Performance Measurement in the Product Development Process

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ABSTRACT

The intention of the programme was to evaluate Product Development (PD) strategies within the automotive industry and to identify areas in which improvements could be made in PD project performance that would also provide a business opportunity for the author's employer RLE INTERNATIONAL (RLE). The research is principally concerned with the automotive industry but also has broader applications within similar industries.

The research was undertaken via three projects. Project 1 involved a study of the structure, drivers and trends within the automotive industry. The aim was to assess the implications for PD in the automotive industry and identify significant issues where opportunities for improvement existed.

The outcome was a portrayal of an industry under extreme competitive pressure and waiting for something to change but without a clear future state. What was apparent was that the competitive pressures, and thus the need to deliver more products without significantly increased resources, were not going to abate in the near future.

PD has to 'deliver more with less' but a definition of success and its associated measures in terms of the PD process is difficult to frame. Therefore, the aim of project 2 focused on performance measurement of the PD process by assessing four internationally diverse development projects carried out by the author's employer with four discrete customers. The projects were all different in their content and were carried out in different countries, i.e. USA, Germany, India and Sweden. Whilst customer specific and cultural aspects of the projects differed, the significant issue identified via the research was common across all the projects. Traditional Key Performance Indicators (KPIs) of cost, time and scope were used but failed to predict issues in project delivery. The key finding was that if project information did not flow as originally planned then resources were wasted resulting in time and cost over-runs.

Project 3 researched alternative solutions to the issue of monitoring information flow and proposes a specific method of indicating the likelihood of success in a project by identifying new PD measurement techniques to be used within the automotive PD process. This new measurement criterion of information flow provides a predictive tool that significantly enhances the project control process.

The predictive method of information flow tracking developed is new to the automotive PD profession. It was trialled on an existing project and was shown to identify specific issues with the Work-in-Progress (WIP) not found by traditional project management methods. The resulting indication of issues enabled the organisation's management to have a substantially different insight and understanding of project performance at a given point in time and therefore enabled immediate changes in resource allocation to improve project performance. The implementation of these changes as a result of the adoption of information flow monitoring resulted in significantly improved project KPI performance.

The contribution of this new PD management method has the potential to significantly impact the competitiveness of any company involved in the design and development process. Its benefits include improved understanding of project performance indicators, powerful predictive attributes resulting in better utilisation of company resources and reductions in both project costs and lead times.

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Finally, a special thank you to my wife Irma and my mother Jean for their on-going support and encouragement throughout my doctoral research.

PERFORMANCE MEASUREMENT IN THE PRODUCT DEVELOPMENT PROCESS

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Glossary of Terms

AIAG	Automotive Industry Action Group
APQP	Advanced Product Quality Planning and Control Plan
ASEAN	Associations of Southeast Asia Nations
AUTOSAR	AUTomotive Open System ARchitecture
BRIC	Brazil, Russia, India, China
BSC	Balanced Scorecard
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAx	Computer Aided x (where x represents any specific task)
CE	Concurrent Engineering
CPM	Critical Path Method
CTC	Concept to Customer
DI	Digital Innovation
Dr	Doctor
E^2	Effectiveness and Efficiency (O'Donnell and Duffy, 2004)
EFQM	European Foundation for Quality Management
EngD	Doctor of Engineering
ERP	Enterprise Resource Planning
ESS	Engineering Service Supplier
EU	European Union
EVM	Earned Value Management
FDJ	Final Data Judgement
FEA	Finite Element Analysis
FMEA	Failure Modes and Effects Analysis

FPDS	Ford Product Development System
FSS	Full Service Supplier
FTE	Full Time Equivalent
GM	General Motors
GPDS	Global Product Development System
IDEF0	Integration Definition for Function Modelling
IFG	Information Flow Graph
IMS	Integrated Management System
IPMA	International Project Management Association
IRR	Internal Rate of Return
ISO	International Standards Organisation
IT	Information Technology
J#1	Job 1 (First Production Vehicle)
KPI	Key Performance Indicator
LAI	Lean Aerospace Initiative
LPD	Lean Product Development
MADA	Multiple Attribute Decision Analysis
MPDS	Mazda Product Development System
NAFTA	North American Free Trade Agreement
OEM	Original Equipment Manufacturer
OPD	On-going Product Development
PD	Product Development
PDCA	Plan Do Check Act
PDM	Product Data Management
PDMA	Product Development & Management Assocaition
PDVSM	Product Development Value Stream Mapping
PhD	Doctor of Philosophy

PLM	Product Lifecycle Management
PM	Project Manager
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMO	Project Management Office
PRINCE2	PRojects IN Controlled Environments 2
QFD	Quality Function Deployment
QM	Quality Management
R&D	Research and Development
RFQ	Request for Quotation
RLE	RLE INTERNATIONAL
ROCE	Return on Capital Employed
ROI	Return on Investment
ROS	Return on Sales
SE	Simultaneous Engineering
SMART	Strategic Measurement And Reporting Technique
SOP	Start of Production
SORP	Start of Regular Production
SOW	Statement of Work
TOC	Theory of Constraints
TQM	Total Quality Management
UH	University of Hertfordshire
UK	United Kingdom
USA	United States of America
USP	Unique Selling Point
VM	Vehicle Manufacturer
VVA	Virtual Vehicle Assessment

WBS	Work Breakdown Structure
WIP	Work in Progress
WCP	World Class Process
WCT	World Class Timing

1 Introduction

Product Development (PD) is undertaken by the majority of the automotive Original Equipment Manufacturers (OEMs) with billions of dollars spent every year on designing and engineering new vehicles. This research programme aims to describe the industry structure and the various roles performed within automotive PD and identify the critical drivers of performance that determine success.

The arrangement of the work undertaken in this research programme encompasses three related projects and in some cases data from RLE INTERNATIONAL (RLE) commercial projects has directly contributed towards the proposals and successful outcome of the programme. The development projects involved are all from the automotive industry. However, the author has also sought to investigate and apply techniques from other industries such as computer software development.

In accordance with the prescribed EngD structure, this exegesis describes the general scope of the investigation; the overarching aims, objectives and research methodology in order to develop the context of the three projects and their outcomes. The three project reports are presented separately and are contained within appendices 1, 2 and 3. A summary of the content and outcomes of each project is included in chapters 4, 5 and 6. The summaries are followed by an evaluation of the deliverables in relation to their contribution to professional practice, the author's employer RLE (the organisation) and their relationship to the broader industrial application. Overall conclusions and recommendations, including future work, are also contained within this overarching thesis.

1.1 Research Background

The automotive industry has been described as the "industry of industries" (Drucker, 1946). The global industry is capable of producing in excess of 70 million vehicles each year and it seems this number will continue to grow despite falls in 2008 and 2009 due to the global financial downturn. However, the industry in the so called triad region of North America, Europe and Japan is witnessing extreme competition and relentless cost cutting activities. Conversely the BRIC nations, as categorised by Goldman Sachs, (O'Neill, 2001) of Brazil, Russia, India and China are experiencing year on year growth. The result is a global industry with local battles being fought on many fronts.

Automakers, commonly referred to in the automotive industry as the Original Equipment Manufacturers (OEMs), must continually bring to market new innovative and exciting products if they are to survive current and future industry shake-outs. Goals such as zero emissions and zero fatalities have been set by legislators and the OEMs themselves. These all add to the pressure on the PD process.

Whilst the need to operate in, and design vehicles for, the global market will continue, certain recurring issues such as project over-runs in terms of budgets and timing must be addressed. The author has been involved in development projects with several global OEMs and observed that whilst very complex PD and project management techniques are employed, understanding of performance measuring techniques that identify when and why things go wrong generally fall short of the companies' needs.

The techniques of Computer Aided Engineering, Design and Manufacture (CAE) (CAD) (CAM), collectively known as CAx, have provided the industry with significant advances in product geometry definition, virtual testing and manufacturing simulation. However, their use, whilst reducing time to market and eliminating costly prototype iterations has not alleviated some of the fundamental issues such as project over-runs in relation to planned budgets and timing.

1.2 Ontology

At this point it is worth outlining the position of the author in the context of the automotive industry. The author started his career with the Rover Group in Cowley, Oxford in 1984 and has since worked predominantly in PD organisations in the global automotive industry. He has lived and worked in Europe (UK, Germany & Spain), North America (USA & Canada) and Asia (Japan & Thailand). Additionally, the author has also been involved in projects that have included exposure to the automotive industries of France, Italy, Sweden, South Korea, Iran, Russia, India and China. He has been employed by OEMs (Rover Group & Ford Motor Company) and Engineering Service Suppliers (ESS) (International Automotive Design & RLE) and has worked with many system suppliers as both a customer and a supplier.

He currently holds the position of Group Vice President International Operations at RLE and in this role he has regular interaction with PD leaders at many global automotive companies, both OEMs and suppliers.

At the outset of this research programme, the author is of the view that PD is a process that involves people and the use of technology. However, how the people and technology are used are only two variables in the process. Other variables in the PD process include time, cost and quality.

1.3 Epistemological assumptions

The automotive industry is a truly global, diverse and very competitive industry. New products, and the processes of creating them, are sources of competitive advantage and are thus subject to very high levels of confidentiality.

The industry has a well-established knowledge base in terms of peer reviewed journals and research at companies, universities and government organisations.

The industry is also widely reported and industry leaders' personal beliefs and preferences are quite often published. However, it should also be noted that these publications can be used deliberately for dis-information campaigns, e.g. suggesting a company might be doing something that it is really not considering. However, by applying scientific methodological approaches involving systematic experiment and observation of phenomena, via qualitative and/or quantitative methods, new industry knowledge can be created. The overall research programme methodology is further explored in Chapter 3.

1.4 Context – Business Improvement Opportunity

RLE is headquartered in Cologne, Germany and is an Engineering Service Supplier (ESS) to the automotive industry providing resources to support the OEMs' PD programmes. These resources include people, facilities, computer systems and prototype build services.

The company has annual revenues of approximately 100M Euro and its competitors include companies such as Bertrandt, EDAG and MSX. An independent external evaluation (Pallis Associates, 2006) of the company's relative strengths versus Bertrandt and MSX was presented to the company's management as part of a strategic review of the organisation (Figure 1.4.1). Whilst the measures of aggressiveness and flexibility were generally the subjective views of the companies' customers, this assessment serves its purpose in identifying the organisation's comparative strengths and weaknesses in the market.

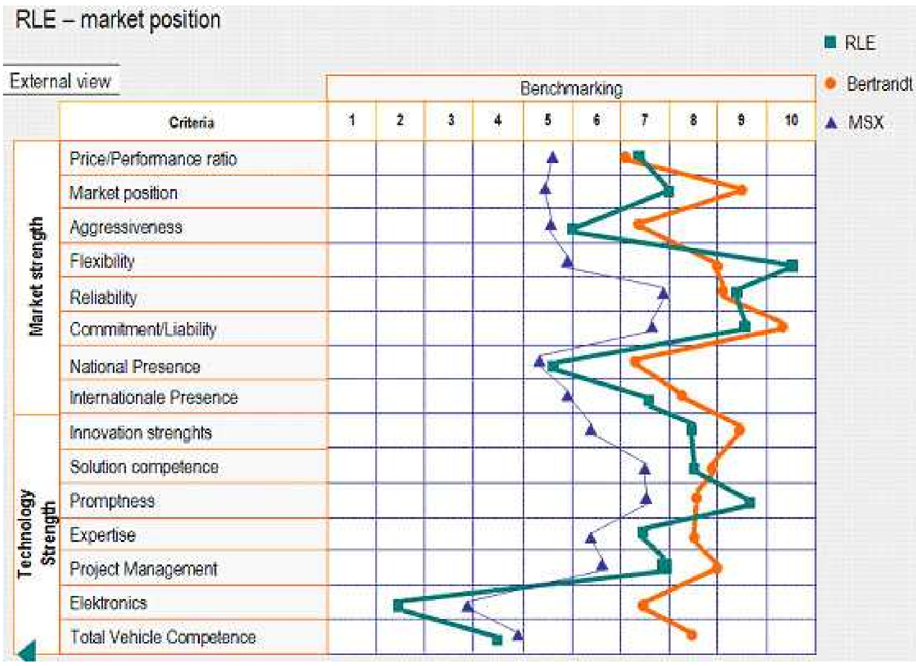


Fig. 1.4.1 – Relative Strengths of RLE (source: Pallis Associates)

The company has historically generated the majority of its revenues from simply supplying human resources to the OEMs and sending invoices on a monthly basis. Small projects involving five to twenty people have been undertaken at the company's various offices but this has not been a significant part of the business. However, the strategic review identified the need to move into broader project support activities.

Figure 1.4.2 shows the relative importance of having particular competence capabilities in-house, i.e. not outsourced to a third party, as the company moved forward.

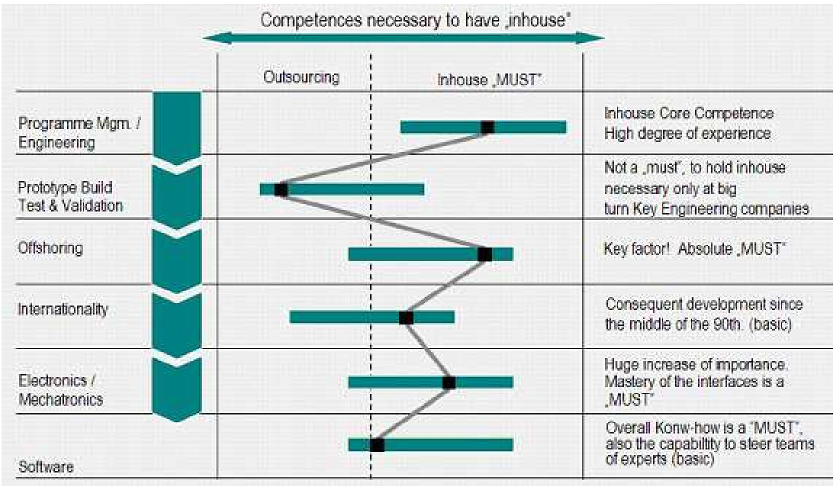


Fig. 1.4.2 – Strategic Evaluation of Future In-House Competences (source: Pallis Associates)

The main competence areas identified as necessary to have in-house at RLE were:

1. Programme Management / Engineering
2. Offshoring
3. Electronics
4. Software

Programme/project management and PD (engineering) competences were identified as the foremost capabilities to develop in-house in order to enhance the company's strength in the market.

This research programme addresses opportunity 1, programme management, and intends to identify best practice in project management of PD and to compare and contrast these to RLE's process capabilities. Simply attaining the same level of project management competence as the competition, e.g. Bertrandt, is not sufficient. The findings of this work must bring something unique to the automotive PD process that can be used to distinguish RLE by conveying a Unique Selling Point (USP) in the company's service offering and by supporting its effectiveness as a PD project delivery business.

Additionally, this EngD rests on the hypothesis that project management of PD in the automotive industry has inherent weaknesses with similar problems re-occurring time after time. Through the author's experience at RLE, and with previous employers in the automotive industry, existing problems were observed in the current methods used in the PD process. These include inappropriate planning, inadequate delivery, inefficient resource usage and project overruns in terms of cost and time. These issues have been witnessed in small projects within a single development centre location and also in projects involving hundreds of designers and engineers spread across three continents. Research has also shown that the PD process itself is one of the underlying factors of why car programmes fail (Hanawalt & Rouse, 2010). Here the term programme refers to the whole process of bringing a new car to the market including PD, manufacturing, purchasing and sales channel development.

It is envisaged that the new techniques developed as a result of this research programme will contribute to professional knowledge within the industry and competitiveness of the organisation by providing an improved PD methodology. The contribution to RLE should also provide a differentiated customer value proposition leading to competitive advantage in the market place.

1.5 General Scope of the Research Programme

This research programme investigates and critically assesses the current strategies and processes used in PD in the global automotive industry and proposes techniques for the future that will contribute to the body of knowledge within the industry. Strategies are only considered from the PD perspective and thus the project does not include other car programme aspects such as manufacturing and assembly supply logistics or the use of supplier parks, etc.

PD has been defined as "the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product" (Ulrich & Eppinger, 2008). This adequately describes the normal approaches within the automotive industry which typically follow the stage-gate model (Figure 1.5.1) that prescribes a formal review or 'gate' between the discrete activities. Adaptions of the stage-gate process with feedback loops are discussed in section 5.2.1. Alternative definitions and models of PD are discussed in research project 2 at appendix 2.

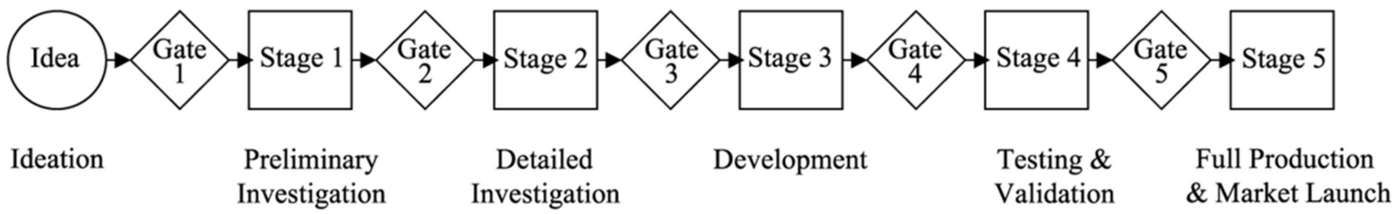


Fig. 1.5.1 – Stage-Gate Process (source: Cooper, 1994)

Initial idea generation, ideation, is often called the "fuzzy front end" and is followed by a preliminary investigation where the business case is justified. The general scope of this research programme is concerned with assessing performance in PD from the completion of the preliminary investigation phase, up until the introduction into full production, i.e. the stages 2, 3 and 4 in figure 1.5.1.

Whilst most of the global OEMs have developed their own PD systems, all generally follow the basic stage-gate framework. These systems or processes are typically adapted to suit the individual company scope and needs and are used to determine project timing and calculate resource allocation. An example from General Motors (GM) (Figure 1.5.2) is offered simply to demonstrate the level of complexity in the automotive PD process. Weeks remaining to Start of Regular Production (SORP) define the timescale across the top of the chart and different work-streams with specific review gateways are prescribed. Whilst the design and development phases are followed by the Complete Vehicle Validation (CVV) phase, involving the testing of physical prototypes prior to SORP, of particular noteworthiness is the use of Virtual Vehicle Assessment (VVA) reviews throughout the project.

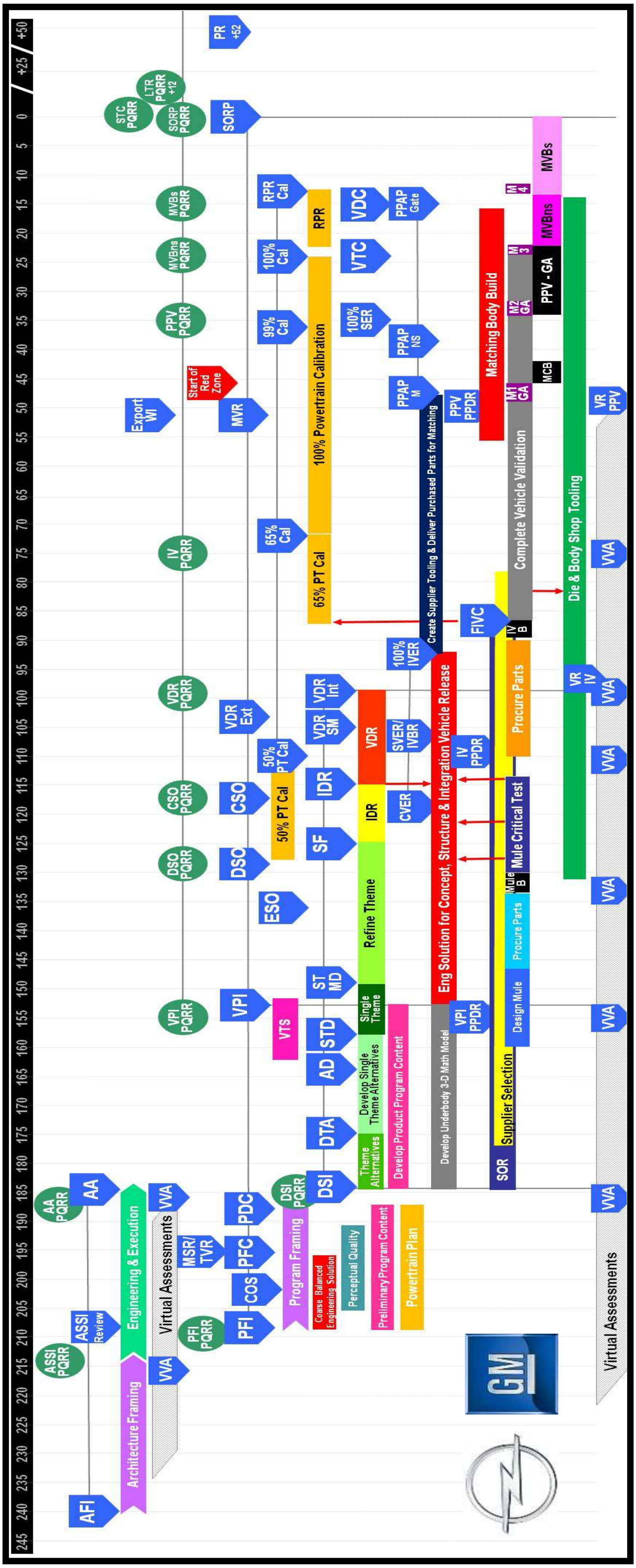


Fig. 1.5.2. – Typical Automotive PD Stage-Gate Process (source: RLE)

The PD departments at the OEMs can be seen as delivering an internal vehicle development service within the company. ESS companies such as RLE complement the OEMs' PD departments by bringing additional capacities or capabilities. Capacities may be simply headcount, i.e. people, whilst capabilities may include those not available within the OEM. The role of an ESS is further explored in project 1 of the research programme.

The vehicle development service offered by an ESS in the automotive industry can be represented as a value chain (Porter, 1985), figure 1.5.3, where the stages in the process are represented as primary activities with support activities or enablers such as:

- Human resources
- Technology
- Purchasing
- Infrastructure

ESS companies charge a margin on their services to generate profits.

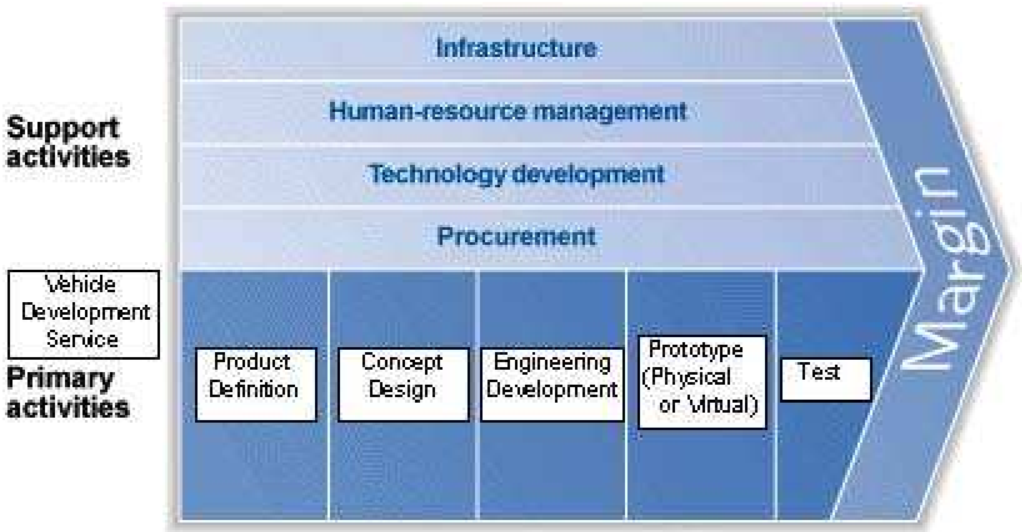


Fig. 1.5.3 – Porter's Value Chain Applied to an ESS Vehicle Development Service

(Adapted from: Porter, 1985)

1.6 Challenges and Complexity beyond PD

Delivering a complete car programme is a challenging undertaking. Whilst the detail in figure 1.6.1 is unimportant the left hand side serves to illustrate that PD, or simply product as it is referred to here, is only one aspect of a complex programme involving many other departments.

Beyond the PD department itself, bringing a new product to the market involves several other departments and organisations including:

- Product Planning
- Marketing
- Finance
- Design Studio (Styling)
- Manufacturing (Production)
- Purchasing (Supply)
- Suppliers
- Testing (Proving)
- After Sales Service

Coordinating the interfaces between these departments and managing trade-offs is a significant organisational task. Conflicts and tension between departments arise and must be controlled. Managing this complexity is an important issue in the performance of PD (Clark & Fujimoto, 1991).

RLE has traditionally managed the PD process by employing industry standard procedures including stage-gate timing, delivery definition, cost control, change control and resource planning.

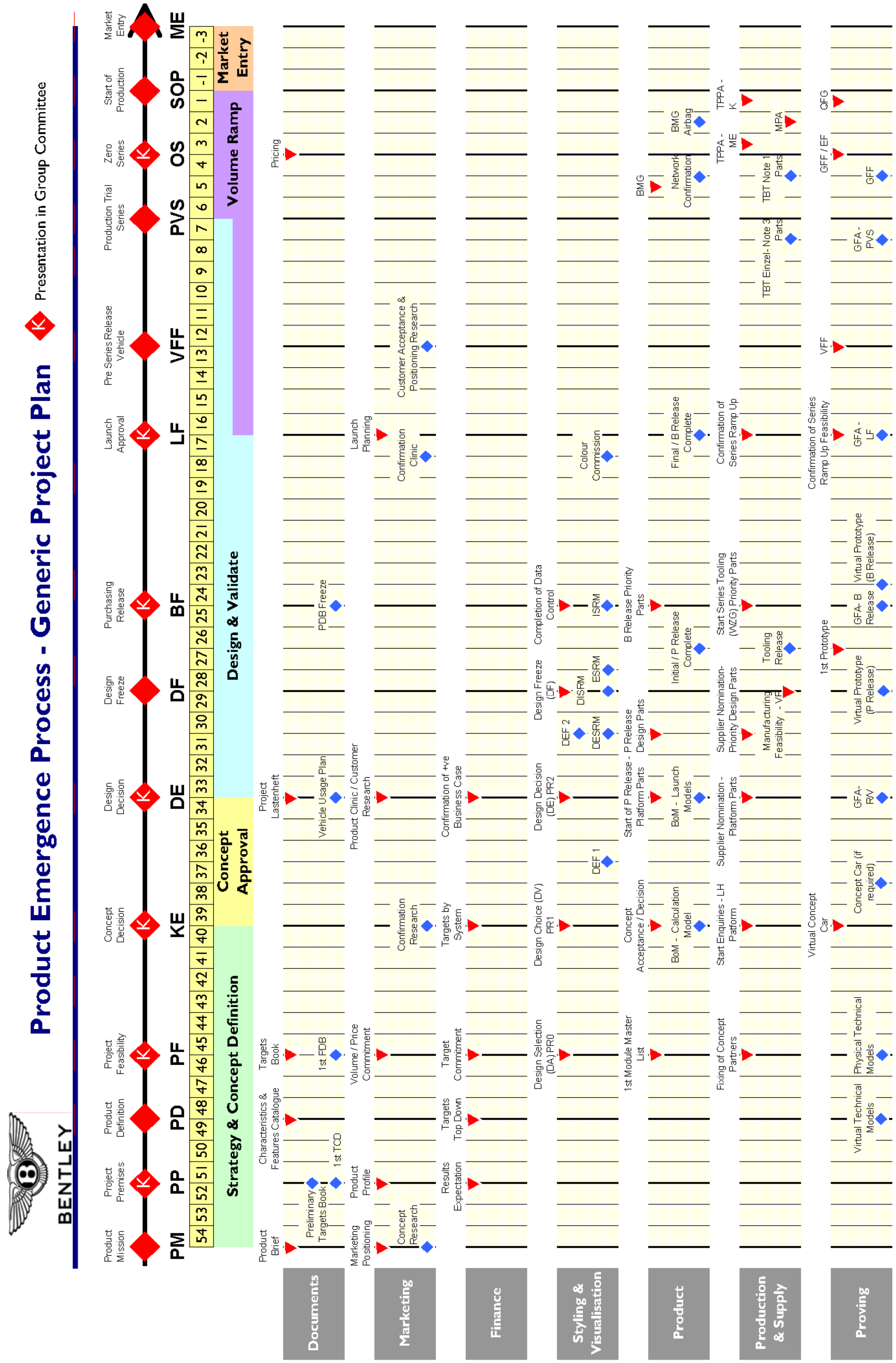


Fig. 1.6.1 – Generic Car Programme Plan (source: RLE)

2 Hypothesis, Aims and Objectives

In the context of the overarching theme of automotive PD, three projects were carried out as part of the research programme. The aims and objectives set out here are the overarching aims and objectives for the overall thesis. Each of the three research projects included in appendices 1, 2 and 3 commence with their specific aims and objectives. These should be seen as sub-sets of the overarching aims and objectives.

2.1 Hypothesis

The hypothesis of this EngD is that current PD processes used in the global automotive industry are inefficient in their use of company resources and not effective in consistently delivering value for the customer. Given the level of competition in the automotive industry, the PD process must be improved as it is fundamental to a company's strategy and competitive positioning.

It is therefore proposed within this research programme to explore and evaluate the efficiency of the PD processes within the global automotive industry and subsequently to propose means by which improvements can be made.

2.2 Aims

1. To provide an overview of the changing structure of the global automotive industry and to identify the consequences for its participants involved in PD.

2. To assess automotive PD and identify specific areas where advances could be made to improve the process.

3. To identify a new method and employ this on an automotive PD project to demonstrate significant process improvement.

2.3 Objectives

The overarching objectives of this thesis are developed from the research aims:

1. To investigate the current status of the global automotive industry and the roles of various organisations involved in automotive PD.

2. To identify industry trends and drivers and how they will impact automotive PD.

3. To analyse current industry PD standards and compare RLE's processes.

4. To assess specific aspects and techniques of current PD processes.

5. To undertake an evaluation on actual PD projects.

6. To explore alternative methods for use in automotive PD.

7. To identify and develop a new approach to improve automotive PD processes.

8. To demonstrate the validity of the new approach on a PD project in the automotive industry.

The overall methodology together with the specific methods and tools employed to achieve the research programme objectives are described in chapter 3.

3 Methodology

A research programme's methodology is concerned with the discussion of how a certain piece of research should be undertaken and to the choice of research strategy (Grix, 2010). A scientific approach is required to create the strategy and choose the research methods that influence the data collection and analysis techniques.

This chapter presents a critical review of the research methods, techniques and procedures used in the thesis and research projects. Each of the individual projects also contains specific project methods and techniques that are presented in more detail in the individual research project reports in appendices 1, 2 and 3.

The overall methodology represents the overarching mechanism of the whole EngD programme of work; a plan of inquiry which includes research design and data collection. The methodology of this thesis is structured sequentially starting with a hypothesis regarding an industry issue, a business improvement area, the derived aims, objectives, specific research questions and methods. Specific methods of data collection and analysis were chosen for each project leading to the overall conclusion of the thesis and contribution to the profession and organisation.

3.1 Overview

This overview sets out to demonstrate the overall programme aims and objectives and that the projects form a coherent and cohesive thread from start to finish.

Figure 3.1.1 shows the sequential flow and relationship between the major components of the thesis and of the three discrete, but related projects.

From the hypothesis that current PD processes used in the global automotive industry are inefficient in their use of company resources and not effective in consistently delivering value for the customer a business opportunity exists for RLE to develop and demonstrate improvements.

From this hypothesis and business opportunity, the 3 aims and 8 objectives are derived.

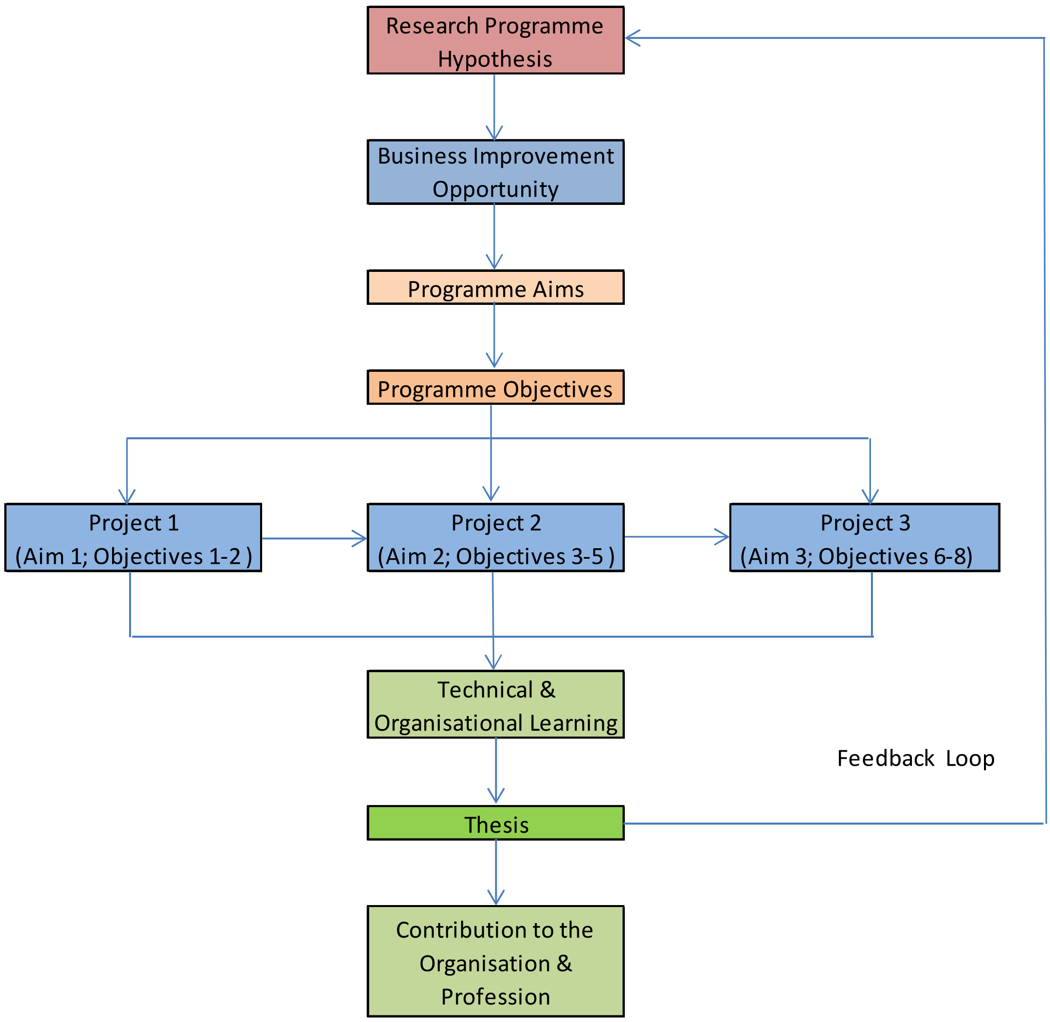


Fig 3.1.1 Research Design Flow Diagram

Project 1 investigates the overall context of PD in the global automotive industry as defined by aim 1 of the research programme and objectives 1 and 2.

Aim 2 and objectives 3 to 5 are addressed in project 2. The output of project 1 informed the research question for project 2. That is, how to more effectively measure performance to ensure a more efficient PD process.

Project 3 addresses aim 3 and research objectives 6 to 8 by employing a literature search for suitable techniques and then goes on to develop and demonstrate a new approach capable of fundamentally changing the control of the PD process.

3.2 Quantitative vs. Qualitative Methods

Quantitative methods are associated with enumerative induction based on the quantification of data. These methods are used to find general patterns and relationships among variables. The strengths of quantitative methods are ease of control and accuracy. Control is achieved by scientific sampling and data collection whilst accuracy is derived from reliable analysis and measurement of the data.

Qualitative methods are those by which the researcher can create knowledge assertions based primarily on constructivist perspectives. Hypotheses can be constructed from engagement with participants and exploration of emerging themes (Maxwell, 1996).

Qualitative methods can be viewed as research methods that emphasise words, rather than quantification in the collection and analysis of data. They tend to investigate the importance of the subjective and experiential to capture how participants interpret complexity. Therefore, qualitative methods are employed when there is a need to discern patterns, trends and relationships. The distinctive characteristic of hypotheses or propositions in qualitative research is that they are typically formulated after the researcher has begun the study. Clearly there are risks associated with subjective data and great care is required to identify truly authoritative voices.

Qualitative methods were employed predominantly in this research programme as the author wanted to establish inherent traits and characteristics of the PD process.

Qualitative researchers rarely engage in statistical significance testing (Maxwell, 1996), but rather state their ideas about what is going on as part of the process of theorising and data analysis. However, data analysis does include quantitative assessment by collating descriptors used, comparing for similarities and grouping into themes.

3.3 Interrelationship between the Research Projects

During the research process for project 1, it became apparent to the author that the competitive pressures within the global automotive industry were significantly more acute than originally considered and that they were not going to disappear. The research results included in project 1 informed and challenged the author’s pre-conceived ideas on the research questions for the subsequent projects to such an extent that projects 2 and 3 were completely re-defined. Moreover, in the post banking crisis economy of 2010, it was quite clear that the competitive pressures on the traditional players in triad regions of North America, Europe and Japan remained as significant if not more so than previously outlined. The bankruptcies of both General Motors and Chrysler in 2009 bear witness to this.

This spotlight on competitive pressure led the author to determine that what was actually needed from project 2 was a method of measuring the efficiency of the PD process before considering the enablers that may lead to a better or more proficient process. Project 2 identifies a significant PD performance measurement issue relating to information flow that is subsequently further explored in project 3 with a literature review culminating in the development of a new, predictive tool that was then tested via a demonstration project.

3.4 Project Specific Methods

Choosing appropriate research methods is central to the research development process. Across the three projects and eight objectives, six methodological tools were used to research the programme:

1. Literature Review

2. Questionnaire
3. Interviews
4. Case Study
5. Document Review
6. Participant Observation

Each discrete project includes an initial literature review to establish the current level of published academic research. Further, the relationship between the outcomes of the primary research and published research was subject to critical analysis throughout the research reports.

Guidance was sought on questionnaire design (Munn & Drever, 2004), interview technique (Kvale, 1996) and case study design (Yin, 2009).

Interviews were used in all three research projects. These qualitative research interviews were used to allow the interviewees to confer their own opinions around the questions and broaden the discussion as required. Ethics approval was granted for all questionnaire and interview stages of the research programme.

Document review in the form of content analysis was used in research project 2 and 3 to analyse the project management documentation in the project case studies.

The action research (Coughlan & Coghlan, 2002) in projects 2 and 3 also included participant observation in the form of complete observation, i.e. the author was not a member of the project teams but attended review meetings. These observations enabled the author to witness first-hand the issues arising on the projects, to log these and analyse for emergent common themes.

4 The Changing Structure of the Global Automotive Industry

Project 1 of the research programme aims to evaluate the current commercial state of the automotive industry and identify the roles and responsibilities of companies involved in the PD process. The full project report including comprehensive referencing is included at appendix 1.

4.1 Background

On a global basis, over 70 million vehicles are produced annually (Legget, 2011) and it seems this number will continue to grow despite the falls in 2008, and 2009 (Figure 4.1.1).

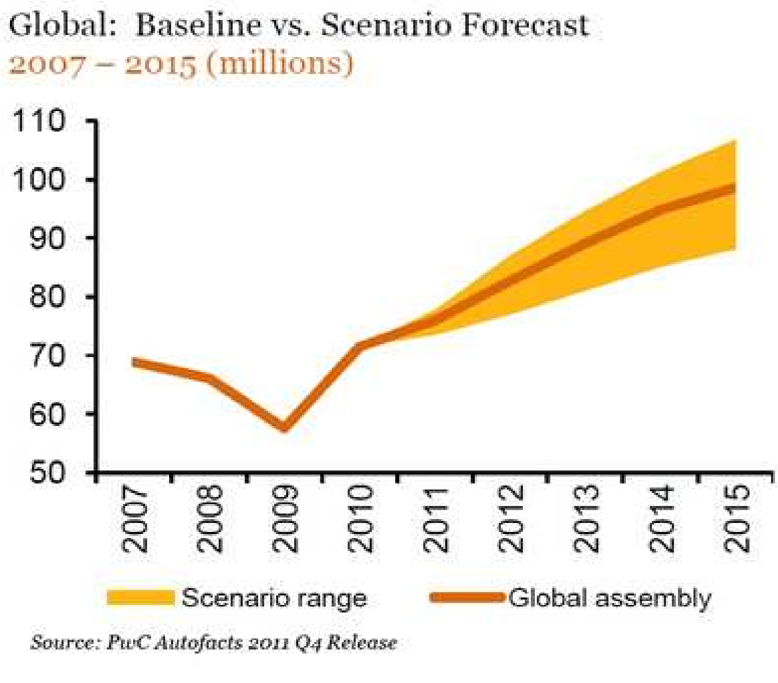


Fig.4.1.1 – Global Assembly Growth of the Automotive Industry (source: Leggett, 2011)

However, the automotive industry is highly competitive. Long term survival, growth and profitability will be the prizes for the companies that develop the most desirable products for their potential customers. The emphasis of Project 1 of this research programme is to explore the current issues within the automotive industry and how they impact on PD. The project also investigates the roles and responsibilities of the major organisations that exist within the global automotive industry:

- Original Equipment Manufacturer (OEM)
- Full Service Supplier (FSS)
- Engineering Service Supplier (ESS)

4.2 Evaluation of Influences and Trends within the Automotive Industry

An initial literature review highlighted that the macro trends and drivers in the industry (MacNiell & Chanaron, 2005a) can be summarised as:

- Global Competition
- Legislation
- Consumer Demand

In terms of how the automotive industry PD is segmented, Rentmeister (1999), figure 4.2.1, provides a useful model of collaboration identifying the two foremost types of suppliers to the car maker or OEM; the Systems Supplier and the Engineering Service Supplier (ESS). A System Supplier that also provides high level of PD capability, as opposed to just manufacturing the systems or modules, is known as a Full Service Supplier (FSS). ESS companies typically only provide PD services, but not components, to the OEMs and charge for their services as they are performed, whereas a FSS may amortise the costs of the PD into the final price of components they will ultimately supply to the OEM as part of a contractual agreement.

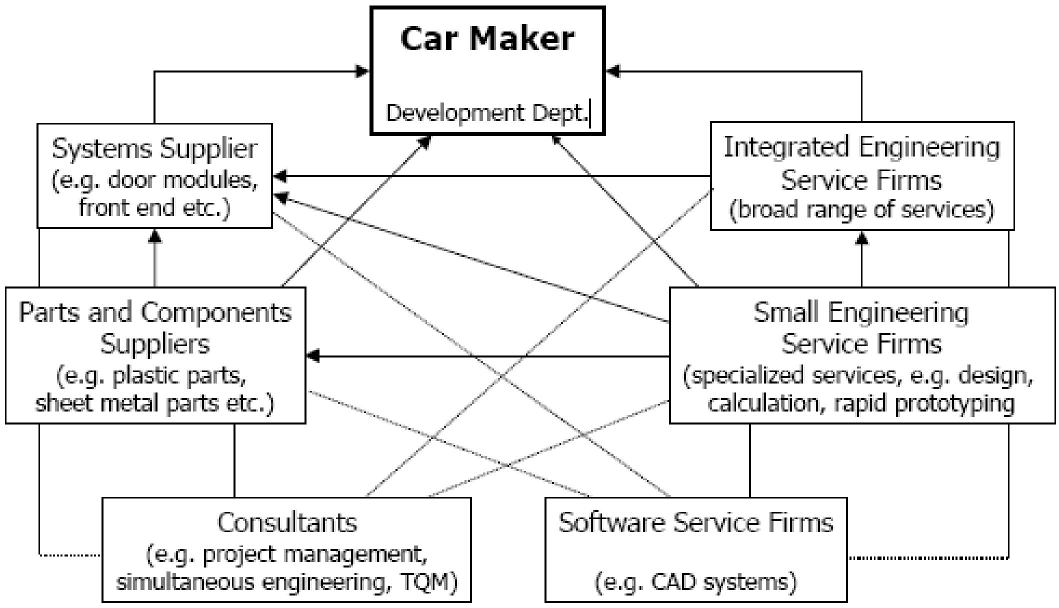


Figure 4.2.1 – Organisations involved in Automotive PD

(source: Rentmeister, 1999)

Rentmeister (1999) does not consider collaboration between OEMs on joint development projects, nor does this model include development by low volume contract manufacturers. For example, the BMW X3 variant was co-developed with Magna and is built by Magna-Steyr at its final assembly plant in Graz, Austria.

4.2.1 Method

Objectives 1 and 2 were researched by means of a literature review on the current status of the global automotive industry and the roles of various organisations involved in automotive PD. Primary research then sought to confirm the findings of the literature review and also identify further industry trends and drivers and how they impact automotive PD.

To meet the objectives of project 1 it was important to seek the opinion key informants with solid industry oversight and significant experience. The profile of the sample group identified comprised individuals with significant overview of PD in the automotive industry rather than detailed engineering responsibility. As the quality of data collected would be directly related to the interviewees' industry knowledge and experience it was decided to target only senior PD executives at global OEMs. This was more important than canvassing the views of hundreds of individuals by a large scale survey or by using focus groups or futures research.

A semi-structured in-depth interview technique based on a pre-prepared questionnaire was used. Derived from the research questions, the questionnaire used as a basis to the interviews sought to inquire as to the influences on the PD process as well as the types of collaboration and supplier relationships the companies had used in PD.

The questionnaire was piloted with a small sample of senior staff at OEMs that represented the sector. The outcome of this trial was a few changes in terms of the questions and structure. In particular, at the suggestion of one of the senior managers, the questionnaire was made to look shorter by combining two questions into one. In addition, the author sought advice on interview technique (Kvale, 1996) prior to organising the data collection events.

The questionnaire included structured questions on the type of PD collaboration and outsourcing employed by the participants and also open-ended questions to illicit their opinions on PD performance and future industry directions. Each interview took between one and two hours to complete.

The final questionnaire was presented in 3 sections addressing:

- Influences and trends in the industry.
- Collaboration and outsourcing on PD projects.
- Implications for the future.

The in depth interviews with the identified key informants were conducted over two days at the Geneva motor show where the author had established that most of the major global OEMs would be represented by their senior management including their PD leadership teams. The questionnaire was used to frame the discussion without leading the interviewees to any specific answers. Rather, it was used steer of the interviews whilst eliciting answers.

The author's company position enabled unique access to this highly experienced cross section of people whose insights are authoritative across a balanced array of companies and scale of PD processes. Interviews were conducted with senior PD executives from the following companies:

- Aston Martin
- BMW
- GM
- Hyundia
- Kia
- Volvo

This range of companies included representation from Europe, America and Asia. A confidential list of interviewees and their roles in their organisations is included in the project 1 report appendices, as is a letter and questionnaire used in the research. With regard to statistical significance, interviews were conducted with six of nineteen major global OEMs represented at the show. Whilst this seems, at first sight, to be a small sample, this is compensated by the combined experience (over 150 years) and provenance of the key informants interviewed. For example, the Volvo respondent managed a PD organisation of over 4,000 staff. The authority and validity of these views cannot be underestimated.

Qualitative analysis of the data collected involved interpretation by transcription of the interview notes, grouping of descriptors and searching for themes. A broader analysis, including questionnaire design and interview technique, is given in the research project 1 report at appendix 1.

4.2.2 Influences and Trends

Throughout the primary research, meeting customer demands and expectations whilst staying on top of cost pressures was a universal response. Consumer demand for a more varied product mix coupled with product life-cycles becoming shorter has resulted in significant increases in new product launches. Further fragmentation of markets and increased customer demand will require greater productivity in PD. The major OEMs are striving to increase sales volumes in their traditional markets whilst also trying to penetrate new developing markets with niche products. Figure 4.2.2.1 demonstrates the proliferation of models at Mercedes Benz over the period 1995 to 2008.

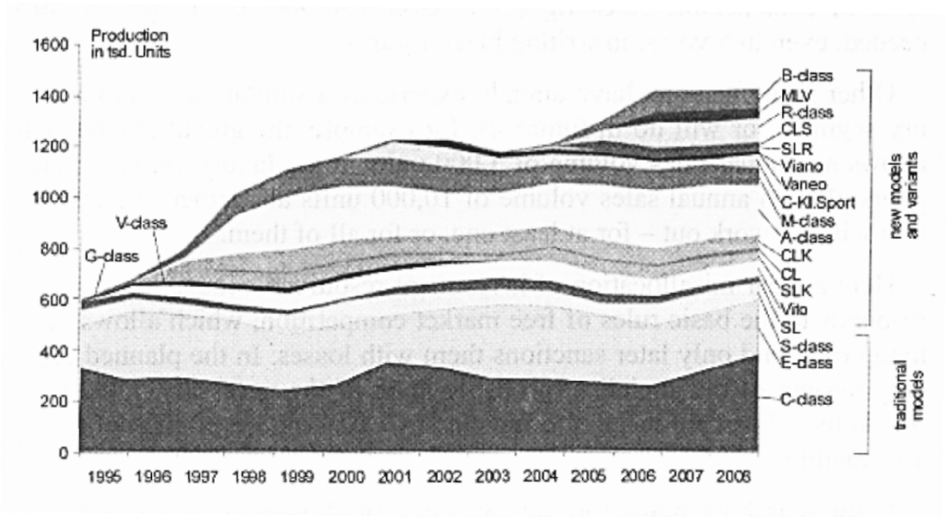


Fig.4.2.2.1 – Development of Mercedes-Benz models

(source: Becker, 2007)

Increasing global competition based on cost and legislation were mentioned by several interviewees and customer expectations were stressed by all respondents. Additionally, the interviewees didn't expect to see a significant change, i.e. reduction, in the challenges of balancing customer needs with the cost pressures resulting from global competition.

Cost issues were described in terms of investment, piece price and PD budgets. Some interviewees stated that they didn't know where cost pressures would stop and that China and India in particular are learning quickly in addition to operating from a lower cost base in terms of materials and labour.

These research findings on the global mega trends that will affect the industry until 2015 are broadly reflected the literature (Becker, 2007):

1. Volume markets in saturation
2. New orientation of global production locations
3. Brand orientation of buyers' preferences
4. Asian competitors on the advance
5. Changing energy supply conditions

In 2013, Becker's predictions are still valid. The latter point of energy supply has been well documented with the price of a barrel of oil exceeding $140 for a brief period in 2008. Whilst this was a peak figure the price is expected to reside above $50 per barrel for the coming years.

At the product or micro level, the needs to design products with the use of modular techniques and for sustainability of the environment were highlighted. Environmental issues and response to global warming fears will also play a part in the future but the OEMs will be led by legislation and incentive from governments (Sutherland, et al., 2004).

Modular manufacturing and design approaches are already prevalent in the automotive industry. Increasing modularity in vehicle design and the broader use of standards and conformity (e.g. AUTOSAR in electronics) has allowed suppliers to account for an increasing share of PD resources and along with greater adoption of computer aided (CAx) techniques this enables PD times to decrease.

In general, a comparison of results of the literature search with the primary research findings shows broad similarities but highlights one noteworthy difference. Of significance was the perceived failure of the system integration role provided by Full Service Supplier (FSS) relationships. This does not seem to be reflected in the academic literature. However, it is validated by the author's own experience and in some industry publications (Whitbread, 2003).

The primary research highlighted that the OEM's reliance on the use of FSS resources for development and integration is reducing and OEMs will do more system integration in-house in the future. Fifty per cent of respondents expressed disillusion with their experience of FSS relationships involving PD. The majority of the OEMs surveyed state that they will take back system integration from the FSS. One respondent in particular stated that this was part of a redefinition of the core competence of the OEM. Engineering Service Suppliers (ESS) should expect to pick up more business from the OEMs as a result of this. However, this increase in ESS revenue from the OEMs will be offset by a reduction of outsourced development work to the ESS from the FSS as their engineering content reduces. All interviewees had experience with, and viewed as successful, bringing ESS headcount into their OEM PD centres.

In general it was thought that specialist work needing a unique expertise would be outsourced in the future, i.e. the OEMs will be looking for specific capabilities in addition to just resource capacities. Additionally, to better utilise limited PD budgets, there is a need to set up networks with Low Cost Countries (LCCs) whilst balancing knowledge with cost levels, i.e. the cost advantages must outweigh the lack of experience of the engineers in these regions. Fifty per cent of respondents already had experience with working with LCCs.

All respondents identified virtual simulation as being of significant importance in the future. Within this, specific references were made to NVH, aerodynamics, craftsmanship and sheet metal stamping simulation and that vehicle attribute prototypes are no longer required. It was also pointed out that in the future the people and culture of companies must be conversant with and have confidence in these virtual CAx tools. The need for speed of reaction and flexibility was also highlighted.

In particular, the critical demand of delivering more projects with relatively fewer resources points toward a need for better understanding of automotive PD performance and efficiency.

4.3 Implications for the Automotive PD Process

Product differentiation will continue to be ultimately important in winning customers particularly in the brand driven markets described by Becker (2007). Thus, whichever way the automotive industry develops in the next few years the customer demand for diversity of product on offer is likely to continue to increase. However, PD budgets are not expected to increase as a percentage of revenues (Roland Berger, 2004). Figure 4.3.1 shows Research and Development (R&D) spend as a percentage of sales over the period 1998-2003. Whilst this chart refers to R&D as opposed to PD, where R&D generally includes advanced research as well as mainstream PD, these can be viewed as the same for this purpose. If OEM overall sales volumes are relatively constant it is clear that budgets for new PD are not increasing. Comparing this to Figure 4.2.2.1 showing new product launches highlights that the PD departments of the major OEMs are being asked to deliver more products with fewer relatively resources.

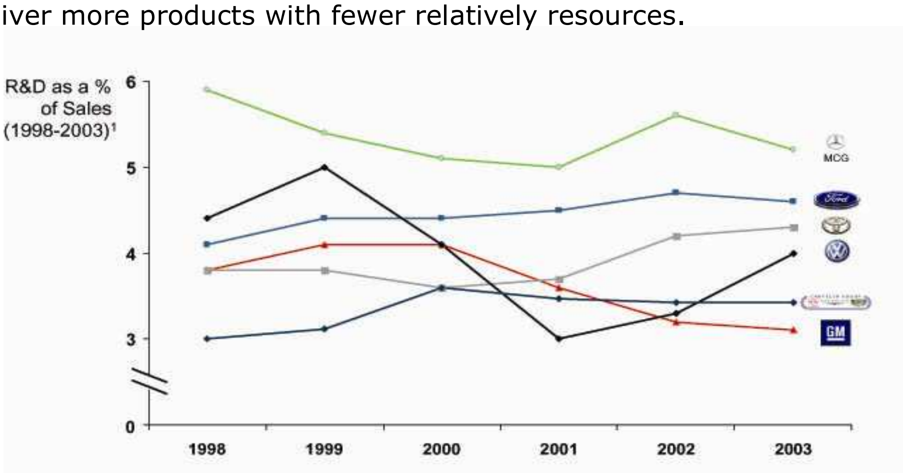


Fig 4.3.1 – Product Development Budgets as a Percentage of Revenues (source: Roland Berger, 2004)

Effective and efficient PD will be the key to success in this uncertain future. Efficiencies via the economies of scale delivered by modular construction techniques based on platform concepts will continue to be followed. This will be particularly so in the volume driven markets (Becker, 2007), where cost is the main issue, more so than in the brand driven markets.

OEMs are further exploring additional production volume benefits based on modular design techniques by investigating scalable platform architectures that can underpin a whole range of different sized vehicles. However, further PD performance improvements are needed within the process itself. Delivering more products with relatively fewer resources will require better PD strategies, improved planning and process controls in terms of budget and staff utilisation, organisational integration and information flow.

OEMs surveyed state that they will take back system integration from the Full Service Suppliers. This will only add to the resource pressures within their own organisations that will likely reside in the higher cost regions.

As already stated, the reliability of computer aided simulations has evolved over that last thirty years and these methods are now fully embedded in most of the OEMs' PD processes. The further use of computer based simulation techniques will enable further reductions in PD time and prototype costs. As 100% of respondents highlighted the increase in virtual simulation technologies to replace expensive physical prototypes, it is fair to predict that whatever happens, the survivors and future players in the automotive industry will have PD strategies that rely heavily on virtual simulation or CAx techniques. Whilst these CAx techniques have brought improvements in the delivery of specific PD tasks and also in manufacturing process development via Computer Aided Manufacturing (CAM) simulations, an overall project management simulation of an integrated PD process with control mechanisms is yet to be attained. The primary research also identified that key to this success will be employing people who are able to operate in a culture that trusts these simulations with fifty per cent of respondents stating this.

4.5 Conclusions

Project 1 of this research programme set out to evaluate the current commercial state of the automotive industry and identify the roles and responsibilities of companies involved in the PD process.

In particular, the project focus was on aspects of the industry that impact or drive future PD strategies in terms of why new vehicles are needed, how they will be developed and who will develop them. Through the research undertaken, it is evident from the interviews and literature that there is considerable pressure on senior PD executives in the automotive industry to deliver a greater array of new products without increasing expenditure. This pressure is almost at bursting point with some executives not knowing where to turn next to find the PD process improvements necessary to be competitive in the future automotive industry. In particular, the respondent from GM stated that he didn't know when this would stop or abate.

The objectives of this project 1 of identifying trends and drivers have been achieved. Additionally, the roles and responsibilities of the key organisational players within the industry, in terms of the OEM, FSS and ESS have been identified.

In summary, the conclusions of project 1 are:

1. The high level of competition seen in the global Automotive Industry will not reduce and will likely increase.
2. The OEMs PD departments will have to deliver a greater array of new products in shorter timescales without a commensurate increase in resources.
3. The OEMs are taking back development responsibility from the FSSs as they seek to improve their commercial power in these relationships. Critically, this will add more complexity to their workload and processes.

4. However, outsourcing of PD activities will continue as the OEMs lack sufficient resource levels to deliver all that is necessary to meet market demands. This should benefit the ESS market.
5. As the OEMs strive to deliver more products in less time the use of digital simulation will continue to increase. Managing the data from these digital processes will further add to the resource issues faced by the OEMs.

Overall, the primary conclusion from project 1 is that PD processes in the future will have to be more efficient in their use of company resources. The increasing importance of the use of performance criteria in PD has also been identified in the research and literature (von Corswant & Fredriksson, 2002).

The question then becomes; how to achieve a more efficient PD process and what to measure to quantify this? This question forms the basis of project 2 - Evaluation of Performance Measurement Techniques in the Automotive Product Development Process.

5 Evaluation of Performance Measurement Techniques in the Automotive Product Development Process

Project 2 of this research programme aimed to evaluate the current use of performance measurement techniques in PD in the global automotive industry. The full project report is included at appendix 2.

5.1 Background

As was concluded by research project 1, the OEMs in the future automotive industry will need to have effective PD strategies that will be more efficient in their use of company resources than those of today. That is, the OEMs will have to deliver a greater range of new products, in less time and without greater levels of resources. The performance and efficiency of the automotive PD process will be central to the success of the OEMs in the future global automotive industry.

5.2 Project Management and Performance Measurement of Product Development in the Automotive Industry

The terms product development, project management and performance measurement are often misunderstood and used without clarifying their definition. An initial literature review sought to remove this ambiguity and provide a framework of best practice against which RLE processes can be compared.

Product development (PD) can simply be defined as the development of new products. However, many definitions are available in the literature (Cedergren, 2011). Within the context of this research project the author prefers "the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product" (Ulrich & Eppinger, 2008). Alternative definitions are discussed in research project 2 at appendix 2.

Bringing new products to market is a key determinant of future success. Some level of PD is undertaken by all automotive OEMs with billions of dollars spent every year on designing and engineering new vehicles.

The PD process in the majority of organisations follows the waterfall or stage-gate process, Figure 5.2.1 (Yadav, et al., 2007). Figure 5.2.1 differs slightly from the stage-gate model at figure 1.5.1 (Cooper, 1994) in that it includes additional feedback loops between the activities. This additional communication and interaction increases the complexity in the PD process.

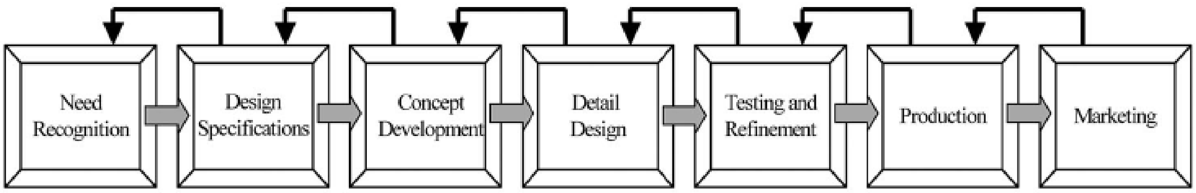


Fig. 5.2.1 – Waterfall or Stage-Gate Process (source: Yadav et al., 2007)

This research project is concerned with the three central phases of this process of concept development, detailed design and validation where the majority of PD resources are deployed. A broader discussion of alternative strategies and techniques used in PD is included in the full project research report at appendix 2.

The Project Management Institute's Body Of Knowledge (PMBOK) provides the following definition:

> 'Project management is the application of knowledge, skills, tools and techniques to meet project requirements'.

The PMBOK prescribed list of project constraints has evolved from the original triple constraint (Phillips, et al., 2002) of time (schedule), cost (budget) and scope and is now often represented as star, figure 5.2.2.

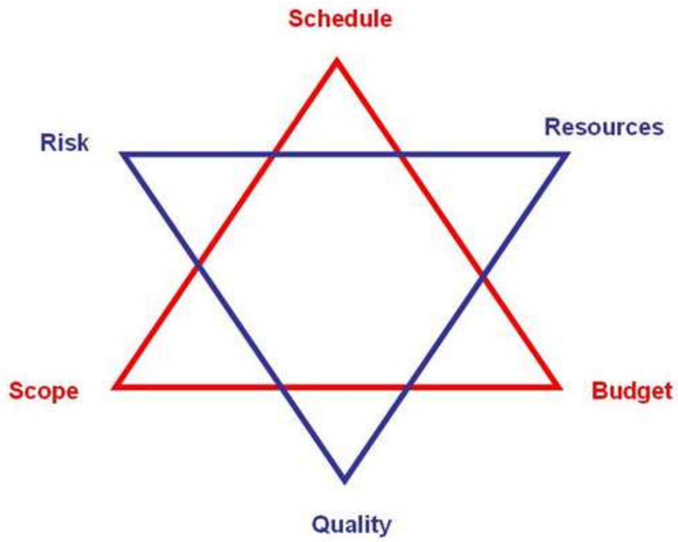


Fig. 5.2.2 – The new 'Triple Constraint' (source: PMBOK)

A project is typically divided into a Work Breakdown Structure (WBS) with sub-projects and tasks. The timing and linkages of tasks can be represented on a Gantt chart (Figure 5.2.3). Software such as Microsoft Project can be utilised to prepare Gantt charts and other depictions of a project, such as Project Evaluation and Review Technique (PERT). However, the complexity of the automotive PD process is not particularly suited to a PERT diagram and the vast majority of OEMs depict their PD processes via Gantt charts.

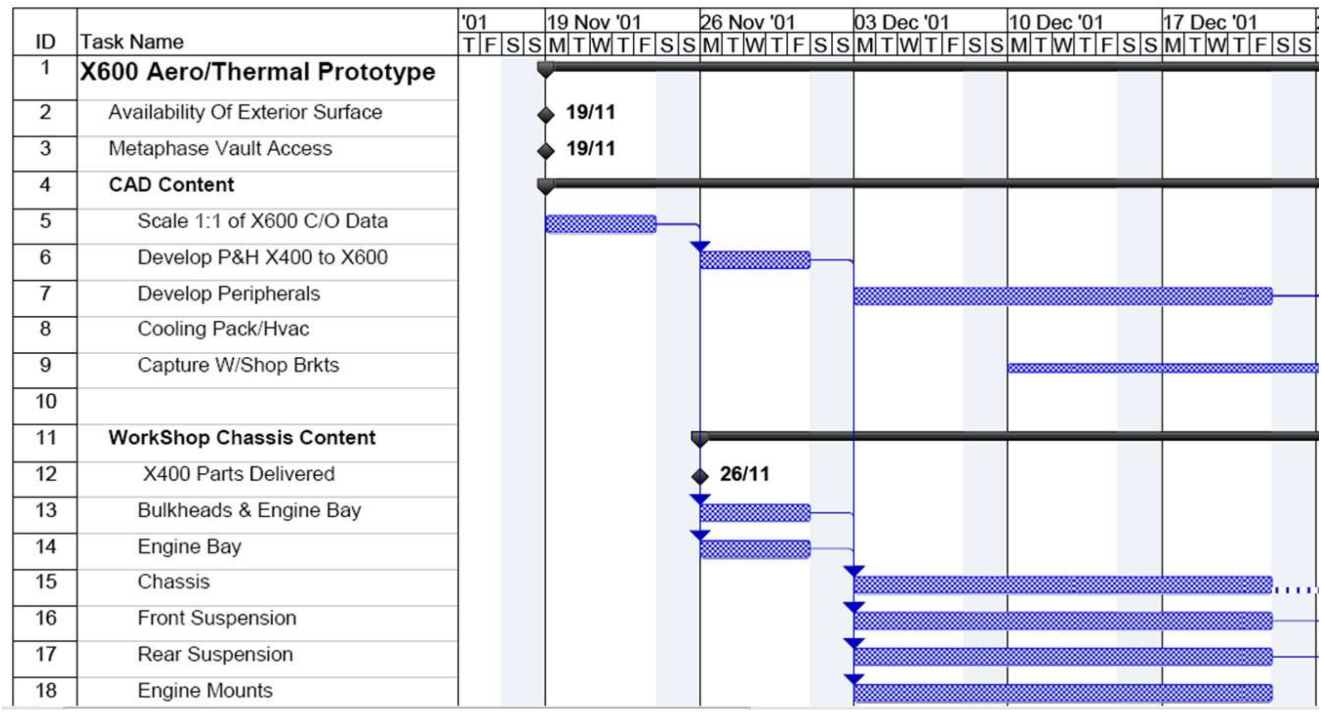


Fig. 5.2.3 – Gantt chart generated in Microsoft Project (source: RLE)

Browning and Ramasesh, (2007) describe how interactions between tasks in the PD process, depicted by linking arrows in the Gantt chart, are as important as actions or tasks but are rarely considered in the actual process.

This research project is specifically concerned with performance measurement in the PD process and as such this is viewed as a sub-process of project management within the PD process. Whilst attempts have been made to adapt the balanced scorecard to PD (Bremser & Barsky, 2004) and to create a project management scorecard (Phillips, et al., 2002), models of performance measurement in PD tend to be focused on the artefact, i.e. the product itself, rather than the development process. Moreover, measures of project revenues and profits are lagging indicators of performance, i.e. they provide a measure of how the product is performing in the market after the PD process is complete. Leading indicators of performance are needed that provide predictive capability and enable timely feedback during the process itself.

A performance based study of PD in the global automotive industry (Clark & Fujimoto, 1991) identified three aspects of the PD process that impact an organisation's ability to attract and satisfy customers with its products:

1. Total product quality
2. Lead time
3. Productivity

Total product quality consists of two aspects; the level of design quality of the product, the artefact, and the organisation's ability to produce the design.

Lead time is the time taken to go from a concept to a saleable product.

Productivity is the level of resources used to take the project from a concept to a saleable product. This includes hours worked (engineering hours), materials used for prototype builds and any equipment and services the organisation uses. Whilst productivity has a direct impact upon on the final cost of the product it also determines the number of projects an organisation can deliver given a fixed level of resources; human, material or financial.

The Clark and Fujimoto study (1991) also identified that management of interfaces, associated trade-offs and complexity are important issues in the performance of automotive PD.

Whilst most OEMs have developed their own PD systems, at the supplier level one of the most widely employed frameworks in the automotive industry is APQP, Advanced Product Quality Planning. APQP (figure 5.2.4) is a structured method for defining and executing the actions necessary to ensure a product satisfies the customer.

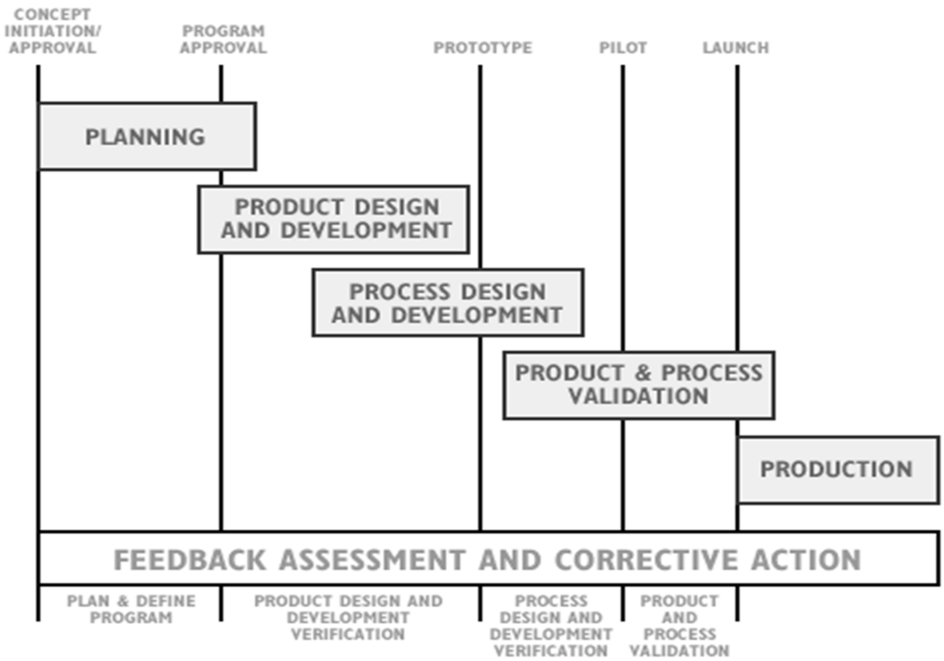


Fig. 5.2.4 – APQP Phases (source: RLE)

In phase 3, process design refers to the manufacturing process rather than the PD process.

Suppliers in the automotive industry are typically required to follow APQP procedures and techniques and are also required to be audited against ISO/TS 16949.

ISO/TS 16949 is an ISO technical specification that specifies the quality system requirements for the development, production, installation and servicing of automotive related products. The organisation should set:

- Objectives for the process.
- Measures for indicating achievement of these objectives.
- A defined sequence of sub-processes or tasks.
- Links with the resource management process so that human and physical resources are made available to the development process when required.
- Review stages to establish that the process is achieving its objectives.
- Processes for improving the effectiveness of the development process.

At a project level, typical objectives and performance measures are set in terms of time, cost and quality levels. Productivity, defined by Clark & Fujimoto (1991) as the efficiency of resource usage, is rarely measured directly within projects. Resource tends to be treated as a sub-set of cost or budget, and a measurement of its efficiency, whilst a project is in progress is often overlooked.

The ISO/TS 16949 standard also requires "the interfaces between different groups involved in the design and development process to be managed to ensure effective communication and clarity of responsibilities." Interfaces require effective information control processes (Hoyle, 2005).

Simultaneous or Concurrent Engineering (CE), figure 5.2.5, is an approach that attempts to integrate the planning, design, development and manufacturing planning of products by overlapping the phases and creating greater interaction and communication between the various departments involved.

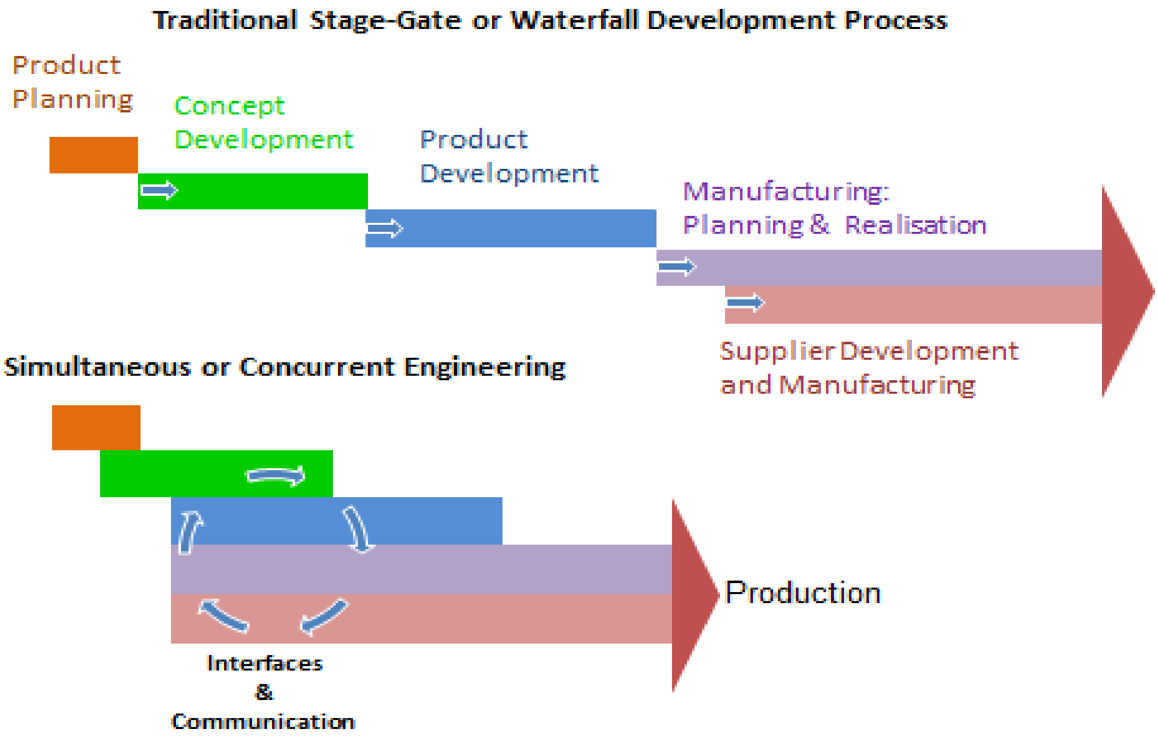


Fig. 5.2.5 Reduction in Lead Time by Simultaneous Engineering (source: RLE)

This identification of the importance of interfaces and the inclusion of additional criteria such as resources and risk recognises the growing complexity of project management. This complexity has led to many organisations setting up departments to define and maintain standards within the project management process. These departments are often referred to as the Project Management Office (PMO).

5.3 Investigation of Project Management and Performance Measurement in Product Development in the Automotive Industry

This section contains an evaluation and critical assessment of project management and performance management in the automotive PD process.

5.3.1 Methods

The primary research of project 2 investigated performance measurement in automotive PD projects in the global automotive industry.

Methods for this qualitative research by case study comprised:

1. Survey by questionnaire and interview. These were used in order to investigate the perceptions and views of the project participants
2. Participant observation. Observation is a recognised form of research and in this case was used alongside the survey to understand and validate the research findings.
3. Documentary analysis in the form of assessment of processes and project management records. Project timing charts and resource usage records were reviewed to compare actual performance to the original plans.

In order to evaluate current practice in the use of performance measurement techniques in the global automotive industry a case study of four discrete projects was conducted involving a questionnaire survey and follow-up interviews.

In addition, the author was involved in all four projects at a steering committee level, had full access to all project documentation and was able to observe the process and progress over the projects' duration. Through this process, the author was able to investigate the validity of expectation and opinion with actual performance. This process, therefore identified the underlying strengths and weaknesses in the processes used.

A set of criteria was developed to ensure a broad analysis. The set of criteria was established to ensure that the data collected from the sample projects would not be influenced by non-PD process related factors. Whilst all four projects in the case study were performed by RLE teams they were chosen as they were different in terms of:

- Geographic location
- Customer
- Engineering scope
- Predominant team culture

The projects were:

	Location	Customer	Engineering Scope	Culture
1.	Germany	Valmet	Electric vehicle show car	German
2.	India	Maruti	Steel tailgate for new model	Indian
3.	Sweden	Volvo	Scalable platform for new vehicle	English
4.	USA	Chrysler	Aluminium door for current model	USA

The questionnaire was developed based on scientific principles (Munn & Drever, 2004) such that:

1. The subsequent data analysis was considered prior to design the structure of the questionnaire.
2. The questions sought to enquire further about the application of the performance measures of PD established in the literature survey.
3. The questions were predominantly structured rather than open.
4. Where open questions were used this was at the end of sections to offer the respondents the opportunity to offer additional information.
5. Suggestion was avoided.
6. A professional appearance and layout was developed.
7. The order of the questions was carefully considered with easier (e.g. general or biographical type) questions put first to ease the respondent into the task.
8. The number of questions was limited as excessive size can reduce response rates.
9. The questionnaire was piloted with a small representative sample initially.

The questionnaire was trialled with a pilot group at the UK office of RLE prior to being sent out to all team members. The outcome was that minor changes were made in terms of grouping and terminology to ensure correct understanding of the questions. In all, twenty-four respondents completed questionnaires which represented a fifty-one per cent sample of the total teams' headcount. In all four cases the project manager was included in the respondents.

The final questionnaire for each project contained twenty-four questions arranged in six sections as follows:

1. General Information & Project Management – to clarify respondent PD experience and assess project hygiene factors.
2. Project Performance Measurement – to test for use of metrics or KPIs from literature survey.
3. Interfaces and Interaction – to understand level of complexity in communication with other departments.
4. Time Usage – to test the amount of time spent on planned activities.
5. Project Information – to test the quality and flow of information.
6. Project Delivery and Satisfaction – to test delivery against original plans in terms of effectiveness and efficiency.

The results of the questionnaire exercise were tabulated and analysed. A full analysis of the questionnaire design and response analysis is given in the full project 2 report at appendix 2.

To further expand on the questionnaire analysis, key informants were identified from the sample group for follow up interviews. Non-structured interviews were conducted with the four project managers and other selected team members to discuss specific responses and the key issues identified. These interviews were of a non-structured nature to allow the interviewees to elaborate on their opinions. However, five open ended questions were employed to elicit the views and opinions of the interviewees. The questions were developed to build on the questionnaire responses and enquire into the project teams' performance management and control mechanisms.

The questions asked were:

- What did the project team actually do?
- How did they ensure customer satisfaction?
- How did they plan and manage cost, timing and deliverables on these projects?
- Did they get anything out of the project other than revenue and profit?
- Did they quantify and document these?

In the document review of all four project cases, the original project plans and actual project data was reviewed. This included:

- Statement of Work – customer specification and corresponding RLE quotation.
- Timing plans - Gantt charts in Microsoft Project or Excel.
- Budgets – monthly spend on people, travel, infra-structure and CAx technologies.
- Resource usage plans.
- Timesheets and project control reports.
- Profit margin analysis.
- Project invoicing.
- Customer satisfaction reports.

Additionally, the general case study was complemented by secondary documentary research into the product development and project management processes employed by an Engineering Service Supplier (ESS) in the automotive PD business. The purpose was to compare these to the processes identified with best practice within the automotive industry, i.e. APQP, TS 16949 etc. and from this analysis shortcomings are demonstrated in order to identify areas for improvement and contribution.

5.3.2 Review of Performance Measurement Techniques in Automotive PD

The descriptive data collected via the research methods was spilt into groups and compared and contrasted. The questionnaire results, interview transcripts, meeting observation notes and project management documents provided a broad data set for analysis. This categorising analysis involved organising the data into broad themes and issues.

5.3.2.1 Questionnaire Outcomes

Outcomes of the survey by questionnaire were:

1. Initial data analysis highlighted that basic project management methods were employed appropriately in all four cases. 75% of respondents stated that they did receive a project organisation chart and attended a project kick-off meeting. The significance of this is that a pattern of adherence to prescribed methods is demonstrated in the four projects under review.
2. The three main performance measurement criteria or KPIs identified were those previously recognised as the triple constraint in the literature review (Phillips, et al., 2002); time, cost and scope. 88% of respondents identified cost as a project metric whilst time and scope were identified by 75% of respondents. Once again, the significance of the findings is that known or prescribed methods are being employed by a statistically high proportion of the research group. Quality was ranked fourth with 66% of respondents identifying this criterion. Resource usage was identified by 33% of the research group and risk by 24% of the twenty-four respondents. When asked if any other criterion were used for performance measurement 38% responded that mass or weight was considered. This however, was viewed as a technical constraint rather than a project management KPI. Overall, the significance is that industry standard metrics were applied in all projects.

3. Two thirds of the respondents were co-located with their project team and 79% had three or more interfaces with other departments with 38% having more than five cross-functional interactions. Communication methods were predominantly face to face, telephone and email with 88% of respondents identifying all three techniques. CAD/Webex meetings had been used by 63% of respondents. Video conferencing and Sharepoint technologies were little used with 12% and 16% usage respectively. Whilst the communication method results were pretty much as expected, of significance is the level of interaction with other departments with 79% having to interface with three or more peripheral departments.
4. With regard to time usage during the projects, the majority (63%) of respondents stated that they were performing design or engineering tasks less than 60% of the time. 71% of respondents were in meetings up to 20% of their time and seven in meetings up to forty per cent of their time. 75% were on the phone or emailing for up to 20% of their time. In addition, 58% of respondents estimated that they had nothing to do for up to 20% of their time spent on their project. Significantly, whilst these are the respondents' estimates rather than accurately timed events, on a project of the type researched, this equates to an approximate resource under-utilisation equivalent of £70k.
5. With regard to information flow, 67% of respondents received information on time and 33% stated that information arrived later than planned. Fifty per cent of respondents judged that the information they received was 61-80% complete against their expectation and one quarter of respondents rated it 41-60%. Two thirds of information from other departments was received in small batches with one third arriving in one large batch. Significantly, 33% of information was delivered later than planned on the project timing plan, which was a Gantt chart in all four projects.
6. In terms of overall project delivery, 67% responded that their project was delivered as originally planned and 92% of respondents rated their project as effective. However, in 67% of responses the project scope was modified and in

50% of the responses the resource usage was different to the original plan. Seven respondents stated that their project was not efficient. Whilst this judgement was based on their own experience on the project its does substantiate the findings from section 4 of the questionnaire, i.e. at time in the projects respondents had nothing to do. 88% of respondents rated customer satisfaction at over 80%. Customer satisfaction in this case was estimated by the respondents but this does correlate with the high level of feedback from customers using the company customer satisfaction form from RLE's Integrated Management System (IMS) process.

The key question becomes: could these levels of customer satisfaction have been achieved with fewer resources and better management processes?

5.3.2.2 Interview Outcomes

The main outcomes of the subsequent follow-up interviews were:

1. The project teams endeavoured to deliver the projects as defined in the original Statement of Work (SOW), on time and on budget.
2. Project control was generally by weekly review of Microsoft Excel documents showing actual status versus project targets.
3. At the start of projects it was common that team members would be waiting for infra-structure and systems to be put in place. As one interviewee stated "we're always late as soon as we start".
4. It was also evident that information needed to begin a project was not always available from the customer at the start point.
5. Project objectives and customer value were not always defined clearly and reviewed regularly.
6. Project manager strength was viewed as a key determinant of project success, i.e. the character of the project manager in dealing with cross-functional issues is

central to delivering the project within the predetermined targets. This was observed by all the key informants as well as the author.

7. There is much wasted time during projects waiting for information. Wasted time was defined as time when the engineers were doing tasks that did not contribute directly to project delivery. Whilst this wasted time was not quantified on the engineers' timesheets, this perception of the participants was also observed and noted by the author.
8. Too much time spent waiting, caused by the lack of flow of information.
9. Project engineers spend too much time in meetings discussing status, reporting on issues and resolution plans rather than implementing these.
10. Engineers spend too much time travelling in some projects. This time is generally non-value adding in terms of project delivery.
11. There is too much to do at certain times, particularly at 'panics' leading up to gateways or project milestone events. In some cases pre-meetings to gateways were requested weeks in advance so management could prepare their arguments.
12. When information arrives in large batches from other departments it is difficult to manage.

5.3.2.3 Document Review and Observation Outcomes

Results from the analysis of records showed all four projects were delivered in terms of scope of delivery, or Statement of Work (SOW), and as per the original timing. However, the Chrysler project over-ran in terms of costs and resulted in very little profit for RLE. This was as a result of excessive resource usage in the project. The project manager had hoped to recoup this expenditure on a follow up project but this never materialised. Investigation determined that in the first phase of the project not all the data required from the customer and other project members was available as planned. However, the RLE team was in place and continued to book time to the project despite the fact that there was insufficient work to do.

Participant observation also logged the frustration and wasted time as a result of information not being delivered on time. Records kept by the author noted team members chasing information from other departments and excessive meetings discussing project status and unachieved tasks. It was also noted that in the Volvo project the project manager had to direct his engineers to stop attending customer meetings as so much of this time was un-productive.

The significance of these findings is, that despite careful planning, project managers had to review and adjust timing plans and resource usage to match the flow of work to be done. In the Chrysler case, where this did not happen, significant cost penalties were incurred.

5.3.2.4 Secondary Analysis Outcomes

The RLE group of companies is certified to the necessary ISO and TS standards and has implemented an Integrated Management System (IMS) to ensure the quality of the product and the service supplied to its customers along with occupational, safety, health and environmental protection. However, the PD process is not specifically described in the IMS. Rather, the IMS manual and its associated procedures, instructions, controlled forms and other support methods seek to ensure that quality & environmental objectives are established and reviewed for effectiveness. This is achieved by providing a framework of Key Performance Indicators (KPIs) for the general business operations rather the PD process, e.g. number of customer complaints.

Additionally, in some locations the documented operational processes do not reflect the complete set of services actually offered. The IMS documentation suggests that the UK operation of RLE only provides onsite headcount support, CAD translations and IT services and does not offer broader PD project services. This is not the case, as the UK operation has delivered PD based project services to its customers.

RLE has historically generated the majority of its revenue from simply supplying human resources to the OEMs. In addition to this labour leasing business small projects involving five to twenty people have been undertaken but this has not been a significant part of the business. However, a strategic review identified the need to move into broader project support activities. In support of this strategy, RLE implemented a project management system, figure 5.3.2.4.1, at its headquarters in Cologne, Germany. The RLE project management system is based on the approach and techniques outlined in Hab & Wagner (2010).

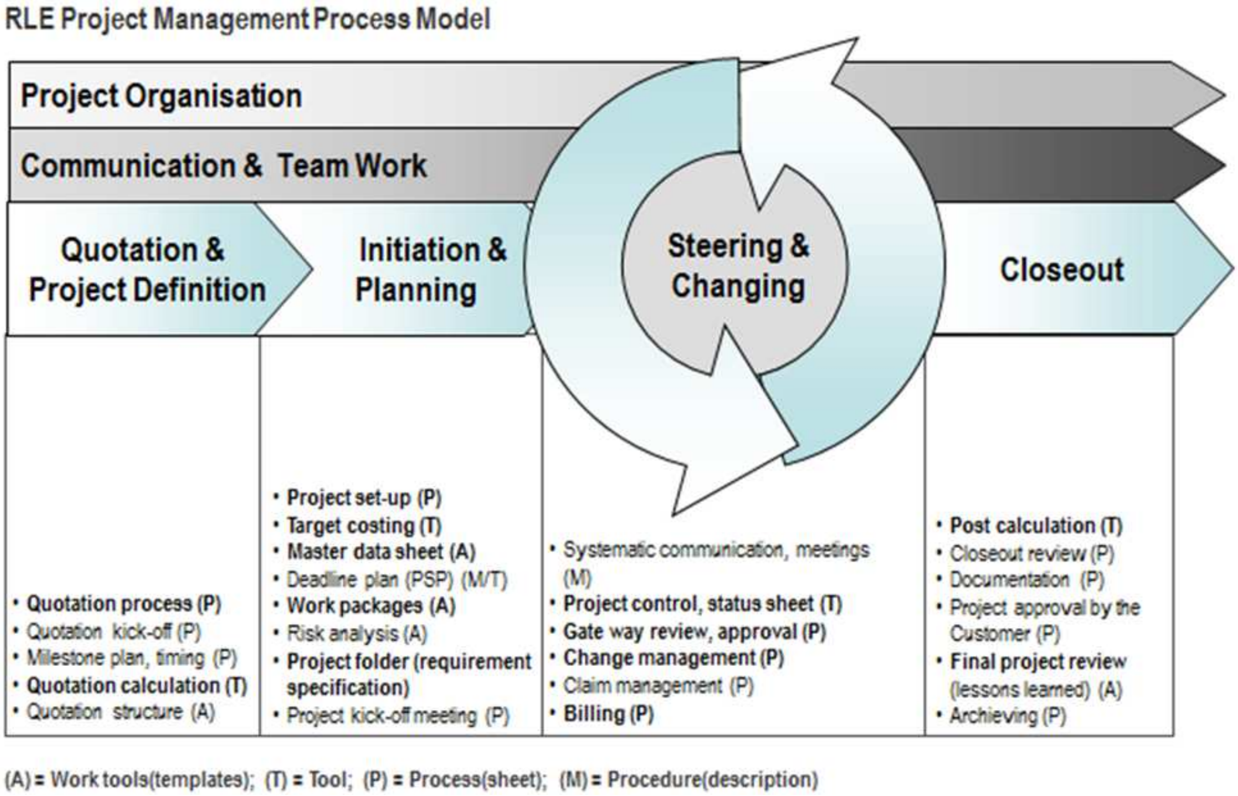


Fig. 5.3.2.4.1 – RLE Project Management Process Model

In Hab & Wagner (2010) a four phase project management process is specified:

1. Quotation and Project Definition
2. Initiation and Planning
3. Steering and Changing
4. Close Out

The quotation and project definition phase involves the detailed review of technical content and customer expectations, i.e. the project scope. Project costs are calculated based on the use of resources over the project's duration.

Throughout projects, performance progress is measured and controlled in terms of quality of service delivery, timing, resource usage and costs. The problem with this is that these Key Performance Indicators (KPIs) are lagging indicators, i.e. they measure something that has already occurred without offering a predictive determinant of success.

The final RLE project review is an internal review where the attendees are the project members, leaders of the sub-projects and the line management. The main focus here is on aspects of project management (organisation, cooperation, planning, regulation, etc.) and particularly customer satisfaction. Final performance in terms of project cost and profit margin is also calculated at this meeting.

Based on the secondary research documentation review the outcomes are:

- RLE has a Project Management process model that is not widely used within the company internationally.
- RLE Project Management process model does not fully describe the PD process.
- The RLE Group has an ISO approved Integrated Management System (IMS) with KPIs that are operations focussed rather than PD specific.
- RLE UK uses a sub-set of the IMS but does not have an ISO Process for PD Projects.
- RLE USA documentation is limited to a Customer Oriented Process (COP) or Turtle Diagram.

5.3.3 Summary of Findings

Whilst acknowledging that the success of a car programme is unquestionably influenced by the effectiveness of the PD process (Hanawalt & Rouse, 2010), this research project has identified an issue with the efficiency of the PD process. Project 2 identified that the rate of information flow impacts project efficiency, i.e. what can be delivered with a specific level of resource. Up until now, rate of information flow has not been seen as a Key Performance Indicator (KPI) or measurement criterion. However, this research into four projects identified information flow as a potential key leading or predictive indicator of project performance and process efficiency.

The primary research of this project identified that during PD projects the team members are not fully utilised in design and engineering tasks for up to forty per cent of their time because they are on the phone, in meetings, emailing or waiting for information. This is validated by the research observations but the records (timesheets) and project reports reflect 100% utilisation of the engineers' time to their project. Further investigation, via the non-structured interviews, highlighted that these non-value adding activities take place because project information is not flowing in an effective manner. If information does not flow as required, assessments of time, cost and the other normally prescribed measures will only confirm that planned targets are not being met.

Attending meetings and communicating via email may be necessary to share information in the course of a project but it is clear that too much time is dedicated to these activities. The research identified that the project engineers and designers spent less than sixty per cent of time doing design or engineering tasks. This observation is substantiated by the analysis of the questionnaire data and in the follow up interviews. Whilst timesheet data and project control records showed the engineers fully utilised on their projects, the reality was that the project team members were waiting for or chasing information. This outcome is supported in some of the literature; non-value added time

(Morgan & Liker, 2006), accounts for a significant proportion of the lead time in the automotive PD process (figure 5.3.3.1).

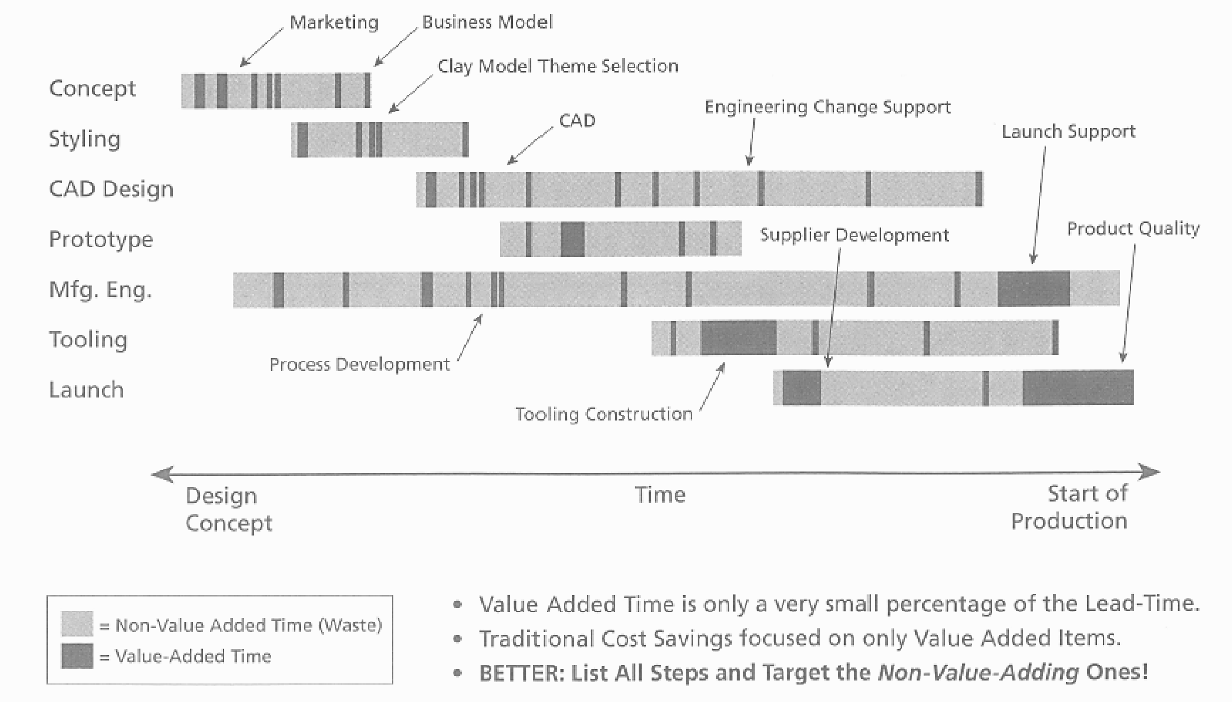


Fig. 5.3.3.1 – Value Added Time as a Proportion of Lead Time

(Source: Morgan & Liker, 2006)

Achieving flow is one of the five key principles of lean thinking (Womack & Jones, 2003). A study at Massachusetts Institute of Technology (MIT) looked at lean principles in automotive PD (Garza, 2005). Flow was found to be not so important in the initial phase of PD, i.e. concept development in the design studio. The value created, i.e. the definition of the product, in this early stage was deemed the most significant of the principles. However, in the middle phase of PD, after concept development, flow was identified as having the most impact of the five lean principles (figure 5.3.3.2); "The effects of not achieving flow in manufacturing can be seen on the plant floor. Idle machinery and high reject rates can be measured, modified and watched for improvement. In product development, the flow is informational and is much more difficult to analyse. Often, the issue is found much too late to correct without delaying key milestones" (Garza, 2005). That is, flow of components is easy to see in a factory but in PD the flow of information is not easily visualised or measured. This can lead to cost and time issues in projects.

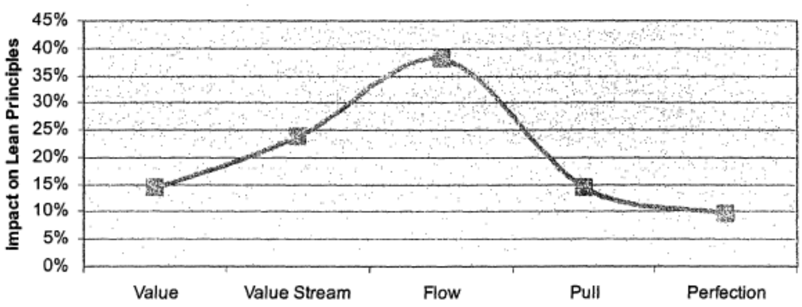


Fig. 5.3.3.2 - Middle Phase Impacts of Lean Principles

(source: Garza, 2005)

This MIT paper recognises the importance of information flow in the main PD phase but offers no proposal for measuring it. The measurement of information flow is a key unresolved issue that has been identified in project 2 of this research programme.

The secondary research has recognised that the RLE approach to project management is fragmented with the three different offices in Germany and all of the international locations adopting differing approaches. Whilst to a certain extent it can be argued that this is because they have different customers that bring with them their own PD and project management templates it does not help the company convey a RLE corporate strength. Referring to the literature, the RLE situation replicates two of the traits described by Hino (2006), figure 5.3.3.3, when considering a company that does not match the Toyota philosophy of corporate learning and growth; the RLE teams consist of very competent engineers but with different work methods rather than adhering to one corporate process that is being constantly improved. This is true of many organisations within the global automotive industry and represents a significant opportunity for improvement and competitive advantage.

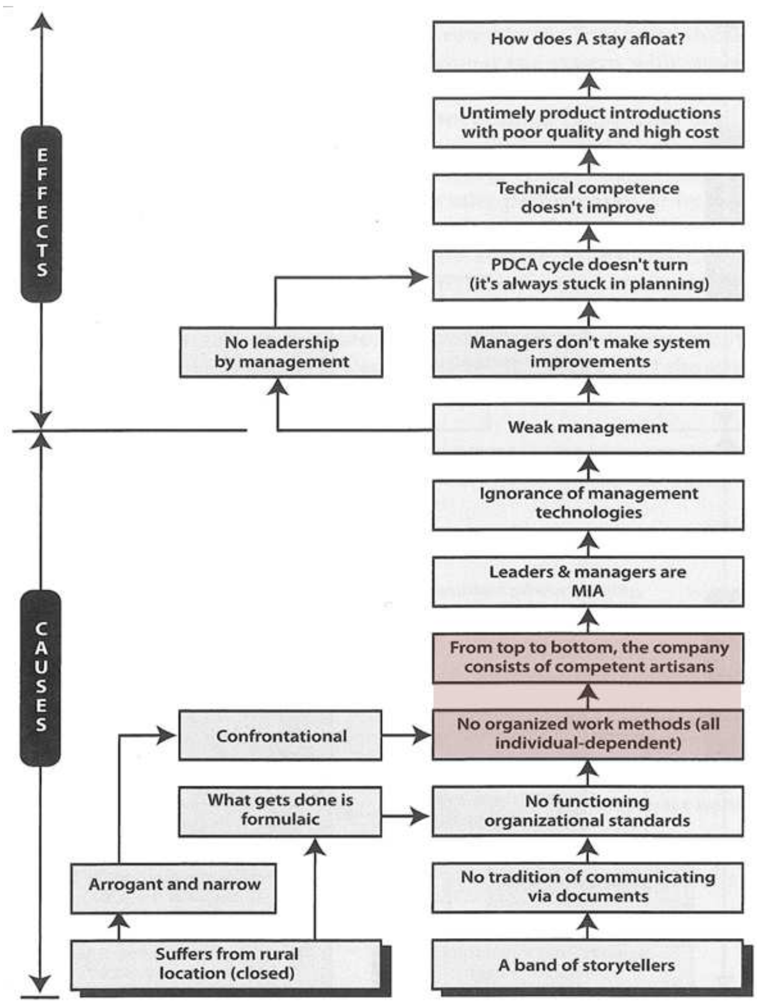


Fig. 5.3.3.3 – Company Traits from Inside the Mind of Toyota (source: Hino, 2006)

5.4 Implications for the Automotive Product Development Process

The OEM PD processes provide a template for delivering projects but not a method for visualising actual progress, other than at gateways. At gateways, a tick box approach to project management and the use of traffic light (green, yellow, red) measuring systems over simplifies many issues with actions marked as complete when in fact they are not. This enables the project team to convince their management that they are on track when in fact significant issues exist that will jeopardise the project's success in the future.

Further, in the digital age it is difficult to visualise the status of a project in terms of progress toward a finished design. To be useful to PD executives and practitioners, a leading indicator is necessary that identifies and communicates how a project is performing as it is happening.

RLE PD processes are generally customer based however, the people are controlled by RLE. However, if RLE is responsible for the project delivery the flow of information within the process needs to be controlled.

5.5 Conclusions

Project 2 set out to evaluate performance measurement in PD with particular emphasis on RLE and its projects for global OEMs.

RLE PD processes are generally customer based, i.e. the overall timing plan and gateway process is generally provided by the OEM. Therefore, RLE cannot define the overall PD process as it normally has to follow a customer template even in off-site (i.e. at RLE) fixed deliverable cases. Likewise, cadence of project launches is difficult for RLE to control and manage as it has multiple independent customers with their own product cycle plans.

The importance of interactions and communication identified as key in modular design (Baldwin & Clark, 1997) also applies to the development process itself. What is highlighted in this research is that for a high percentage of their time, engineers and designers are not fully utilised. This is also recognised in the literature (Bickerstaffe, 2011).

What is important, and the key outcome of research project 2, is that measuring or indicating the flow of information versus that prescribed by the original project plan is a Key Performance Indicator (KPI) that is not currently recognised by the automotive industry. The literature supports this in some cases (Garza, 2005), but does not offer a solution.

Flow of information has the potential to be a key leading indicator of project performance that facilitates:

- The ability to predict and to modify resource allocation.
- Identification of bottle necks and constraints to be eliminated.

Identifying and visualising the information flow in the PD process forms the basis of project 3 - Performance Prediction through Information Flow Assessment in Automotive Product Development.

6 Performance Prediction through Information Flow Assessment in Automotive Product Development

Research project 3 of the programme aimed to evaluate the broader use of information flow measurement techniques and adopt a new method in automotive PD. The full project report is included at appendix 3.

6.1 Background

Project 2 of this research programme proposed that the flow of information in the automotive PD process is a key leading indicator or predictor of project success. This proposition is substantiated by the primary data collected in the questionnaire and follow up interviews together with the records from the participant observations. Whilst the automotive industry has a culture of using data to make decisions, the flow of the information is not currently used as a Key Performance Indicator (KPI) in the PD process. This results in lost time and inefficient use of resources. If information flow were considered it would enable control and feedback measures to drive improvement in project performance.

6.2 Exploration of Information Flow as a Leading Key Performance Indicator

The automotive industry needs a tool or method that predicts performance by measuring or visualising information flows in the PD process. This research project considers and critically assesses methods for establishing a leading indicator of project performance, i.e. a tool for monitoring information flow.

Enabling clear visualisation of information and enhancing communication have been recognised by Toyota with its Obeya (large room) concept (Tanaka, 2011), figure 6.2.1. Here cross-functional teams meet in a continuous session to clarify all project issues and agree on next steps. However, no technique for measuring information flow is considered.

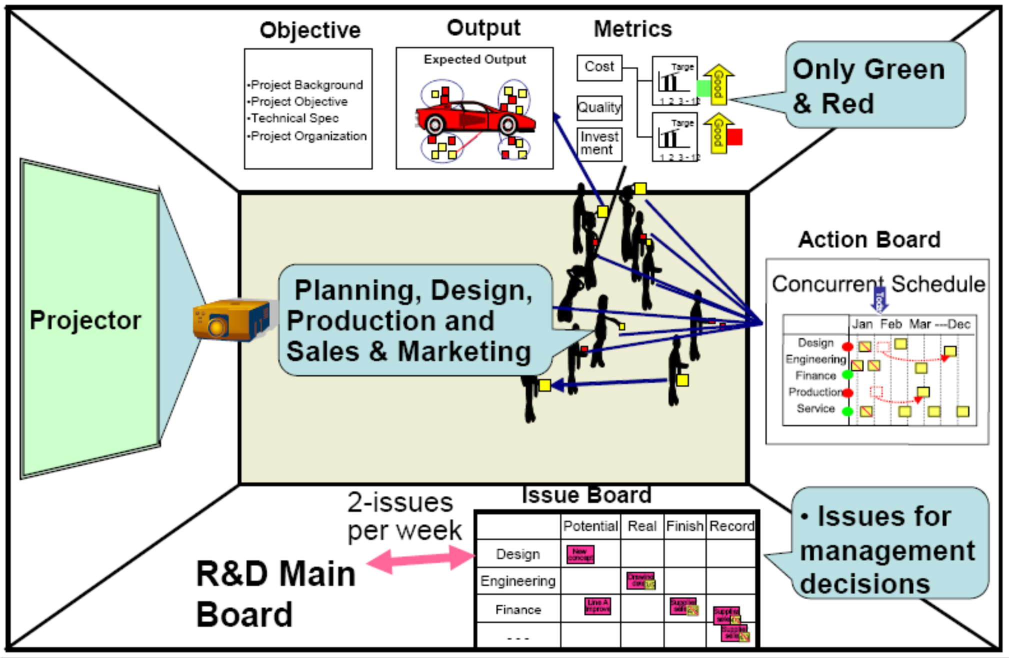


Fig. 6.2.1 - The Toyota Obeya Room Concept (source: Tanaka, 2011)

Gonzales-Rivas & Larsson (2011) recognise flow as a key aspect of process performance and consider its usage and challenges in three environments:

1. Flow as a key principle of lean manufacturing.
2. Flow in the office environment.
3. Flow in the paperless (digital) office.

Gonzales-Rivas & Larsson (2011) also agree that the challenge is made more difficult the further from the factory floor you go as as information flows tend to become more elusive and invisible.

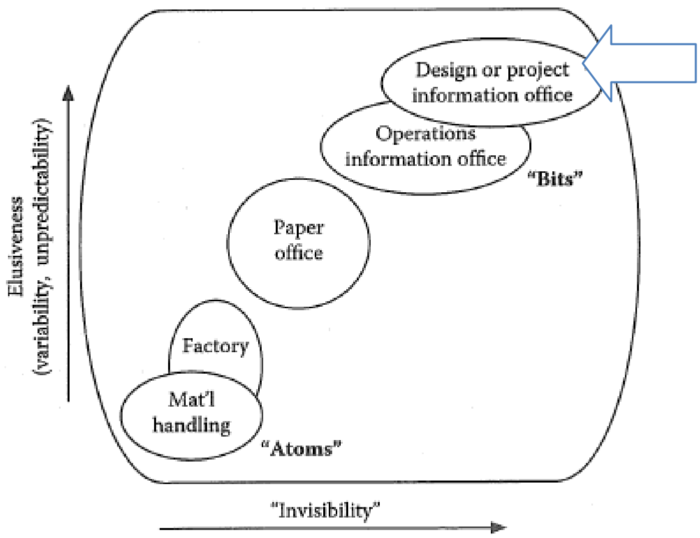


Figure 6.2.2 – Invisibility and Elusiveness of Information Flow

(source: Gonzales-Rivas & Larsson, 2011)

The automotive PD process is both complex and challenging and would be at the utmost top right in figure 6.2.2.

In modern digital automotive PD processes the deliverable between departments is information and this creates the value in the PD process. A leading indicator needs to be developed that provides timely feedback on measures of value creation and progress toward it, i.e. process performance.

The importance of information flow in development projects has been recognised (Tribelsky & Sacks, 2011). In a study of civil engineering projects they found direct correlation between objective measures of information flow and the measures of the effectiveness of design documents. However, the study used provided a retrospective outcome rather than predicting performance.

6.2.1 Methods

Project 3 comprises four phases:

1. Verification of information flow as a leading indicator of performance in the automotive PD process.
2. Exploration of techniques to measure information flow.
3. Verification of the applicability of chosen technique to the Automotive PD process.
4. Development and validation of the new technique for the Automotive PD process.

In phase 1, the identification of information flow as a key leading performance indicator of project performance in automotive PD was tested on a RLE project performed in the UK for a global OEM.

This case study followed a five component research design (Yin, 2009):

1. Study question – what is a new method of predicting performance in the automotive PD process?

2. Proposition – information flow is a predictive Key Performance Indicator (KPI).
3. Unit of analysis – the PD process is the unit of analysis.
4. Logic of linking data to the proposition – pattern matching and explanation building via qualitative and quantitative data.
5. Criteria for interpreting the findings – statistical significance but also addressing rival or alternative explanations.

Phase 2 evaluated twelve techniques for their applicability to the automotive PD process via a Multiple Attribute Decision Analysis (MADA) (Mitten & Gallant, 1997) with particular emphasis on the ability of the method to be utilised by an ESS such as RLE in conjunction with several different OEM PD processes.

In phase 3, the application of the chosen technique in development processes is further explored and then verified on an automotive PD project.

Phase 4 describes the further development of the technique at RLE and its validation on an automotive PD project.

6.3 Verification of Information Flow as a Key Leading Indicator in the Automotive PD Process

In order to test the proposition it was necessary to select a project that was known to be failing in terms of delivery to its original plan and KPIs, e.g. timing, cost and scope or a combination of all three. A project already underway at RLE UK was identified.

RLE involvement in the project commenced in April 2011 and planned completion or Start of Production (SOP) was in late 2013. Key to this was achieving a Final Data Judgement (FDJ) milestone in early 2012 when CAD data would be released to the manufacturing department to commence tool construction. Figure 6.3.1 shows an extract from the initial project timing Gantt chart. Overall project timing is shown at A, with design studio and manufacturing feasibility activities at B and design engineering and virtual testing via CAE analysis shown at C.

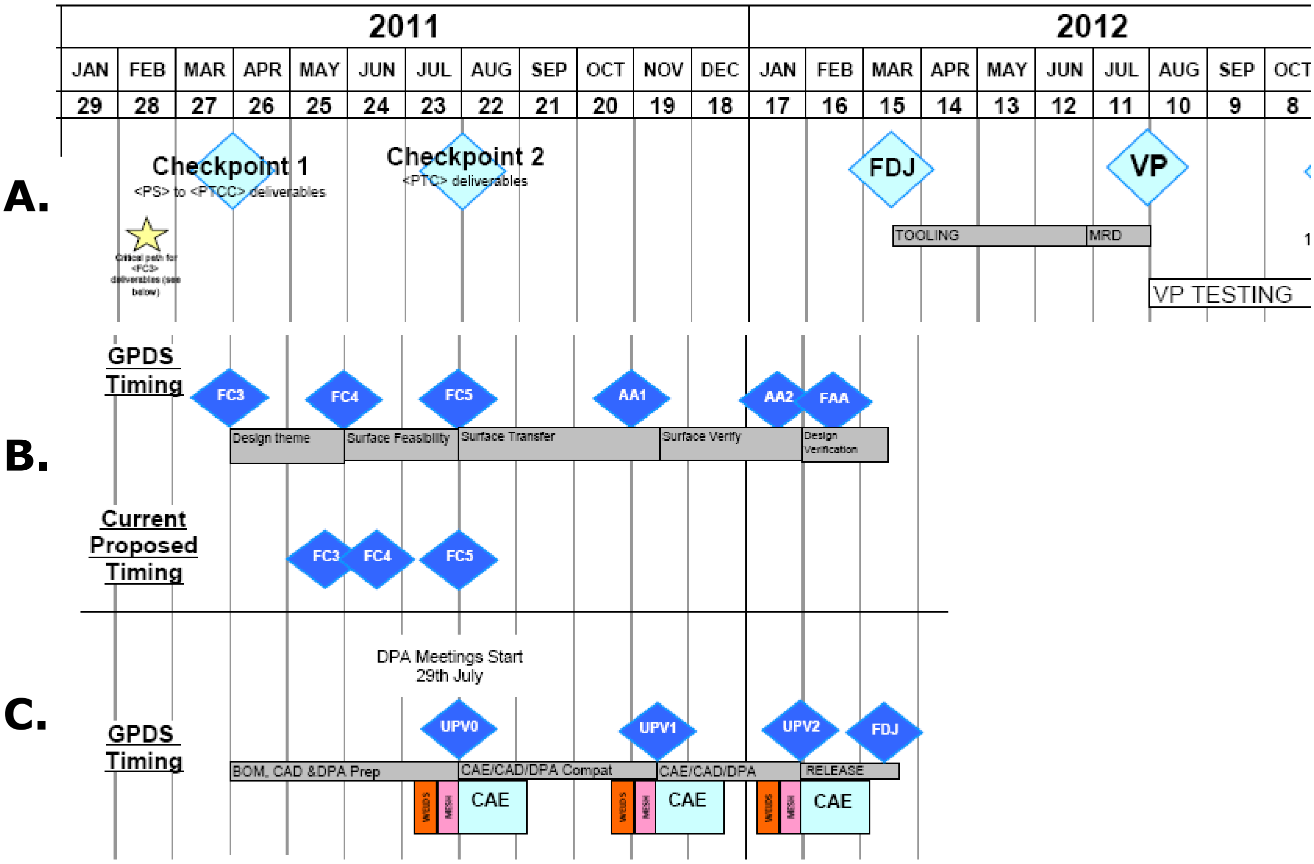


Figure 6.3.1 – Original Timing Plan Excerpt as Planned at March 2011

The key date is the FDJ gateway timed at mid-March 2012 when all design, engineering and analysis activity should be 100% complete. Initial design theme completion and Feasibility Check 4 (FC4) was planned to be complete at mid-June 2011 and FC5 complete at the end of July 2011. Appearance Approval 1 (AA1) and AA2 surface releases were timed for early November 2011 and mid-January 2012 respectively. Data from FC4, FC5, AA1 and AA2 feeds into the body engineering work-stream and enables the development of 3D CAD data and a series of three CAE Upper-body Virtual Prototypes, UPV0 – UPV2, to be complete and fully tested in the virtual environment by FDJ. RLE's responsibility in this project is for the body engineering work-stream.

6.3.1.1 Proposition Testing

To test the proposition that information flow is a key predictor of PD project performance, data was collected from the RLE team on the project. The same questionnaire as used in research project 2 to assess the four projects was employed again. Of the eight experienced engineers on the project, six completed the survey.

The KPIs used on the project as identified by the respondents is shown on figure 6.3.1.1.1. Time, cost and quality were acknowledged as the most recognised KPIs.

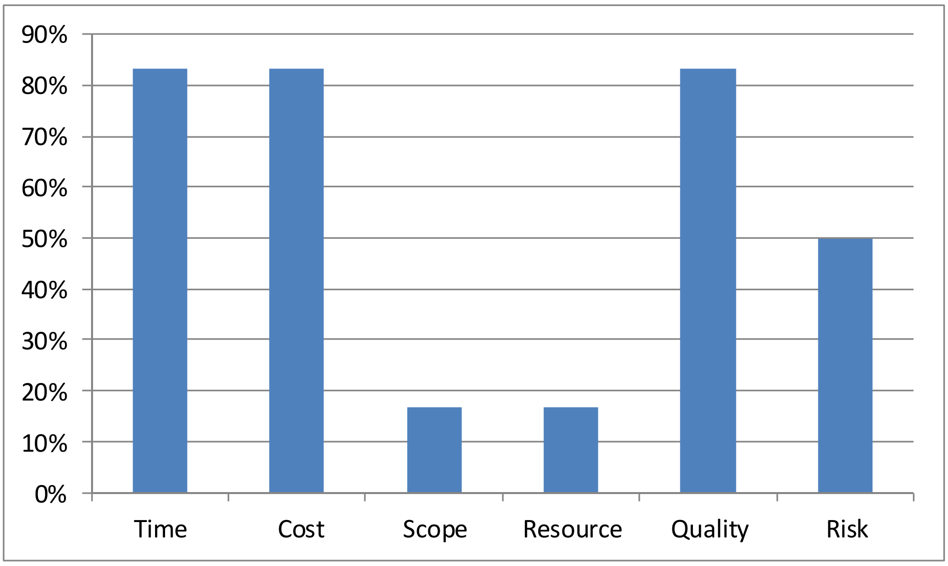


Figure 6.3.1.1.1 – Key Performance Indicators

However, as already acknowledged by RLE, this project was not being delivered as original planned and 100% of the respondents corroborated this in their questionnaire responses. In terms of statistical significance, five other questions received 100% responses and thus had a direct correlation with the deficiency in project delivery:

1. Respondents did not attend a kick-off meeting.
2. Respondents were co-located with the majority of the project team.
3. Communication by telephone, email, CAD/Webex and face to face.
4. Information was received later than planned.

5. Information was received in small batches.

Item 4 supports the proposition that information flow is a predictor of project performance, i.e. if the information does not flow as planned then project delivery will be affected. However, items 1, 2, 3 and 5 generate rival explanations to this theory. These theories were investigated via a focus group interview with the project team members. Via the focus group, items 3 and 5 were quickly dismissed as not being root causes of the project delivery failure.

However, items 1 and 2 required lengthier discussion with the group. The 100% response to item 2, on co-location, was found to reflect 100% co-location of the RLE team in one office and not with the entire project team, i.e. including the customer's design studio and manufacturing teams. It was established that this co-location of the RLE team was not directly related to project failure but, conversely, co-location with the customer team may have positively impacted project delivery.

Item 1, the fact that none of the team attended a project kick-off meeting, was more difficult to dismiss. The interpretation that this was a factor in the deficient project delivery was clearly expressed by the team at the focus group. Discussion with the project manager identified that there was not a definitive kick-off meeting because the team members had joined at several intervals. As previously stated the project timing did not transpire as originally planned. FC3 timed originally at the end of March 2011, and the starting point of RLE's involvement, had not been completed correctly by the OEM customer and another ESS that RLE was supplanting on the project. FC3 was delayed until late August 2011, i.e. some of the information RLE required to perform its contracted tasks was late by almost five months. This meant that the project manager had not called resources into the project as originally planned and at no point had a kick-off meeting been held. Whilst it is clear that the lack of a kick-off meeting had a detrimental effect on the project, if the meeting had taken place the project would not have been delivered as per the original plan. This is because the information to do the job was not available at the right time and this would have prevented the work being done to the original timing and cost plan.

Therefore, this reflects and supports the proposition that if information does not flow as planned then project performance will be impacted directly. Therefore, information flow is a key predictor of project performance.

6.4 Evaluation of Information Flow Measurement Techniques for use in the Automotive PD Process

In all, twelve methods and techniques were assessed and complete analysis is provided in research project 3 at appendix 3. In each case the strength, weakness and applicability to the automotive PD process were assessed via a Multiple Attribute Decision Analysis (MADA) (Mitten & Gallant, 1997) with particular emphasis on the ability of the method to be utilised by an ESS such as RLE in conjunction with several different OEM PD processes, figures 6.4.1 and 6.4.2. The assigned values were determined via a paired comparison analysis by the RLE project management team (see report 3 at appendix 3).

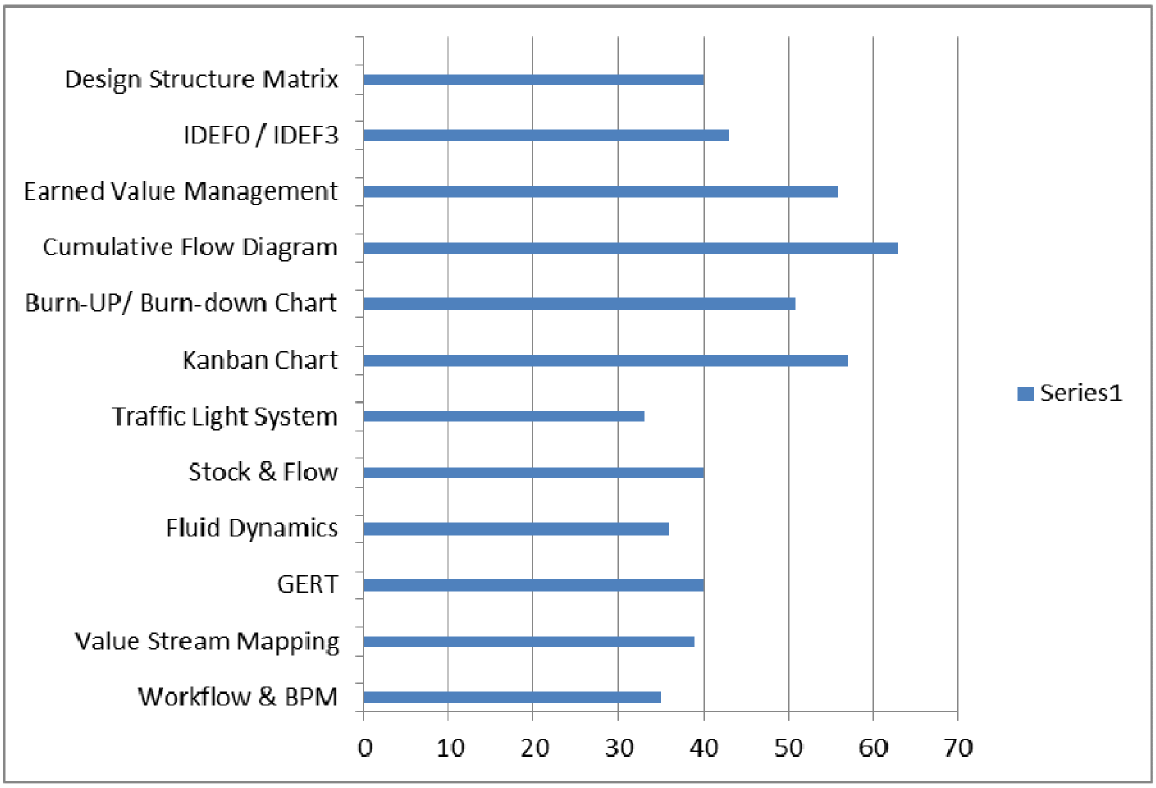


Table 6.4.1 – Result of Assessment of Information Flow Methods via MADA

Evaluation Matrix

No.	Method	Ease of Use/Application	Reliability	Ease of Output Understanding	Predictive Capability	Real Time Capability	Total
	Assigned Value:	1	3	1	5	4	
1	Workflow & BPM	4	9	5	5	12	35
2	Value Stream Mapping	2	12	2	15	8	39
3	GERT	2	12	3	15	8	40
4	Fluid Dynamics	3	4	2	15	12	36
5	Stock & Flow	3	12	3	10	12	40
6	Traffic Light System	5	6	5	5	12	33
7	Kanban Chart	4	12	5	20	16	57
8	Burn-UP/ Burn-down Chart	5	15	5	10	16	51
9	Cumulative Flow Diagram	3	15	4	25	16	63
10	Earned Value Management	4	12	3	25	12	56
11	IDEF0 / IDEF3	1	12	3	15	12	43
12	Design Structure Matrix	3	12	3	10	12	40

Poor	1
Fair	2
Good	3
Very Good	4
Excellent	5

Figure 6.4.2 – Evaluation Matrix for MADA

Four approaches were identified to have potential for application for use by an ESS in monitoring information flows on OEM customer projects:

1. The Kanban method with card wall charts
2. Simple burn-down and burn-up charts
3. The cumulative flow diagram
4. Earned value management

Kanban is a Japanese word meaning sign-card that has become synonymous with just-in-time delivery techniques used in lean manufacturing. Over the last decade the word Kanban has been adopted by the Agile software development approach to monitor and control work in progress and flow of information (Kniberg, 2011). A common way to vizualise the workflow is a card wall, or Kanban chart (figure 6.4.3), with columns and cards representing the whereabouts of work in the different steps of the workflow.

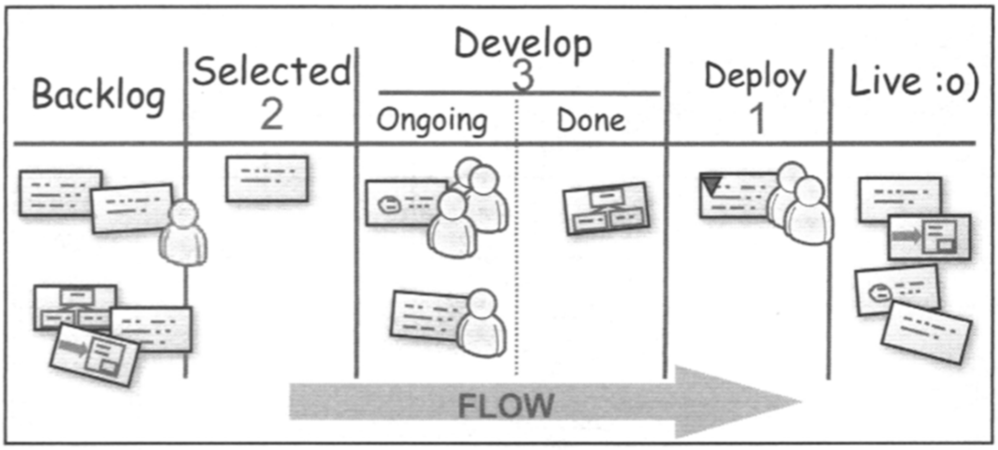


Figure 6.4.3 – Kanban Chart (source: Kniberg, 2011)

Whilst the approach visualises the workflow by identifying where pieces of work, or information, are at a specific time it does not provide an indication of rate of flow over time.

A burn-down chart shows over a period of time how much work remains on a particular activity. Whilst a burn-up chart shows the cumulative work being completed over a period of time on a particular activity, figure 6.4.4. The slope of the curve provides an indication of the rate at which work is being done.

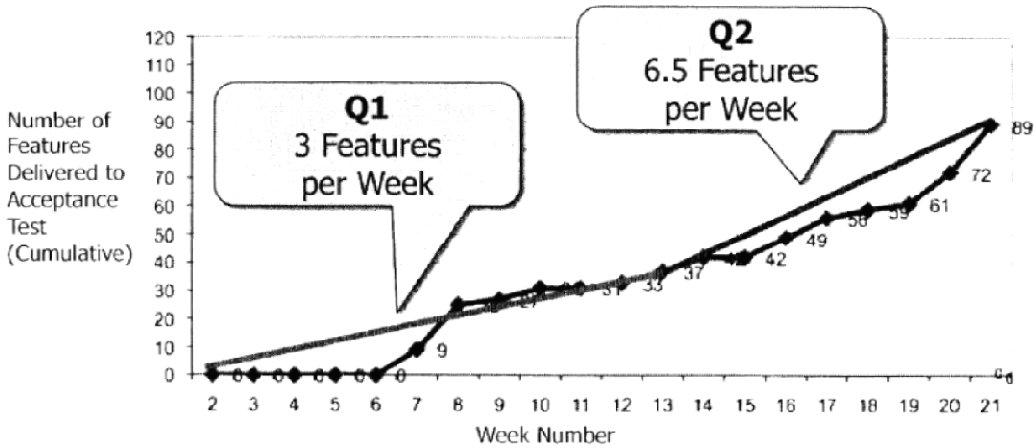


Figure 6.4.4 – Burn-Up Chart (source: Kniberg, 2011)

The Cumulative Flow Diagram (CFD), figure 6.4.5, is a simple adaption of the burn-up chart. Reinertsen (2009) extols its use and describes its applicability for depicting queues over time but states that most organisations do not use CFDs.

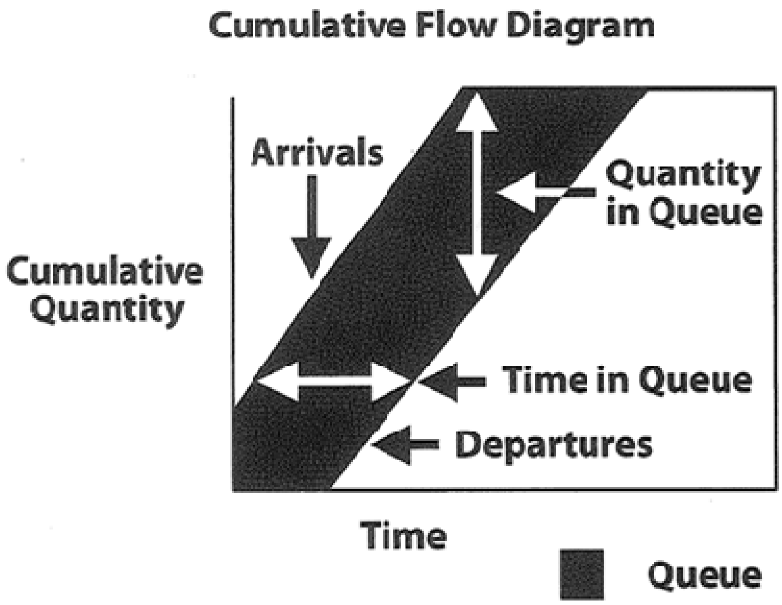


Figure 6.4.5 - Cumulative Flow Diagram (source: Reinertsen, 2009)

Earned Value Management (EVM), figure 6.4.6, with its comparison of earned value against a planned value and the facility to extrapolate estimate at completion provides a useful method. This is a strong aspect supporting predictive capability of EVM.

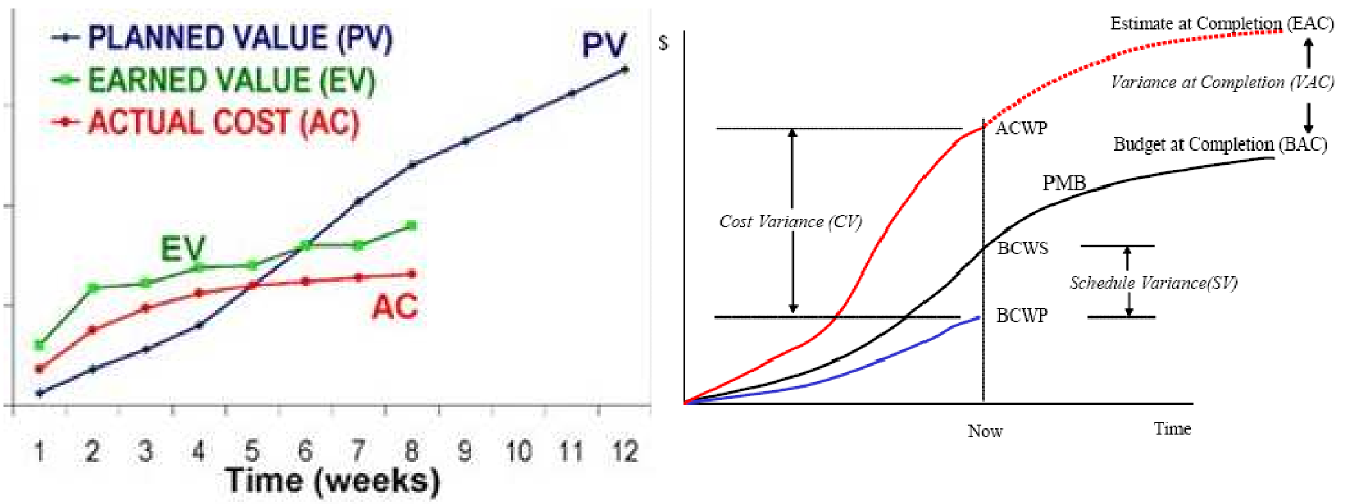


Figure 6.4.6 – Earned Value Management

(source: Lyneis, de Weck, & Eppinger, 2003)

However, figure 6.4.7 (Yeret, 2011) demonstrates the extrapolation possibilities with CFDs. The straight line extrapolation capabilities provide an indication of future performance and also enable the CFD to be used for planning and as a predictive tool.

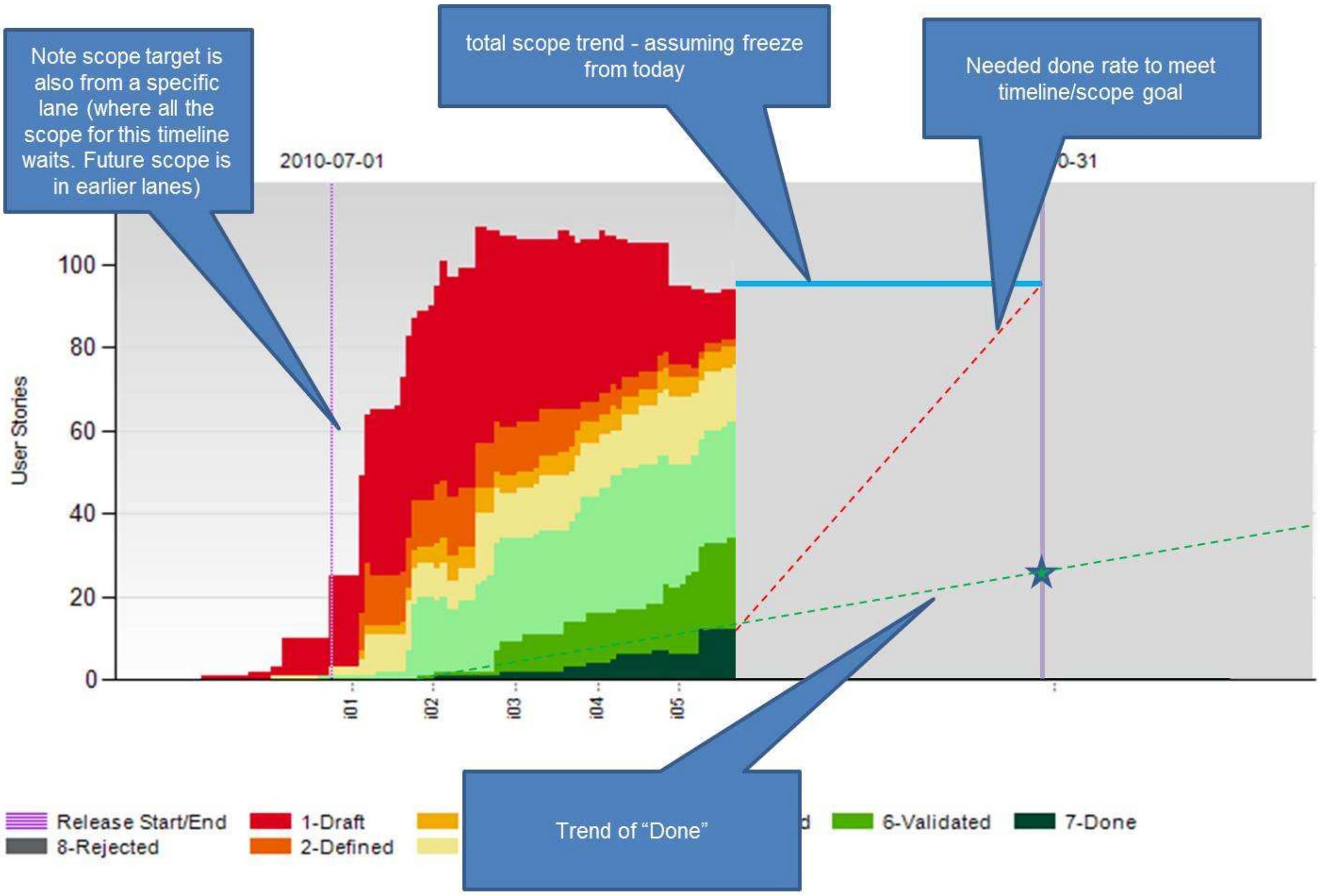
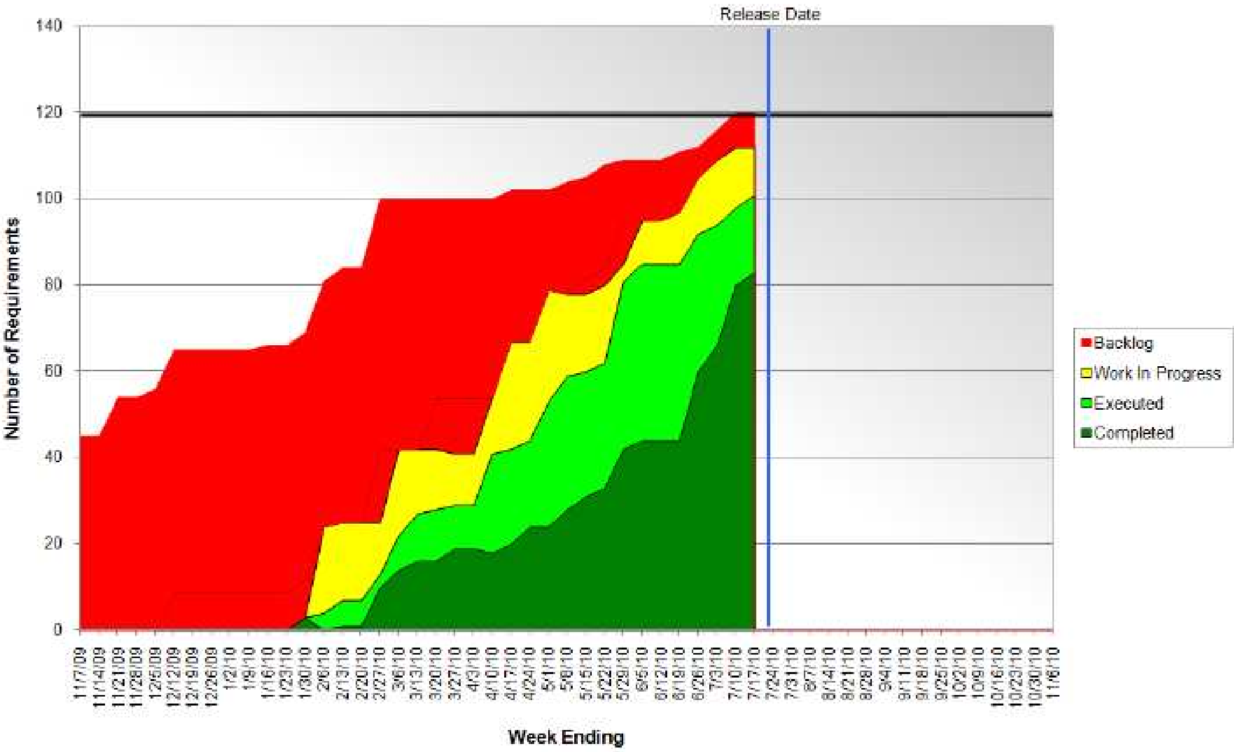


Figure 6.4.7 – Extrapolation with CFD (source: Yeret, 2011)

The key outcome of the evaluation in phase 2 of the project was that the use and application of the Cumulative Flow Diagram (CFD) was selected for further exploration and investigation.

6.5 Application of the Cumulative Flow Diagrams in Development Processes

The advantage of the CFD is that it delivers a visualisation of the rate of flow of work being done and also provides a depiction of the work sitting in each stage of the process, i.e. the Work In Progress (WIP). The CFD is employed in the software development industry. Hewlett Packard has recommended their broader adoption and use colour in their chart (Iberle, 2010). Figure 6.5.1 depicts one department's work in a backlog (i.e. not yet started), WIP, executed work needing a fix or rework and finally fully completed. The colours used are similar to a traffic light system; red, yellow, green and finally dark green for completed.



6.5.1 - Cumulative Flow Diagram use at Hewlett Packard

(source: Iberle, 2010)

Whilst at first glance this resembles the status charts used to depict traffic light system metrics the CFD can provide a lot more information about a process. Petersen & Wohlin, (2010) studied the use of CFDs in an industrial context at Ericsson and concluded that the visualisation and measures are especially valuable for developing large scale products involving many teams and tasks as here high levels of process transparency are important. Figure 6.5.2 shows the monotone chart used at Ericsson (Petersen & Wohlin, 2010) which also designates the hand-overs between stages in the overall process.

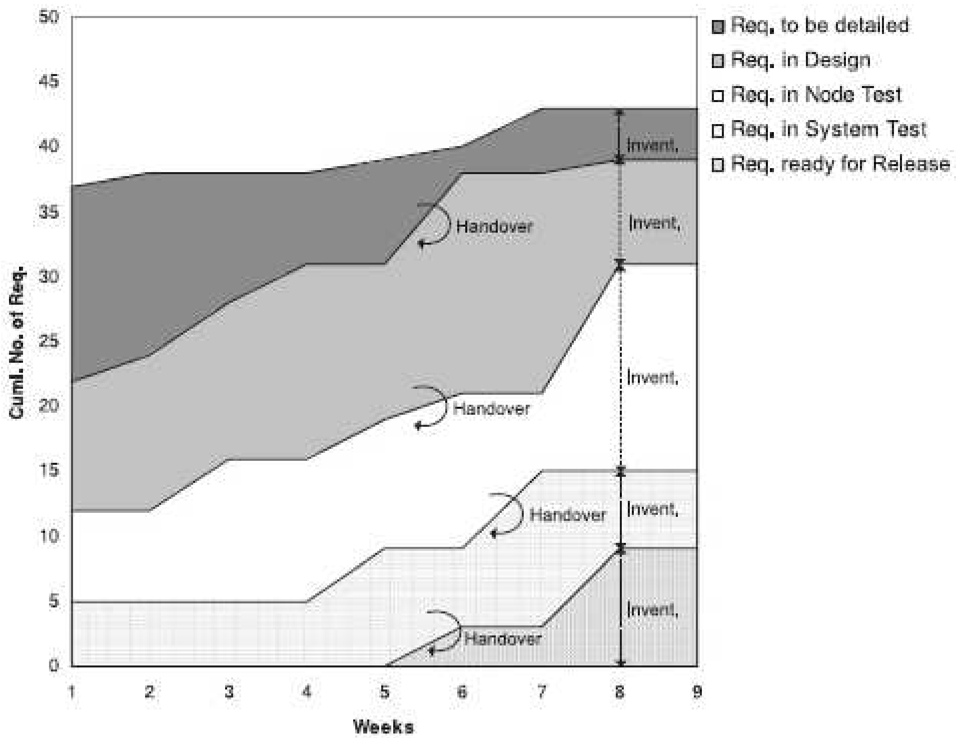


Fig. 6.5.2 - Ericsson Software Engineering (Petersen and Wohlin, 2010)

Academic search tools using the university online library and associated journals yielded zero results for "cumulative flow diagram" with "automotive product development". Further research investigation, using the author's extensive industry network, has shown no evidence of this method being used in the professional context of the automotive industry.

However, the automotive PD process is complex and the CFD needs to be modified to cover more activities than considered by Iberle (2010). Petersen and Wohlin (2010) demonstrate the CFD's use to demonstrate information flow between different stages of development but do not use colour as an indicator of progress.

6.5.1 Verification of the Applicability of the Cumulative Flow Diagram to the Automotive PD Process

The CFD technique was identified as having potential to meet the identified need of information flow tracking. However, further exploration and verification of its applicability to the automotive PD process was required. Specifically, could the CFD be made functional in the automotive environment, is the correct data available to enable its construction and could further improvements be made in terms of predictive capability.

In order to verify the use of the CFD in the automotive PD process, information flow on a project in progress at RLE UK's CAD department was reviewed. Investigation of the CAD department's control records showed only output from the CAD process, figure 6.5.1.1.

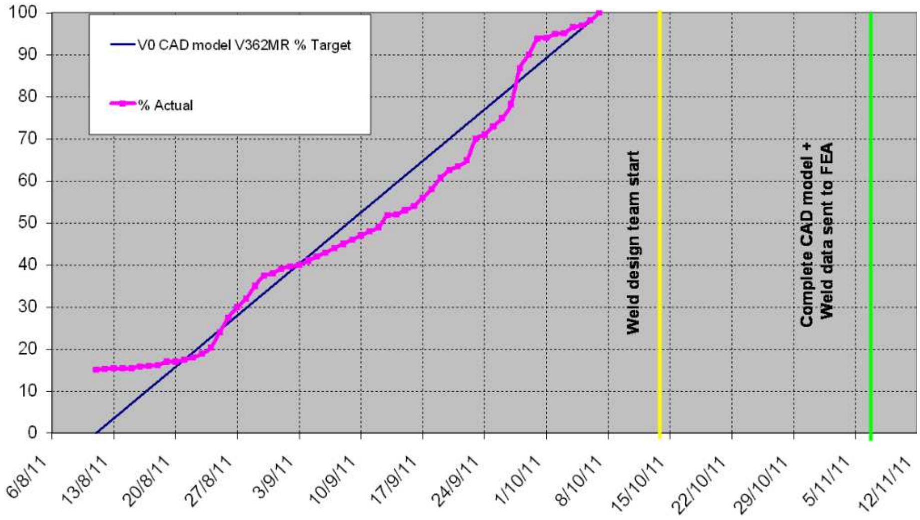


Figure 6.5.1.1 – CAD Release Data (source: RLE)

The '% Actual' line on the graph shows output from RLE UK CAD department and is similar to the burn-up chart described earlier in this report at section 6.4. Whilst this demonstrates the 100% of the CAD data will be released to the weld design team and FEA (CAE) teams prior to the target dates, it is a lagging indicator of performance, i.e. it only shows when the work was complete. If the date of the work's arrival at the CAD department had also been plotted on the same graph, Work-in-Progress (WIP) could have been monitored, figure 6.5.1.2. This shaded area between the work arriving (red dotted line) and its completion (green dotted line) is typically referred to as a funnel of work on a CFD chart (Gonzales-Rivas & Larsson, 2011).

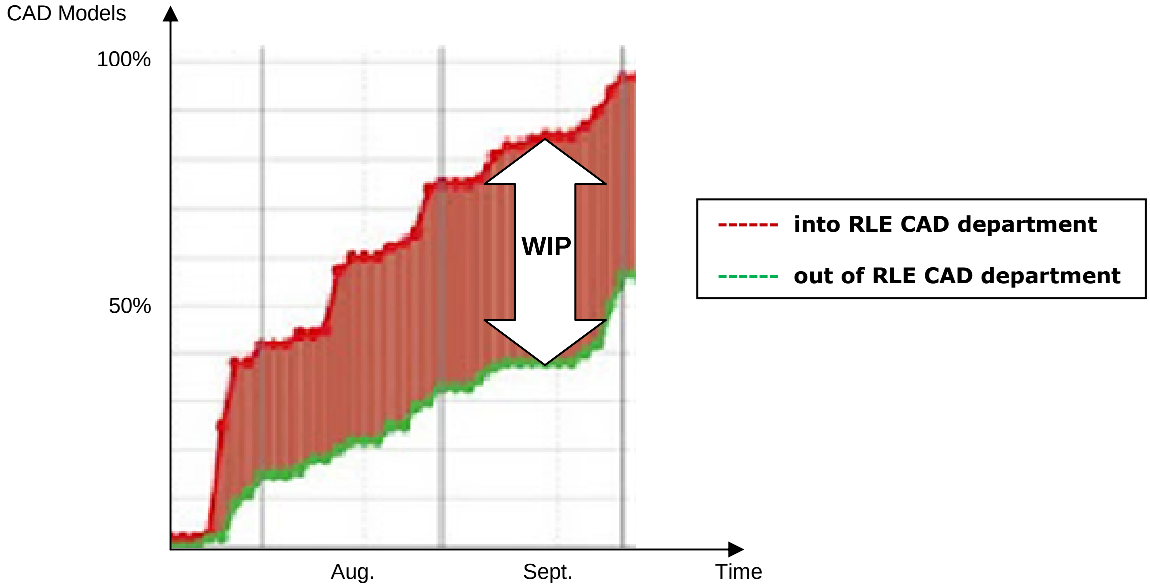


Fig 6.5.1.2 – Example showing how CAD Work-in-Progress (WIP) could have been portrayed via a CFD (source: RLE)

The identification of the WIP provides a measure of the amount of work in the department on any given day. This enables resource levels, i.e. the number of CAD operators required, to be calculated. Extrapolation of the boundaries on the WIP funnel on the chart provides an indication of future WIP, and thus future resource requirement.

This demonstration is analogous to the Hewlett Packard case (Iberle, 2010) shown in figure 6.5.1 of this report, in that it only considers one department. If the status of the backlog of the parts not having reached the CAD department could be understood then a superior project control plan could be developed. In the Ericsson case (Petersen & Wohlin, 2010) the handovers between departments in the development process are considered. This is what is required in the automotive PD process. However, the complexity of the automotive PD process needs to be considered to determine the precise area of application.

Figure 6.5.2.3 (Klipp, 2010) provides a very useful overview on the CFD and the information it can portray.

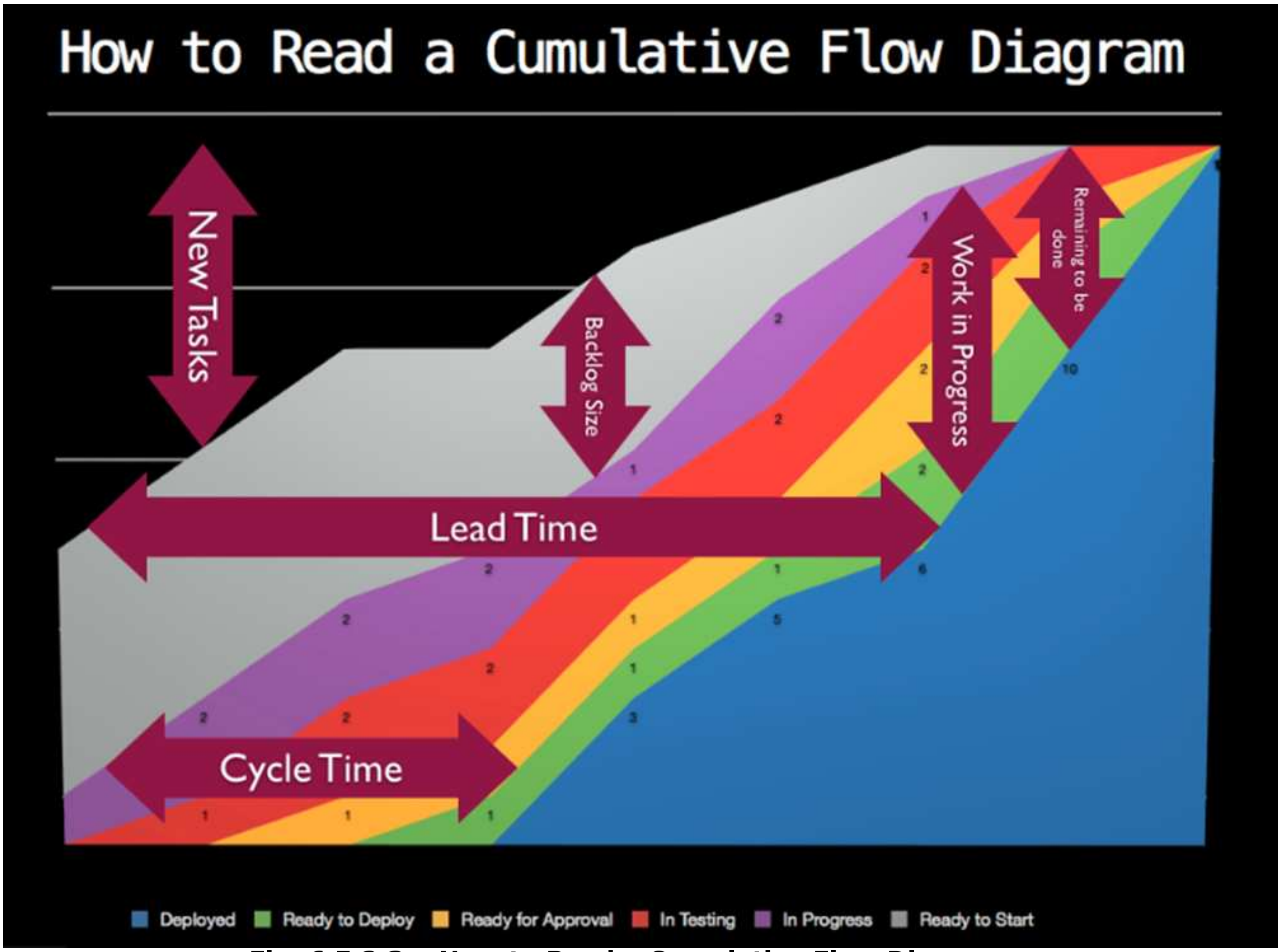


Fig. 6.5.2.3 – How to Read a Cumulative Flow Diagram
(source: Klipp, 2011)

On reflecting on this chart the author recognised that the CFD chart could be extended to include a series of activities in the automotive PD process.

6.6 Development of the Extended Cumulative Flow Diagram at RLE

The development of the Extended Cumulative Flow Diagram (ECFD) to better represent the interactions between several departments in the automotive PD process was conducted at RLE UK. An Extended Cumulative Flow Diagram (ECFD) was proposed that considered the workload and output of information flow from upstream departments in the automotive PD process and could be used as a predictive tool for downstream planning and project control purposes. Further details on the development of the ECFD are given in the project 3 report at appendix 3.

The possibilities offered by the use of CFDs and the ECFD were presented by the author to the management of RLE UK in December 2011. Figure 6.6.1 is offered as a working document from the meeting. The basis of the chart is Microsoft Excel.

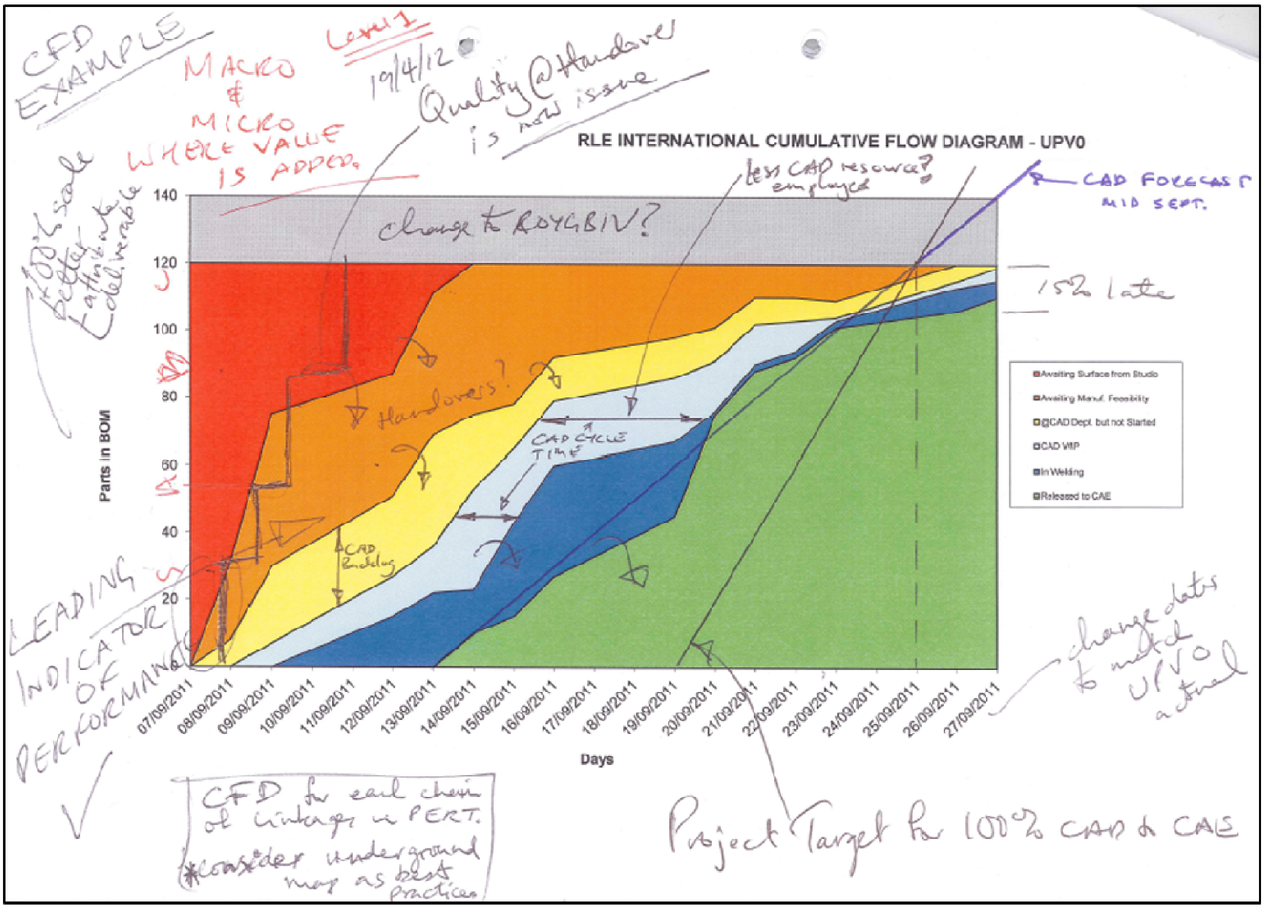


Figure 6.6.1 – CFD as initially discussed with RLE UK Management

Potential modifications discussed included developing the chart as a planning tool and using upstream performance to predict downstream Work-in-Progress (WIP) and thus regulate resource requirements. The RLE management team agreed the ECFD approach presented an innovative perspective on information flow in the automotive PD process.

6.7 Demonstration of the Extended Cumulative Flow Diagram on an Automotive Product Development Project

The use ECFD was demonstrated and validated on a live project at RLE UK. Both Microsoft Project and Excel were trialled to depict the ECFD with Excel being chosen for the implementation on this project, figure 6.7.1. The 'x' axis represents time and the 'y' axis the work to be done. Time was tracked in terms of days and also hours. In figure 6.7.1 the parts from the project BOM are sorted on the left and the transition between departments is shown as staggered in batches.

In this project, RLE was responsible for the CAD and the OEM customer was responsible for the CAE and Manufacturing Engineering (ME). The ECFD chart was updated on a daily basis, to display for each BOM part, whereabouts in the PD process, i.e. which department it was sitting in. Future resource levels were automatically adjusted as per the predicted information flows and workload at each department.

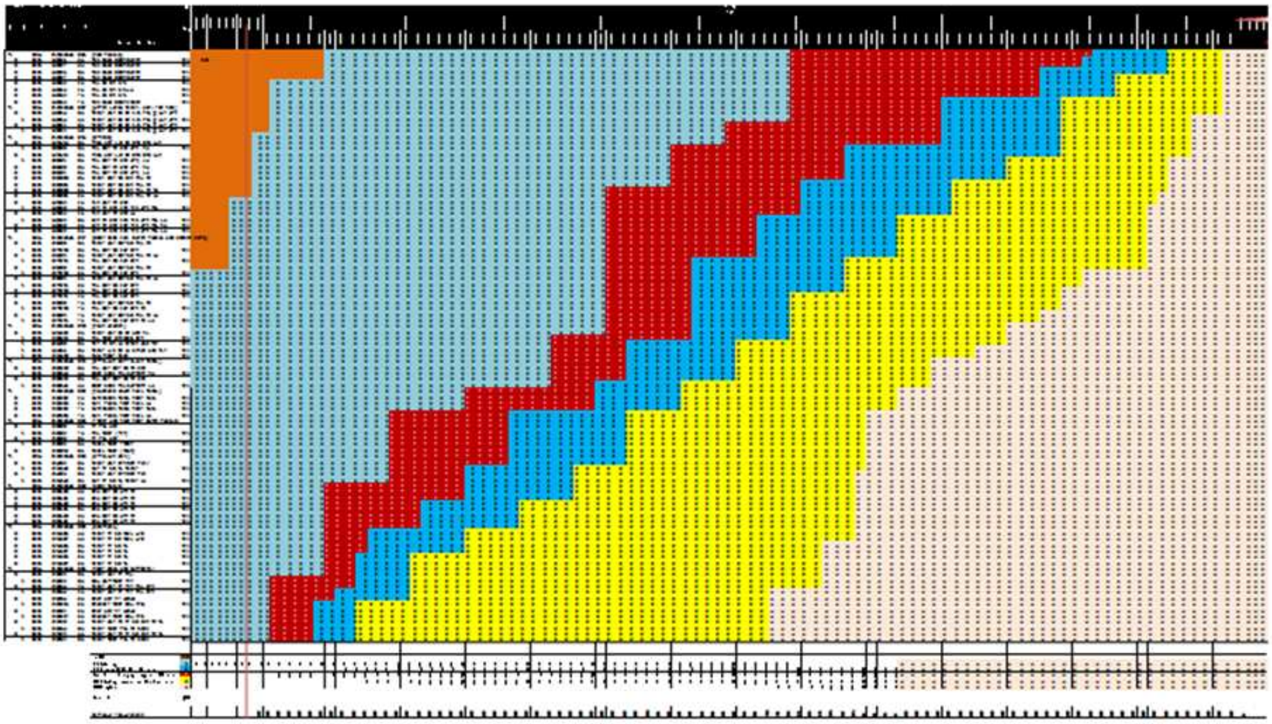


Fig 6.7.1 – ECFD as Implemented at RLE

Whilst updating the excel chart on a daily basis was a laborious process, this should be automated on future projects (Haque & James-Moore Mike, 2004). Figure 6.7.2 shows as example of the lower section of the ECFD. From this extract, it can be shown that the reinforcement to the roof assembly (Reinf Assy Rf Pnl) will remain in the OEM's CAE department for a further two hours before being handed over to the RLE CAD department for 3D modelling, that is forecast to take 13 hours. Subsequent to this the part is planned to be transitioned to ME for feasibility assessment then back to the CAD department for 2D drawing generation and checking prior to final release into the OEM's releasing system, Worldwide Alert & Concern Tracking System (WACTS). The key predictive aspect of the ECFD is that if the part remains with CAE for a longer period the whole forecast will move the right, thus changing the WIP in each department and the CAD resource level calculation incorporated at the bottom of the chart.

PANEL ROOF (REAR)	Yes	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	F	F	F
REINF ASY CTR BDY PLR/	Yes	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	3	F	F	F
EXT RF SD RL REINF	Yes	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	3	F	F	F
BRA BDY SD UPR RR	Yes	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	F	F	F	F	F	F	F	F	F
REINF RF SD RAIL W/O	Yes	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	F	F	F	F	2	2	2	2	2
REINF RF SD RL	Yes	CAE	CAE	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	F	F	F	2	2	2	2	2	C
REINF ASY RF PNL	Yes	CAE	CAE	3	3	3	3	3	3	3	3	3	3	3	3	3	F	F	F	2	2	2	2	2	C
BOW ASY-ROOF FRT	Yes	CAE	CAE	3	3	3	3	3	3	3	3	F	F	F	F	F	F	F	F	2	2	2	2	2	C
REINF ASY RF FRT PNL CTR	Yes	CAE	CAE	3	3	3	3	3	3	3	3	F	F	F	F	F	F	2	2	2	2	2	2	2	C
BRKT ASY RF H/DWN	Yes	CAE	CAE	3	3	3	3	3	3	3	3	F	F	F	F	F	F	2	2	2	2	2	2	2	C
BRACKET ROOF BOW MTG.	Yes	3	3	3	3	3	3	3	3	3	3	F	F	F	F	2	2	2	2	C	C	C	C	C	C
BRKT ASY RF H/DWN	Yes	3	3	3	3	3	3	3	3	3	3	F	F	F	F	2	2	2	2	C	C	C	C	C	C
REINF ASY RR RF SD INR RR RL	Yes	3	3	3	3	3	3	3	3	3	3	F	F	F	F	2	2	2	2	C	C	C	C	C	C
REINF ROOF PNL RR SIDE	Yes	3	3	3	3	3	3	3	3	3	3	F	F	F	F	2	2	2	2	C	C	C	C	C	C
Headcount Requirement																									
In CAE	CAE	10	10	6	6	3	3	3	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-D Modelling	3	4	4	8	8	11	11	11	11	11	13	7	7	7	7	7	3	3	3	3	3	3	0	0	0
2-D Drawing(GD&T, FFI, PMI, etc.)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	6	6	5	6	6	6	6	1
Feasibility (Stamping, supplier, CAE, etc.	F	0	0	0	0	0	0	0	0	0	0	7	7	7	7	3	7	5	5	2	1	1	4	4	4
CAD Checking (annotation, CN object, etc.)	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	9
WACTS updates	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total CAD @ RLE		**4**	**4**	**8**	**8**	**11**	**11**	**11**	**11**	**11**	**13**	**7**	**7**	**7**	**7**	**11**	**7**	**9**	**9**	**12**	**13**	**13**	**10**	**10**	**10**

Fig 6.7.2 – Lower Section of ECFD as implemented at RLE

Resources were moved between projects to ensure the best use of resource and reduce wasted time waiting for information that would not arrive on time. The ECFD enabled RLE to meet the OEM customer's final timing plan and justified adding significant additional resource over and above that originally planned in March 2011.

Performance measurement of the ECFD can be related back to the six point PMBOK 'triple constraint':

- Schedule
- Budget
- Scope
- Quality
- Risk
- Resources

Once applied, the ECFD maintained the planned schedule, scope, quality and risk level of the project. The resource levels were adjusted throughout the remaining project period resulting in a budget over-run for the OEM customer. However, had the ECFD been adopted at the projects inception in March 2011, resource levels in the earlier stages would have been reduced as the lack of information flow and WIP would have been anticipated. The additional costs would have been avoided and ten weeks could have been taken out of the final lead time. These ten weeks, involved the utilisation of approximately thirteen engineers and designers and represents around £300,000 of project overspend.

6.8 Implications for the Product Development and Project Management Process

The ECFD provides PD executives and practitioners with a method that allows them to see the information flows in the PD process and take immediate remedial actions by changing project resource levels as required. This may involve deferring resource usage or increasing resource levels in the short term to get a better utilisation over the longer term.

Moreover, the utilisation of the ECFD and the portrayal of information flows it provides will enable the identification of constraints or bottle-necks in the PD process. Management will then be able to predict issues and remove or manage these blockages before problems arise to best suit project performance requirements.

Ensuring information flow will lead to improved project performance and ultimately competitive advantage.

6.9 Conclusions

Project 3 of this research programme set out to identify a method that could be used for measuring or indicating information flow in the automotive PD process. This has been achieved by the use of the Extended Cumulative Flow Diagram (ECFD).

The indication and visualisation of information flow provided by the ECFD have enabled project control and feedback measures to drive improvement in performance in the automotive PD process.

The demonstration of the ECFD in research project 3 on a relatively small project identified potential cost savings of £300,000 to the OEM alongside a lead time reduction of ten weeks.

The following accolade has been received from global OEM customer where the ECFD was deployed:

"I have been impressed by the professionalism & commitment of the RLE team. Yesterday's handover event was again robust and demonstrated completion of the project deliverables" - Body Programmes Senior Manager.

In summary, whilst existing project management tools, such as the Gantt chart, deliver a good planning tool they do not provide a real-time project control tool that predicts performance.

Similarly, the traditional KPIs of time, budget and scope are set as targets but reporting against them is lagging indicator of performance. The ECFD provides a leading indicator of project performance that predicts WIP levels and facilitates real-time resource levelling.

The ECFD assimilates a huge amount of data into one picture that enables decision makers, at both the project management and OEM corporate level, to make key judgements.

7 Contribution to the Profession and Organisation

This research programme set out to make a significant contribution to the automotive PD profession and to the author's organisation. This chapter provides a critical analysis of the outcomes, results and learning within the context of a unique contribution to the professional practice of automotive PD and to the author's organisation, RLE.

Project 3 described a new approach in automotive PD that will allow project management practitioners and engineers to better understand project progress and make adjustments to resource usage in a timely manner. The case study in project 3 validated the hypothesis that information flow is a key indicator of project performance. Moreover, the use of the ECFD approach on a live OEM project demonstrated the benefits of visualising information flow during the project.

7.1 Contribution to the Profession

Used as part of the agile development approach in the software development industry, simple cumulative flow diagrams provide an easy to understand visual representation of project progress and departmental interactions.

The new concept of the Extended Cumulative Flow Diagram (ECFD) is proposed and its contribution of the visualisation of information flows over a range of activities and their interfaces in a PD project is unique. Additionally, the addition of a resource requirement calculation tool based on departmental WIP variation provides a matchless predictive capability.

There is no evidence that cumulative flow diagrams are used in automotive PD. Where similar looking charts do appear they are simply tracking the development of performance traffic light based metrics over a specified period of time. These do not provide an overview of information flow and multiple department interactions over an extended period of time.

Whilst tooling time in the automotive industry determines significantly product lead time to market, any process agility enabled by the use of cumulative flow diagrams is a benefit to the automotive PD process in uncertain times. Understanding and controlling information flows and resource levels empowers an ability to react to and accommodate late design changes brought about by changing market demands or competitive pressures.

The Extended Cumulative Flow Diagram (ECFD) is unique as it covers several sub-processes and provides a broad overview of project performance. Development processes have become increasingly virtual in their approach and thus the use of physical prototype parts as an aid to understanding and communication has been lost. The use of the Extended Cumulative Flow Diagram (ECFD) enables better understanding of information flows and project progress that can be applied to many multi-step digital or virtual processes.

The ECFD is unique in that it provides:

- A planning tool that visualises multi-department WIP and enables predictive resource level requirements and cost decisions to be made.
- Considers workload and performance in prior departments and sub-processes up-stream in the overall PD process.
- Effective project control by providing a leading predictive indicator of project success or failure.
- Real-time monitoring of performance thus enabling effective modification of resource usage.
- Reduces resource overload and panic at project gateways.

Benefits include:

- Metrics to evaluate project performance internally and externally.
- Real-time control and feedback measures to drive improvement.

- Competitive advantage in the industry.

In short, this approach shifts the paradigm from reactive problem solving and retrospective action to predictive indication and real time control.

It is envisaged that the application of the ECFD is transferable to other OEM and supplier PD processes irrespective of company size, culture or PD system.

7.2 Contribution to the Organisation

RLE has been able to apply this new ECFD technique on an actual live project and has seen the benefit in terms of improved project performance leading to increased profitability and enhanced reputation with its OEM customers. Feedback from customers has been very positive and the tool is being further developed and deployed in several projects. The following accolade has been received from global OEM customer where the ECFD was deployed:

"I have been impressed by the professionalism & commitment of the RLE team. Yesterday's handover event was again robust and demonstrated completion of the project deliverables" - Body Programmes Senior Manager.

The ECFD can be used to monitor information flows on any customer prescribed OEM PD plan and therefore provides a real and unique competitive advantage for RLE over its competition in the engineering services market.

The focus on information flow as a key performance indicator provides a business opportunity for the organisation in that it allows RLE to demonstrate thought leadership in automotive PD processes. To capitalise on this opportunity an industry white paper on information flow assessment will be prepared as part of the organisation's sales and marketing activities for its growth strategy into the project management business.

The use of the ECFD also contributes to the organisation's learning process in that it requires designers and engineers to consider their interfaces in the PD process and understand the upstream processes that impact on their ability to deliver project requirements. This provides the project team members with a broader understanding of the whole PD and allows them to comprehend where possible issues might arise.

The ECFD has increased the level of transparency in RLE's daily business and allowed management to better understand the daily issues that arise on projects, make decisions and apply the appropriate level of resource.

7.3 Contribution to the Broader Industry

Projects in other industries, e.g. civil engineering, suffer delays and budget overruns. Although the author's industrial experience is not in these sectors it is expected that the application of ECFDs to monitor information flows and predict performance in projects has wide-ranging applications.

Lean PD is regarded as a body of knowledge that is needed, growing quickly, demonstrating success, but is not fully established (Oppenheim, 2011). This research programme and the use of the ECFD to the PD process provide a valuable contribution to this body of knowledge.

8 Research Evaluation and Conclusions

This chapter provides an evaluation of the research programme and describes the primary conclusions established in response to the original overarching aims and objectives specified in Chapter 2. It also describes additional conclusions that have been drawn based on the research findings. Table 8.1 provides an overview of the stages undertaken throughout this research programme.

	Project 1	Project 2	Project 3
The Problem	Failure of Automotive PD Projects	Measurement of Performance in PD	Information Flow Assessment in PD
Explain Basics (Author)	Automotive Industry and PD History & Structure	Project Management of PD & Automotive OEM processes	Information in PD BOM, CAD, CAE etc.
Explore Issue (Primary Research)	Forces & Trends in the Auto Industry & Impacts on PD Process & Actors	Performance Measurement in the Automotive PD Process	Information Flow Measurement Approaches in other Industries
Research Methodology	Qualitative: Semi-Structured Interviews with Automotive PD Experts and follow up discussions with respondents. Analysis: Transcription, grouping of descriptors & identification of themes.	Qualitative: Case Study of 4 International Projects by questionnaire and follow up interviews with key respondents. Triangulation with project records and observation notes. Analysis: Coding of Questionnaire responses, transcription, grouping of descriptors & identification of themes.	Qualitative: Verification of Information Flow as a KPI via Case Study with questionnaire and interviews. Demonstration and Validation of ECFD on Automotive PD Project. Analysis: Coding of Questionnaire responses, hypothesis testing via case study & measurement of ECFD to KPIs.
Secondary Research	Literature Review on Automotive Industry & Actors' Roles & Responsibilities	Literature Review & Critical Analysis of Project Management at a Service Supplier	Literature Review & Critical Analysis of Information Flow techniques via MADA.
Compare & Contrast Results	Research Findings, Literature & Author's Observations	Research Findings, Literature & Author's Observations	Research Findings, Literature & Author's Observations
Discuss Outcomes and Implication to the Overall Research Programme	Impacts on PD Process and Actors	Time and Money are wasted when Information does not Flow correctly	Information Flow determines PD Performance and its Visualisation is a Key Perfomance Indicator that enables timely corrective action in Projects
Conclude	Aims & Objectives Met? Lessons learnt and impact on subsequent work	Aims & Objectives Met? Lessons learnt and impact on subsequent work	Project 3 Aims & Objectives Met? Contribution - Organisation/ Profession
Future Work	Need to Measure PD Performance	Need to Monitor Information Flow in the PD Process	Automation of the Information Flow Leading KPI (ECFD) via PDM or PLM. Further investigation into the measurement of the quality of information at departmental handovers.

Table 8.1 – Overview of Research Project Process

This thesis set out to research PD in the global automotive industry from the hypothesis that current automotive PD processes are inefficient in their use of company resources and not effective in consistently delivering value for the customer.

From the hypothesis three principal research aims were established and developed into three discrete research projects containing eight objectives.

The original research aims were:

1. To provide an overview of the changing structure of the global automotive industry and to identify the consequences for its participants involved in PD.

2. To assess automotive PD and identify specific areas where advances could be made to improve the process.

3. To identify new methods and employ these on an automotive PD project to demonstrate significant process improvement.

Project 1 confirmed the need for improved processes in automotive PD based on the findings of high levels of competition in the industry that are unlikely to subside and may indeed increase with the implementation of aggressive export strategies by Chinese OEMs. Therefore, the PD departments of OEMs will need to deliver a greater number of new products, in a shorter time with fewer resources. Aligned to this, the PD process must be more efficient in it use of these resources.

Project 2 explored performance measurement in the PD process and identified a need for measures that provide a leading indicator of success. Moreover, the project identified information flow as a key performance indicator. This is not to suggest that current measures of schedule, budget and scope of delivery are irrelevant but rather that ensuring positive information flow enables PD organisations to meet project targets. In addition, tracking information flows allows PD practitioners to better understand project interactions and internal customer delivery requirements.

Project 3 set out to research and identify a suitable technique that could be applied in the automotive PD process to enable better performance prediction and this improved resource allocation. The proposed method of using extended cumulative flow diagrams, adapted from the software development process, provides a simple visualisation technique that provides various performance analysis opportunities:

- Backlog
- Throughput or Cycle time
- Work-in-Progress

The applicability of this technique prescribed as it is in computer based software development is particularly valid in the virtual engineering environment widely employed in automotive PD and serves to demystify the level of project progress along the virtual value chain (Rayport & Sviokla, 1995).

During the evaluation of automotive PD projects in projects 2 and 3 it became apparent that whilst information flow within departments flows smoothly it is the interactions between departments where issues and delays arise.

The approach of considering handovers at interfaces and using Extended Cumulative Flow Diagrams (ECFDs) to monitor information flows between departments has therefore been validated through application on actual live project and the organisation has benefited from the improved project performance. This demonstration has satisfied the original research programme expectation and research aims and from the research undertaken it is clear that the hypothesis is well founded. This affirmation is confirmed resolutely by the issues identified in project 2 and recognised in the case study in project 3. That is:

1. Current performance measurement techniques employed in the automotive PD process do not adequately indicate progress toward project success.
2. If information flow is not monitored and regulated in line with the project plan then company resources are wasted as they are under-utilised.

The solution developed and demonstrated in project 3 enabled the project team and its management to understand how information was flowing against the project plan and adjust resources levels as required, therefore reducing wasted time.

8.1 Primary Conclusions

The primary conclusions are aligned to the eight objectives which were derived from the three macro aims.

Objective No. 1

- To explain the current status of the global automotive industry and the roles of various organisations involved in automotive PD.

The automotive industry is highly competitive and this level of competition is unlikely to reduce in the near future. Whilst global demand for vehicles will increase, particularly in the emerging markets, the successful companies of the future will bring new desirable products to market in a quicker time and at lower costs. M&A activity, particularly over the last twenty years, has led to an industry dominated by a few large OEMs and suppliers. The OEMs will continue to be supported by system suppliers and engineering service suppliers in their PD activities but as this research has shown the roles and responsibilities within these relationships can change over time depending on perceptions of project delivery and power within the industry. The emergence of a competent Chinese automotive industry is seen as significant threat to the OEMs of the traditional triad region of North America, Western Europe and Japan.

Objective No. 2

- To describe industry trends and drivers and how they will impact automotive PD.

On a macro level the industry drivers are global competition, legislation and consumer demand for an increasingly diverse range of vehicles. Future automotive PD processes must be more efficient as they will have to deliver more products with fewer resources. The use of computer aided simulations will continue to increase but key to their successful adoption will be people who understand and are confident in their application. Additionally, development processes must be adapted to ensure that the lack of physical prototypes does not hinder understanding of project progress toward the agreed goal.

Objective No. 3

- To describe current industry PD standards and compare RLE’s processes.

Most of the global OEMs have developed their own complex PD systems that have evolved over time and been subject to change as companies have merged and acquired former competitors. These processes have also been modified to bring new products to the market in a shorter time and at a lower cost. The use of computer aided simulations in place of expensive physical prototypes has been seen as an enabler of both these goals. The reduction in the number of OEMs and suppliers has enabled the wide spread adoption of international standards in the supply chain, e.g. AUTOSAR and APQP. This research has shown that the adherence to these standards in engineering service suppliers is not as controlled and strict as with system suppliers.

Objective No. 4

- To assess specific aspects and techniques of current PD processes.

With project 1 identifying the focus of project 2 as performance measurement this objective became an assessment of current project performance measurement techniques in the automotive industry. The research confirmed that whilst performance measurement techniques have developed considerably over the last twenty years the majority of the well-established automotive PD processes measure the triple constraint parameters of cost, time and project scope. The problem is that these are not leading, i.e. predictive, indicators of success.

Objective No. 5

- To undertake an evaluation on actual PD projects.

Similar to objective 4 this evolved to an evaluation of performance in actual PD projects. The results showed that whilst the majority of projects studied adopted the traditional triple constraint measures of cost, time and scope as their metrics the use of quality, risk and resource as indicators of progress were less prevalent. In particular the research identified that company resources were being wasted as designers and engineers spent too much time waiting for the delivery of information to enable them to perform their tasks or in meetings discussing the delivery and quality of information.

Objective No. 6

- To explore alternative methods for use in automotive PD.

This objective evolved as a result of project 2 into an exploration of alternative methods of assessing performance in automotive PD and specifically into a search for a method to monitor information flow between interfacing departments in a project. Real time visualisation of information flow was identified as a leading indicator of product development process success. The research found references to information flow measurement in both civil engineering and software development.

Objective No. 7

- To identify a new approach to improve automotive PD processes.

Based on the findings of project 2 this objective was modified to focus on the identification of a new approach to indicating the likely success of a PD project. This objective is satisfied by the identification of the cumulative flow diagram as a suitable tool to track information flow in the automotive PD process. Project 3 studied a real life project being undertaken by RLE in the UK and through the study of information flows between departments verified that inadequate information flow was the key contributor to the sub-standard project performance. This was acknowledged by the OEM customer and the project was re-timed and importantly project resource levels were re-assessed.

Objective No. 8

- To demonstrate the validity of the new approach on a PD project in the automotive industry.

The validity of using cumulative flow diagrams in the automotive PD process was demonstrated on the same, now re-timed, project that was investigated under objective 7. The application of the cumulative flow diagram was explained to the RLE project team and its use extended beyond just considering local department work-in-progress and backlog queues. This approach allowed the project's management to foresee future workloads and adopt control and feedback measures to drive improvements in project performance.

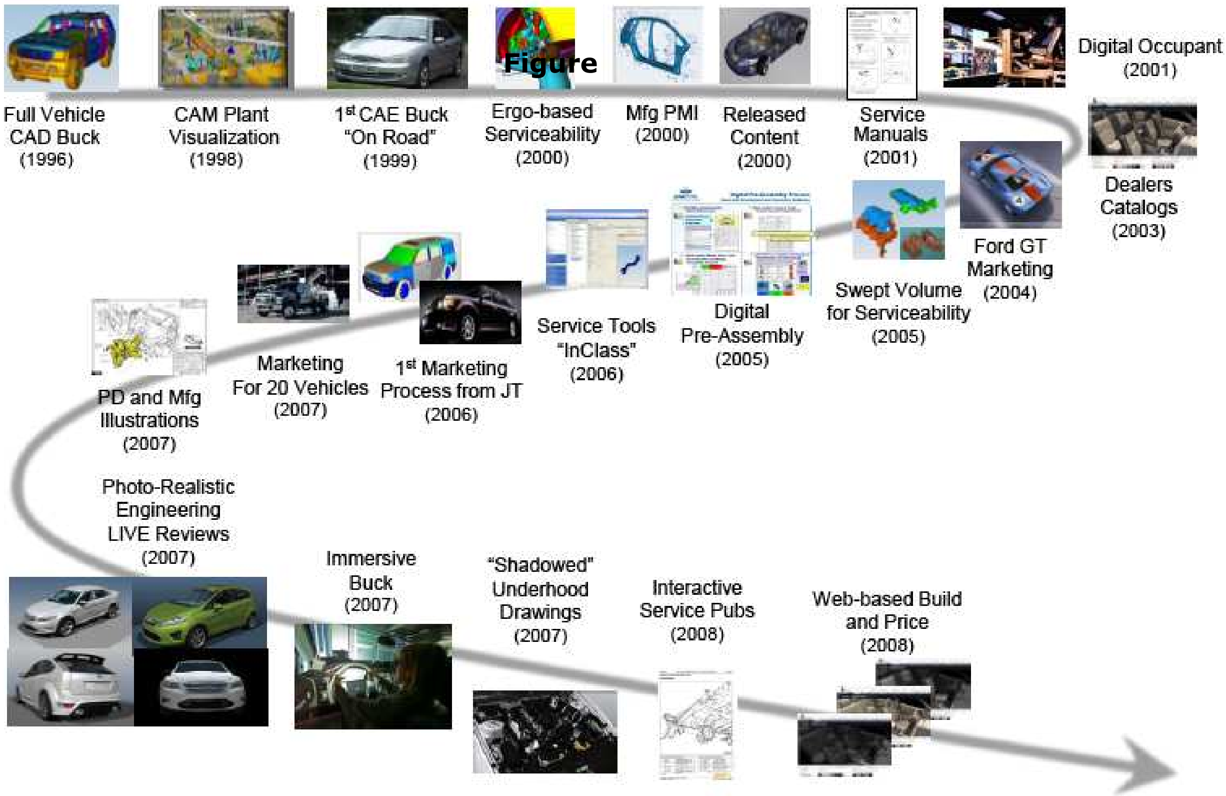
The outcome of the final project is the ECFD tool that provides a unique project planning and control tool.

The objectives of this research programme have been achieved. The three research projects have confirmed that there is an issue in the automotive PD process, isolated one of the root causes, proposed a unique solution and validated this on a live project. Moreover, the simplicity of the solution facilitates its transferability to other automotive OEM PD systems and indeed to PD processes in other industries.

8.2 Additional Conclusions

This section outlines three additional conclusions that can be drawn from the research programme when reflecting on the synthesis of the project areas as a whole.

1. Virtual engineering or digital innovation (DI) as it has also come to be known at several OEMs has accelerated the automotive PD process. The 3D geometry created in the PD process is now essential to many OEMs processes including those beyond the PD department as shown in figure 8.2.1.



8.2.1 – Evolution of the use of Digital Information at Ford Motor Company (source: Riff, 2010)

Without the correct measurement or indication techniques the PD process can become lost in the machine that is the digital development factory. Project 1 identified the importance of having the right people and culture to work within virtual engineering. The PD process must also recognise the use of computer aided techniques and resultant lack of physical prototypes, previously central to many project meetings and decision making processes, creates an issue for development teams. The absence of physical prototypes has removed a focal point that was significant in the PD process in relation to understanding of project status and forward planning.

2. Depiction of the multiple development iterations in the automotive PD process are not demonstrated clearly by the traditional stage-gate or waterfall diagram. Figure 8.2.2 adapted by the author from a software development depiction demonstrates that the iterations are more reminiscent of the spiral PD process. This is not recognised in the OEM PD process Gantt charts but is portrayed in the RLE project management process.

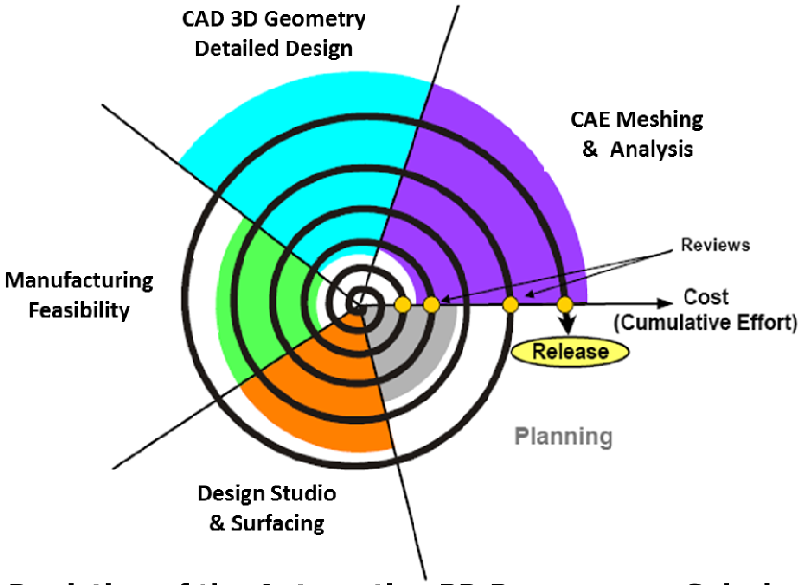


Figure 8.2.2 – Depiction of the Automotive PD Process as a Spiral (adapted from: Lyneis, et al., 2003)

3. RLE needs to implement a global Project Management Office (PMO) to provide a central role in controlling its approach to project management. The current approach with different techniques adopted in the various offices is too fragmented and does not portray a coherent global organisation.

8.3 Summary

The research has provided a fundamental insight into the performance of the automotive PD process and proposed the use of information flow a key leading indicator of success. The outcome demonstrates a new and unique contribution to professional practice and the organisation.

9 Recommendations for Future Work

This work has achieved its objectives and defined a usable method for immediate use in the automotive PD industry but areas of further work can still be highlighted. Therefore, recommendations are given that define key issues for possible continuation of the research.

Future research requirements into flow in the PD process have been recognised (Martinez Leon & Farris, 2011). The research programme has established that information flow measurement is a key characteristic of successful PD. The application to larger development projects and with different OEMs needs to be further evaluated.

The PD process has evolved to include the use of virtual simulation models but the project management of PD has shown little progress in its use of simulation of digital data. The automotive industry OEM PD processes have advanced over several years and a full assessment involving Value Stream Mapping and/or Design Structure Matrices would be a significant piece of research work but one that may lead to fundamentally new approaches. Maybe even a truly agile design and development process. Included in this work would be need to recognise the iterative or spiral nature of the automotive PD process.

Whilst the cumulative flow diagram is used in software development it could be applied in many PD processes in other industries. Indeed, not just PD, but any multi-stage digital process. The use of feature based functions in CAD models may facilitate this. Additionally, the use of modern Product Data Management (PDM) applications and Product Life-cycle Management (PLM) software such as SmarTeam or TeamCentre may facilitate the automation of the ECFD approach, removing the need to manual daily updates.

The inclusion of a measure of the quality of information at handovers would also provide a useful further development of the ECFD.

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Appendix 1

Research Report 1

The Changing Structure of the Global Automotive Industry

Appendix 2

Research Report 2

Evaluation of Performance Measurement in Product Development in the Automotive Industry

Appendix 3

Research Report 3

Performance Prediction through Information Flow Assessment

in Automotive Product Development

Appendix 4

Portfolio

Darren Gowland, Engineering Doctorate

1.0 Professional Development and Experience

Qualifications:

BEng(Hons)	Mechanical Engineering	1988
Postgraduate Certificate	Engineering Management	1992
MBA	Business Strategy	2002

Experience:

Austin Rover Group – 1984 - 89

CAE Engineer – Body Engineering

International Automotive Design – 1989 - 91

Senior Structural Engineer – CAE group

Ford Motor Company – 1991 - 97

Various engineering and supervisory positions in Detroit, Toronto, Hiroshima, Cologne and Valencia

RLE International Product Development Ltd – 1997 - 07

Director UK Operations

Established UK company in 1997 and increased revenue to £7m by 2000.

RLE International Group – 2007 - to date

Group VP International Operations

Responsible for all of the RLE Group's office and activities outside of Germany.

2.0 Programme of Supporting Studies

University of Hertfordshire - GTRS module: Thesis what Thesis	2007
Harvard Business School - Leading Professional Service Firms	2011
Cranfield University - Lean Process and Product Development	2011

Attendance and discussions on the recovery of the Automotive Industry at SIAT 2009, Pune, India January 2009.

Presentation on the design of future electric vehicles at Environmentally Friendly Vehicle Conference - Delhi November 2009.

Review of RLE operations in Trollhattan, Sweden as a result of the re-organisation of SAAB following its exit from GM. July 2009.

Assessment of automotive industry prospects following the bankruptcy of GM and Chrysler in Detroit and subsequenst re-organisation of RLE Inc. 2009/2010.