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A Case Analysis for PEArL: software on wheels

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Introduction

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.

Keywords: PEArL, Complex systems design, Collaborative design

Case Analysis

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 and Wilson, 2010; Champion and 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

[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.

undertaken. The last section offers some reflections on practice, lessons learnt and makes some suggestions for future research.

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 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.

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 and Stowell, 2001, 2003; Champion and 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.

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.

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 messy, real-world design practice, subjective judgements about validity, integrity and appropriateness are made continually. The purpose of this application of the PEArL framework was to focus attention on these subjective aspects of a collaborative design process in order to develop and maintain the necessary communication and relationship network. In prioritising, these relationships, the PEArL framework places primary importance on demonstrating a design can be validated as having being created through engaging with the people with the right knowledge and expertise. In use, the PEArL framework essentially creates an audit trail showing who was involved in the design, when, for how long and for what purpose. This audit trail offers insight into the credibility of the final design by evidencing who was involved in making any judgements and the way that different teams contributed throughout the design and development process. As can be seen in Figure 1, the make-up of each element of the PEArL mnemonic could (and usually does) change throughout each stage of the design process:

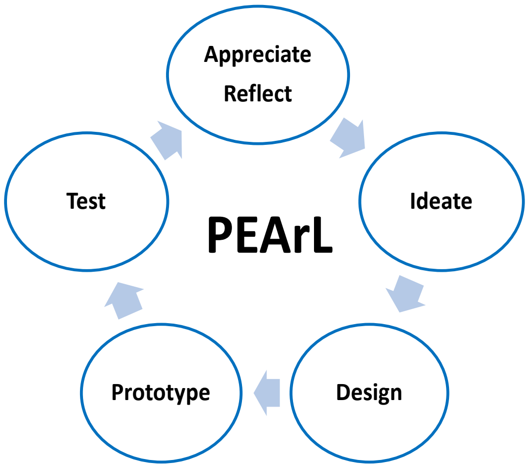

Figure 1: PEArL is applied at each stage of a design process

Figure 1 illustrates the way that at each stage of a design process, the participants (P), the methods of engagement (E), who has authority (A) and the relationships (r) between teams can be different. The Learning (L) will also be different at each stage and across each participant. This will be true for any design or change framework that is applied. In the context of complex systems design, there can also be multiple layers of design practice. The case set out below, demonstrates the application of PEArL in the context of complex product design and development in this automotive OEM.

The Project: Applying PEArL

The example set out here describes the application of the PEArL framework to improve collaborative practice across the product creation processes in an automotive OEM. As with most automotive OEM's, the company applied a standard approach to programme and project management using gateways at various points along a design process that was structured according to a waterfall mode of development. The senior managers overseeing gateways had financial responsibility for the programme being reviewed. Most of these programme managers had a background in mechanical engineering, due to the legacy of car design being a more physical/mechanical challenge in the past; very few of these managers had any experience of software development, or of managing software development teams. This traditional approach to programme development and review had resulted in the Software, Electronic and Electrical (SEE) teams having to put the systems they designed through inappropriate gateways. Appropriate design practices for mechanical systems are very different to those that are appropriate for software development. The senior programme managers who controlled the gateway processes lacked the knowledge to understand potential integration issues as a programme progressed and had often pushed through work before a new system or technology was ready. This had resulted in the OEM increasingly experiencing integration issues late in programme development due to unexpected software glitches, particularly when different software systems did not integrate as expected. Senior managers responsible for the programmes and gateways were blaming the senior managers in SEE for not producing their systems correctly, whereas the managers from SEE were pointing out that there was no time allocated to integration testing in the programme development process. SEE managers criticised the senior management for still thinking of the car as a physical product. They argued the car was now ‘distributed software on wheels’.

As part of a wider action research project, the senior director in SEE made the decision to use the PEArL framework, to review who was currently engaged in cross-disciplinary working, and to apply the framework as a tool to monitor who was involved in design decisions with a view to increasing the range of experience and diversity of knowledge that contributed to design and gateway review decisions. The first step was to investigate how gateway reviews were practiced at that time, ascertain who was involved, who took the decisions, who had the financial authority to make those decisions and who had the authority to change current practice on the ground. To do this, PEArL was applied as a monitoring tool at gateway review meetings for six months. Table 2 below summarises the elements of PEArL as applied to the review meetings at the start of this initiative.

PEArL	Review Meetings: Initial Analysis
Participants	Programme Manager and project managers for the programme, one technical specialist from design team, not necessarily with technical knowledge of systems being discussed
Engagement	Two hour meeting focusing on programme delivery problems
Authority	Programme Manager with financial authority for project only signature required.
relationships	Characterised by distrust between Programme and Design teams. Each regarding the other as lacking expertise and failing to understand the issues.
Learning	Standard documentation created according to PRinCE 2

Table 2: PEArL for review meetings summarised from the initial analysis.

In considering this initial review of participation in review meetings, it is important to emphasise that everyone in the OEM was working under very tight deadlines; designers, project managers and all the connecting support teams were under acute pressure to deliver on time and according to strict performance criteria. Everyone was focused on achieving their own performance indicators. It was equally apparent, that everyone was working to the best of their ability in a difficult environment, which was not conducive to reflection.

The process of identifying the PEArL elements associated with the gateway processes exposed a number of problem issues that needed to be addressed. First, it was clear that the majority of the senior personnel in programme delivery teams came from a mechanical engineering disciplinary background. This was unsurprising considering the heritage of the brand of the company. But the prevailing 'mechanical mind-set' across the company meant that there was a lack of understanding around how best to approach and monitor software development, and the integration of systems controlled through embedded software.

One of the main differences between senior managers from a mechanical engineering background to those with a systems, or electrical engineering background, was that the former, did not recognise the importance of cross-disciplinary working throughout the design process. This was evidenced by the fact that technical specialist engineers were often excluded from gateway reviews. These technical specialists were the people with the intellectual knowledge of the systems under review, but they were not invited to review meetings, as they were deemed to be insufficiently senior to attend. By excluding those with intellectual authority, problems and issues were then not discussed, and decisions were taken without a full consideration of the implications for downstream integration and build. The practice at gateway meetings was that the manager with financial authority for the programme made the final decision. This person was always one of the most senior managers, and was under a very exacting set of delivery performance indicators.

A further example of relevant expertise being excluded from review meetings could be found in the experience of the 'service engineers'. This group were responsible for designing the service protocols and also for creating any testing equipment required to service a vehicle with new functionality. One example of their work could be seen in the new protocols and systems they had developed to test and fix automatic parking systems, and cruise control features. The engineers in the service division, were often drawn from a software design background due to the nature of their work. This group had been excluded from almost all of the design process and review meetings due to senior gateway review managers not being aware of their expertise, or the potential value of their contribution. Indeed, one of the most senior engineers had instructed the research team "not to waste time in Service", but the engineers in the Service department were keen to be included, as they wanted much more collaboration with the other design engineers during the early stages of the process so they could input their needs and requirements. The application of the PEArL framework highlighted the need to incorporate relevant knowledge and intellectual expertise of both the technical specialists and the service engineers in the whole design process. This was identified as a priority, however, it was not a straightforward issue to address because of the way performance of individuals and teams was managed in the OEM.

Performance management across the OEM, as is common in Automotive and other manufacturing industries, was centred on delivery of product, to time and to budget. In practice this had resulted in disincentives for people to have uncomfortable, but honest conversations and to address problems early in the design process. Any delay in a project passing through a gateway impacted on an individual's score for performance, and this action could result in someone having their contract terminated. This approach was imposed on the OEM by its parent company. But this culture of performance management could be seen to be having a detrimental impact by the number of integration issues occurring late in the design and build phase; programme launches had been delayed very close to the specified delivery date on a number of occasions, costing the company a great deal of money. New ways of having difficult conversations as early as possible needed to be designed into the process, and so new relationships between design and programme teams needed to be forged and embedded into the gateway review process.

To reimagine the review processes, the research team ran a number of workshops and world café events to gain input from a large cross-section of the design and programme teams and created a new PEArL that set out an idealized view of how collaboration and knowledge exchange could effectively be undertaken and integrated into the OEM processes. Table 3 below summarises the idealized view of programme reviews created through this process.

PEArL	**Idealised View of Gateway Reviews**
Participants	Programme Manager, project managers, technical specialists, relevant design expertise with representatives from manufacturing and service for some systems.
Engagement	Half day meeting focusing on design and integration to correctly identify any programme delivery problems
Authority	Programme Manager with financial authority, and relevant technical specialists required for sign off.
relationships	Characterised by respect and trust for the expert knowledge each member contributes.
Learning	Standard documentation created according to PRinCE 2. Plus documentation associated with software development from Agile teams, with PEArL elements also being recorded. For some critical safety systems, documentation associated with manufacturing and service was also required

Table 3: Idealised view of Gateway reviews for systems with embedded software

However, it became apparent, that because the technical specialists (including functional safety experts) were usually more junior than the programme manager, simply inviting these people to attend reviews did not necessarily mean their professional opinions were taken into account. What was needed in order to promote the credibility of intellectual knowledge was a new organisational structure to give more weight to some of the technical expertise in the

OEM. The first example of such a new structure came in the form of a technical working group composed of the functional safety experts from across the OEM. This group met regularly to exchange knowledge and also to review the design specifications for systems going through reviews. Any recommendations, particularly if the recommendation was not to permit a system passing a gateway, came from the whole group, not an individual engineer. This process gave the recommendation much more weight, and also avoided a situation where undue pressure might be put on one individual. This group also reported to a more senior Steering Group meeting of OEM directors. The purpose of the Steering group was to improve practice and understanding across the more senior management team and also to monitor progress towards targets. Involving the senior team in discussing the issues around integrating systems with embedded software into complex products also helped to create a body of evidence to demonstrate how the performance review process actively prevented the OEM from having the conversations they needed to have in order to prevent late integration issues in a programme. Although officially the performance review process remained unchanged, the new organisational structures for technical specialists resulted in a different approach to conducting individual performance reviews, so individuals were not blamed for delays.

Lessons Learnt

Unlike frameworks for systems design, such as the waterfall approach, or prototyping and agile approaches, PEArL focuses attention on the manner in which activities are undertaken, and so offers insight into the collaborative practice in any organisational setting. PEArL can be applied to analyse current practice, to design new collaborative practices, or to monitor if new practices are being taken up and embedded in any particular situation. PEArL can also be used to monitor the changes that will inevitably take place in the make-up of a team through a long term project. The application of PEArL in this case highlighted the following lessons:

1. Designing complex systems and products requires an organisational culture and a reward structure that actively values knowledge exchange across disciplines, specialisms and professions.

Over time, the processes associated with the review meetings, and the new structure for technical specialists to discuss judgements before a recommendation is made, have given rise to new collaborations and relationships across programme and design teams. These collaborations have been demonstrated to impact on decision making practice, have resulted in fewer late-stage issues in software design. Additionally, the new structure has demonstrated value on a number of occasions with requirements and design for critical safety systems being reviewed and changed early in the process, preventing later programme delays.

2. The ability to leverage cross-functional relationships and knowledge exchange promotes the safe manipulation of information in logical architectures throughout the life of a complex system.

The importance of managing cross-functional relationships across an enterprise has been widely acknowledged for many years. But with the advent of digital systems and services, the need to be able to adapt and understand how to integrate systems almost instantaneously is fundamental to safety. In digital ecosystems, the ability to re-conceptualise and manipulate performance of a product, or a service, is increasingly necessary as a means of creating new value. PEArL focuses attention on ensuring the right intellectual knowledge and structures for engagement are in place to facilitate knowledge and information exchange throughout the life of a product.

3. Developing mechanisms in complex systems design to enable commercial judgements and decision making by senior management can be overlooked.

Systems design frameworks of every type are focused on designing the technical systems. Senior managers are rarely involved in detailed technical work, and so often need to make commercial decisions without active engagement in the detailed design work. The new organisational structures and practices that resulted from this work, provided a mechanism for facilitating senior management access to technical expertise from across the OEM in a manner that did not impinge on their seniority and credibility. The importance of senior managers needing to be seen to lead is an under researched issue in the literature on systems design.

CONCLUSIONS

The PEArL framework has been established across widely varying contexts as offering support to manage the ambiguities in complex systems design. PEArL has been applied in both fast-moving, market-driven environments and in community-based social enterprise contexts (Champion, 2014). The impacts resulting from the case set out here have been sustained for over five years with the OEM. One manager stated that PEArL had enabled the product creation teams to identify and drive business transformation towards a fully co-ordinated systemic design pipeline. The information created through traditional and agile approaches to requirements specifications and design work does not give insight into the context of decisions, or offer audit trails as to why decisions were taken. The PEArL framework can be applied to every stage of design, development, maintenance and upgrade to offer logical continuity for the context of decision making, giving important background for future judgements. Complex systems and products require highly effective knowledge exchange over time, and PEArL provides insight into this context in a world of dynamically changing teams and technology leadership.

Work is progressing to test the PEArL framework in increasingly complex environments. The connected and driverless cars of the future are dependent on complex software systems and products having the ability to communicate across digital infrastructures and networks in real time, and this is raising new sociotechnical challenges. The Information Systems community has not given these issues much attention to date, but developing new tools and methods for an increasingly digital world of networked complex systems and services would significantly contribute to offering value to business and academia in the future.

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