration issues between systems only become apparent when a design enters the build phase, and issues identified at a late stage of the development process are notoriously difficult and expensive to fix. Integration bugs in software controllers embedded in 'black box' components sourced globally can lead to expensive changes and reworking of designs further down the work stream. Other, more flexible approaches to systems design, such as Rapid Application Development or Agile Development are often used to build software prototypes, but are unsuited to managing the development process for very complex products as these methods do not facilitate the full traceability and detailed documentation required for safety critical systems. Model-Based approaches, or Product Line Engineering (PLE) can be helpful, but focus on achieving re-use and commonality across programme lines and while these approaches can help to reduce costs and keep programmes to schedule, these frameworks are still difficult to implement on a large scale, as they have been found in practice, to dis-incentivise collaborative design activity across different teams.

Managing and integrating the different forms of information that are created during complex systems design is a socio-technical challenge, where communication and relationship building activities are just as essential to successful design as ensuring the technical details are correct. Many companies use specific company-wide processes to capture information, but in practice, there is simultaneous design and development activity for several product lines in modern manufacturing environments, so a 'single-capture process' approach to requirements is infeasible. In addition, project management approaches focus only on the specific build in progress, and do not take into consideration downstream users of information, or the need for upstream feedback once a product is out in the field.

This case takes place in an automotive OEM which operates as a global player in the automotive market and produces a range of vehicles in the luxury and mid-price markets. Within the company, there was a recognition that they did not have a holistic view of the social processes that were currently being engaged in to support collaborative design work across teams within the enterprise. There was also a belief that these conversations and social activities were likely to be inefficient and that much work was being repeated across different teams. The design team managers were keen to understand what cross-team collaboration was essential, and how they could build the necessary relationships and inter-connections, to manage design effectively, efficiently and in a way that facilitated knowledge exchange and learning across the whole enterprise.

The core team that participated in the work described here was made up of a team of eight people, all but one of the team were employed by the OEM. The eighth person was the researcher. The project eventually involved contributions from 54 personnel, who were each involved in the product creation processes in this OEM. It is important to note that in this wider group of participants, as is common across automotive OEMs, some of the personnel involved in design work, (and who engaged in this project because they were considered members of one of the design teams), were actually employed by companies other than the OEM. For example, some design engineers were employed by component supplier organisations, or for technology companies who collaborated with the OEM on product creation and delivery projects. The aim of the project was to develop an approach to validate the collaborative working practices that were an essential part of the design work. In this case, the collaborative process of design was itself under scrutiny.

3. The PEArL framework

To successfully design complex systems and products, there is an obvious need to agree on the functionality of the system. This is where most engineering and technological frameworks are focused, including the NASA Vee model. The dynamic, fluid nature of collaborative practice that is essential to successful, robust design work is often overlooked in published research. This is because, traditional engineering approaches focus on constructing a description of the current system and then aim to abstract the requirements for a new system from their models. But successful design work also requires individual teams to agree *how* they are going to collaborate, in some detail. And this process also needs to take into account that, as a design process unfolds, participants change and modes of interaction and engagement can also change.

The PEArL framework was developed from systems theory to focus on the collaborative practices that make up a dynamically unfolding design process (see Champion & Stowell, 2001, 2003; Champion & Wilson,2010). In order to manage the social and subjective elements of a design process effectively, PEArL focuses attention on managing the changing relationships and on how to engage with an often dynamically changing team in the process. People can and do leave and join projects all the time in practical environments, e.g. due to changing jobs, parental leave, reassignment or promotion. The elements of PEArL help to maintain coherence in the face of a fluid practical reality. Table 1 provides an overview of the elements that make up the PEArL mnemonic.

Each element of PEArL will be in constant flux throughout a design process. PEArL operates as an integrating mechanism for collaboration activity and knowledge exchange, as demonstrated in the case.

One of the less acknowledged realities of collaborative design, particularly with critical safety systems, is that the mathematical approaches to modelling and testing that are commonly applied, are not sufficient on their own to demonstrate the appropriateness and validity of a particular design blueprint (in whatever format it is presented). In

Table 1
The Elements of PEArL.

Participants:	Most approaches to systems design undertake stakeholder analysis to determine who will use the system being built. The 'participants' element of PEArL focuses on identifying those people who are actively collaborating in the design process. By focusing on who is engaging, and who is not, it is possible to understand where there may be gaps in knowledge, and also to gain insight into if the project is gaining traction with the people who need to become engaged for project success. Setting out a plan for who ideally should be at meetings, and who actually attends, gives insight into the importance and value people place on an initiative, and who is choosing not to engage.
Engagement:	This element focuses on the myriad of ways people can be persuaded to engage and asks 'what type of engagement with different groups will achieve the desired outcome'? It asks people to consider the culture of the teams whose participation is required and then be creative in the mechanisms used to gain engagement.
Authority:	Projects are often led by those with financial authority over activities, but there are other forms of authority that need to be considered during complex design activities such as, where the intellectual authority resides for a specific design, and who has the social capital to get people engaged and motivated.
relationships:	The lower case 'r' has been chosen to emphasize this element of PEArL: managing relationships is the most important aspect of any social inquiry process and this includes the design of complex systems and products. Persuading people to collaborate and work together requires a team to think through what lines of communication are needed and what relationships are key to success. This aspect emphasises the need to build relationships before issues become acute and to ensure there are mechanisms for honest conversations where people's performance evaluations are not at risk if problems are raised.
Learning	The practical outcomes from the inquiry/design process reflect the transformation achieved. Ongoing reflection over the longer term can offer insights and knowledge into what network activities had the most value and how to manage constantly changing teams and priorities. Reflection over the longer term can also offer insight into any unintended consequences that can take time to manifest and can make an important contribution to achieving sustainable change.