Automotive material uncertainty and business risk at the concept phase using existing metadata.

PhD Thesis

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In accordance with regulation 16.5 (I), I declare that the material contained in this thesis has not been incorporated from a submission for another degree. The preparation of this thesis is the work of Robert Mills and has not been carried out by other people.

i. Abstract

New product development has attracted a significant amount of academic attention, and its application within the automotive sector is no exception. The research presented in this thesis places its focus at the concept phase of the process and seeks to identify the commercial uncertainties allowing them to be treated as business risks for mitigation during the design phase of the new product development. Within this research, the attention is on the uncertainties concealed within the tier 1 cost base, commercial uncertainties, such as sales and product function are out of scope. The presented research develops a hybrid methodology which builds upon existing cost estimating tools and existing metadata to provide a structured identification of the uncertainties and the scale of business risks to which new product developments are exposed. The hybrid methodology is first applied to a simple example to present the fundamental notions and then to the automotive domain to demonstrate its application. The results obtained confirm that the hybrid methodology allows uncertainty, hitherto hidden during new product development concept phase evaluation to be realised as potential business risks.

Potential Keywords: Cost Estimation, Parametric Cost Estimating, Should Cost estimating, Uncertainty, Risk, New Product Development, Product Lifecycle, Global Supplier Selection.

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v. Contents

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viii. Nomenclature

Analogous An estimation method that takes something similar to what is required and walks the adjustments required through judgement.

Attribute The key metrics which govern the Engineering Quality, i.e., Weight, CO_2, Noise Vibration & Harshness (NVH).

Black box parts These are OEM specified parts, but the precise design is defined by the tier 1 supplier. The OEM specifies the interfaces, fitment space that the tier 1 design is required to meet.

Brand Jaguar, Land Rover, Range Rover.

CER Cost Estimating Relationship. The name given to the regression lines resulting from the comparison of two independent variables.

Comovement The correlated or similar movement of two or more entities.

Contingent Liability A contracted action based upon something is triggered. A typical contextual example from the automotive industry would be a volume of parts being achieved within a period of time or at the end of the program where the investment is amortised and might result in a residual investment needing to be repaid.

CRM Critical Raw Material. Are those raw materials that are both economically and strategically important for the economy, but have a high-risk associated with their supply.

Detailed sources A group of data sources created using the principles of 'bottom-up', that is created from the very lowest form of data. Within the context of this research, theses include; SCE; QAF; MSDB; IMDS; Raw material claim.

DFD Design for Disassembly. Designing the NPD to improve the disassembly and recyclability of the ELV. Closely aligned with Design for Serviceability.

Economically Volatile Price fluctuation. Normally measured against a baseline and over a set period of time.

FAST Function Analysis System Technique is a structured method to allocate an attribute, typically cost, to the delivery of the desired function.

Feature The items that may be specified when ordering a new car at the dealerships. Within JLR these can be classified as either Major or Minor features. Major form the LHD or RHD, type of transmission, engine, or body style. Minor are features that can be used in combination with Major features such as Heated seats, Satellite Navigation. Minor features are grouped into subsets of feature families.

GAAP Generally accepted accounting principles, is a collection of commonly-followed accounting rules and standards for financial reporting.

Hedging Hedging contracts are financial devices designed to fix the cost of currency and other commodities between to two parties – a financial betting slip. In a fixed hedge a rate is agreed ahead of time that at a future date the market rate will be ‘x’. If at that agreed point in time the market is lower, the buyer still pays the higher agreed rate for a fixed quantity of the currency, if the market is higher, then the buyer pays at the lower agreed rate, and the seller loses on the fixed quantity of the currency. There is a charge for this type of contract being underwritten, but the charge is higher if taken out as an option hedge where the buyer can withdraw if the rate at the point in time is lower than the contract rate.

IMDS International Material Data System. Material data recorded by the OEM tier 1 supplier including the delivered weight of the material. Originally used to support recyclability declarations.

Import Duty A levy charged by the government who administer the territory into which goods are being imported.

LCA Life Cycle Assessment is based on the analysis of products or the assessment of objectives (such as technical characteristics, economic characteristics, and environmental coordination). LCA provides a detailed analysis or assessment of all stages of the product lifecycle and obtains related information for product improvement.

Locally Sourced In the context of this thesis local sourced shall mean the European Union of 28. Within the European customs union. The details are likely to change post-Brexit.

Material Cost Costs incurred for production material sourced from the JLR tier 1 supplier base. Also known as Piece Cost.

Metadata Secondary data that shows the construction of lower order structures.

Model Line Jaguar – XE, XJ, XF, Land Rover – Defender, Freelander, Discovery. Also known as vehicle line or nameplate.

Non-Locally Sourced In the context of this thesis non-local sourced shall mean not within the European Union of 28. The details are likely to change post-Brexit.

NPD New Product Development. A new vehicle proposal which can range from small but essential legal actions to a new Platform for a group of future vehicles.

OEM Original Equipment Manufacturer, i.e., JLR, BMW, Honda …

Offal Sometimes spoken of a scrap, offal is planned waste resulting from a manufacturing process such as stamping rather than scrap which is better described a result of something having gone wrong in the manufacturing process.

PCE Parametric Cost Estimating, in this context the application of historical data via statistical methods.

Piece Cost Costs incurred for production material sourced from the JLR supplier base. Also known as Material Cost or tier 1 supplier costs

Platform A group of Model Lines, i.e., Discovery and old Range Rover Sport formed the T5 platform.

POC Proof of Concept.

Preference Duty Relief Import duty relief given by the controlling authorities of the importing territory if prescribed content conditions are met.

Preference Markets Territories with whom preference duty agreements have been agreed for imported goods.

PVI Price Volatility Index, a normalised index of economic volatility for traded commodities that are used as materials within an NPD.

QAF Quotation Analysis Form is the supplier provided breakdown of their price quotation. The supplier compliment to the Should Cost.

Raw Material Claim A claim made by the tier 1 upon the OEM for raw material cost fluctuations compared to the agreed raw material rate in the contract price. (Other types of claims are possible such as exchange rate.)

SCE Should Cost Estimate. A cost estimate built up from the first principals of manufacturing processes.

Should Cost A cost estimate built up from the first principals of manufacturing processes. Sometimes referred to as an Engineering Estimate.

VA Value Analysis. Within the contextual usage of this research paper, Value Analysis is a structured method to allocate cost to individual feature delivery of a part or in this case a system. (See also FAST)

Variable Marketing Within the marketing tools of an OEM is a budgeted fund for the OEM to stimulate sales by subsidising the recommended retail price.

Vendor tooling This is tooling funded by the OEM and used in the manufacture of the parts to be supplied by the tier 1 + supply base. It is alternatively known as adaptive tooling because it adapts the tier 1 machine or workstation to the specific requirements of the parts to be manufactured.

USC Unique System Code. Adopted from other closely related literature, this is the representation of engineering product structure classification.

Chapter 1. Introduction

Is there anything new to be researched in automotive New Product Developments (NPD)? In (Pugh, 1990), Pugh (pg 160-161 of Pugh's book) makes the statement that "… the motor car is a prime example of a product whose total system architecture is conceptually static." Pugh goes on to confirm though that he is addressing the basic system structures of the product in terms of wheels at each corner, an engine, steering and seating. He also confirms that designers operating in such industries are still refining the products with technology, new materials and to meet additional legislation. Pugh does however claim that the differential gear represents a static concept as it is used in all cars today. But, a technological revolution is and has taken place because the mechanical differential, some may know this as a 'drive unit', is being replaced by electronic differentials. Is this a concept change or simply a technology adjustment? Whichever choice is made, change in materials and sourcing are continuously taking place, modifying business risks as a result of change.

The hypothesis being addressed within this research is that by identifying and quantifying commercial uncertainties in a New Product Development (NPD), uncertainties that would manifest during the volume production and disposal phases, it is possible to deal with them as the business risks that they represent during the concept phase of the NPD. Uncertainties once revealed can be addressed through mitigation, either through engineering design or commercial contract and in some cases a combination of both. The delivery of this new data during the early concept phase relies upon the establishment of a new methodology to apply existing secondary data to underpin and establish a data provenance for the new concept data. Moreno et al., (2015), and (Gear et al., 2018) make the point that "The earlier in the development of a process a design change is made, the lower the cost and the higher the impact on the final performance.". Mirdamadi et al., (2013); and (Saravi et al., 2013) also focus their research upon better quality cost data earlier in the NPD process, but their attention is upon the transition between the concept and design phases. Mirdamadi et al., (2013) specifically seek to understand uncertainties through cost estimation, but they fail to apply their thinking to the very early concept phase. The establishment of the new data at the concept phase allows informed decisions and mitigating actions to be undertaken at the earliest point in the NPD timeline. The aim of this research, therefore, is to establish early confidence that once in volume production the risks to NPD profitability due to volatile economic forces and other commercial issues can be reduced.

In the Moreno et al. paper the authors declare that, unfortunately, designers encounter difficulties in addressing the environmental challenge in the case of NPD’s due to the absence of environmental impact feedback. In the case of the introduction of entirely new technology, there may well be a lack of environmental feedback from within an Original Equipment Manufacturer (OEM)s own application or industrial sector. In most cases, there will be some level of industrial cross-over of technology application where some environmental feedback can be obtained.

NPD confidence is created by reducing uncertainty. Within the context of this research, it is not the uncertainty that the engineering will work, neither is it that the customer base will receive the product and buy it, these aspects are out of scope. The uncertainty to be addressed with this body of research is the consumption of all externally bought tier 1 material, the included materials; corresponding tier 31 manufacturing processes; business trading tariffs and taxes that are dependent upon the externally bought tier 1 material.

Fig 1 shows the automotive timeline, typical within Jaguar Land Rover (JLR). It is also indicating the focal point where the presented research is to be applied, left-hand side of the timeline, and the impact points where the respective summaries of the impacts mature, midpoint and righthand side of the timeline. By seeking to address the use of recycled and economically volatile materials in general, it is addressing the concerns raised by Moreno et al.

As illustrated in Fig 1, and proposed within the hypothesis, volume production and end of life consideration applied during the early phases of any NPD is critical to ensuring that not only is the design correct for the customer's satisfaction but also correct to achieve minimum cost throughout the NPD lifetime. Because the delivery of an NPD involves many different resources, the cost is being used as the common performance indicator for this research.

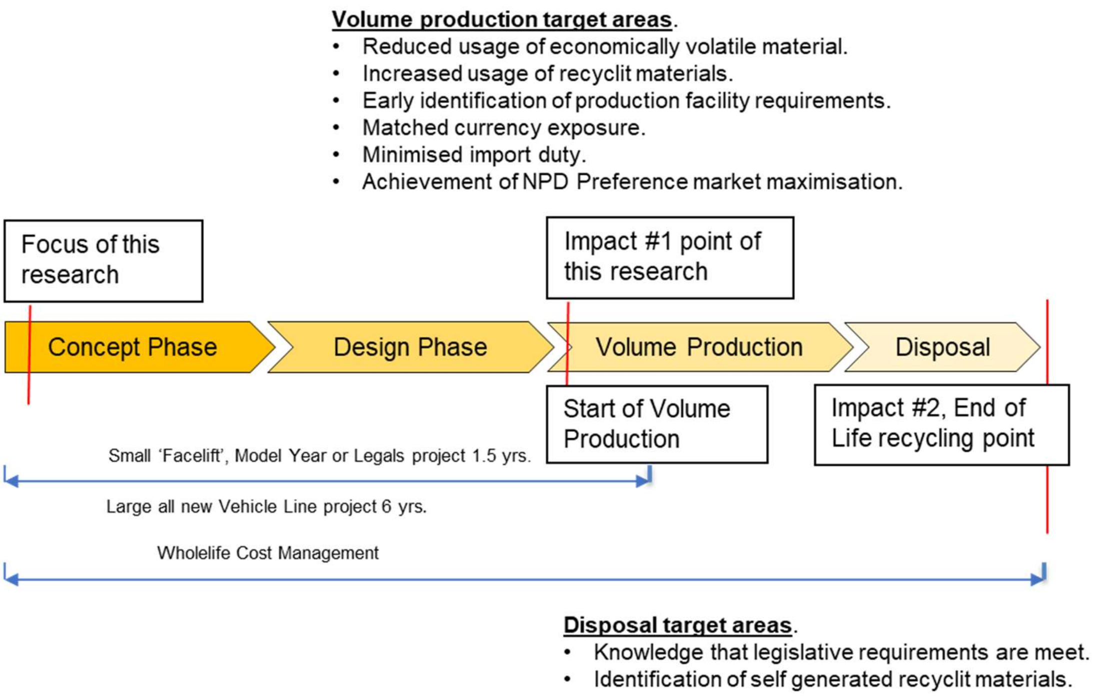


Fig 1: Automotive NPD timeline, focus and impact of this research.

This thesis reports the research to use metadata that already exists as secondary data and applying modification as required by the performance adjustment to achieve the NPD during the early concept phase. Material cost as seen by the OEM has been used as the common denominator. Available literature is presented that confirms tier 1 material cost as seen by the OEM to be worth up to 65% of the costs to be covered by the NPD revenue. Tier 1 material cost is a very significant part of the NPD has been selected as the focus of the research.

Within this research, the early identification of potential tier 1 material costs; the materials and processes that define those costs are considered. The research enables the early identification of high-cost materials that are proposed to be used. High-cost material usage, if proved to be value for money, can be allowed for within the cost performance of an NPD. However, this research goes further and seeks to identify high usage of economically volatile materials where the cost fluctuates with the commodity markets putting the business at risk. In addition to the business risk posed by the uncertainty of economically volatile materials in tier 1 material, this research presents the early identification of other business risks that are co-dependent upon tier 1 material costs and the geographic origin of cost. This sub-group of business risks are typically 'below the radar' at the concept phase of an NPD, but as the engineering and or sourcing profile of the tier 1 material can have a significant effect on the mitigation activity, they are valid and valuable inclusions within this research. The specific tier 1 dependencies that are covered include, tier 1 manufacturing processes, currency, importation duty and preference markets are discussed, all of which are aspects of early NPD uncertainty that the proposed methodology can uncover allowing mitigation of business risk to be undertaken.

Successful NPDs rarely happen without significant effort. James Dyson produced over 500 prototype vacuum cleaners before he knew he had developed the product that he first launched, (Dyson, 2018). Many papers have been applied to review how NPDs can be improved. Google scholar shows 5,460,000 returns for a simple “New Product Development” search alone, (20th Dec 2017). A sample of these have been reviewed resulting in the opinion that the literature shows a very heavy bias towards the improvement in the development process itself. A limited appraisal of these papers is given in the opening of Chapter 2 and section 2.1 This research sets out to extend the existing knowledge base seeking to understand better the potential business risk likely to occur in the delivery phase of an NPD while still in the early stages of the concept phase of that same NPD. The resulting methodology will prove that by treating the known data and its metadata in a novel way that the uncertainty that introduces a lack of early confidence can be identified resulting in the establishment that once in volume production the risk due to volatile economic forces can be reduced. The impact of the presented research extends beyond the volume production phase and achieves additional impact upon the recycling phase by allowing the requirements of the end of life legislation to be considered while the NPD is still in the concept phase.

Treated correctly a closed loop can be identified as the recycled materials are included in the NPD material specifications and in so doing lowering the initial cost of the materials consumed in the volume phase.

1.1. Research structure

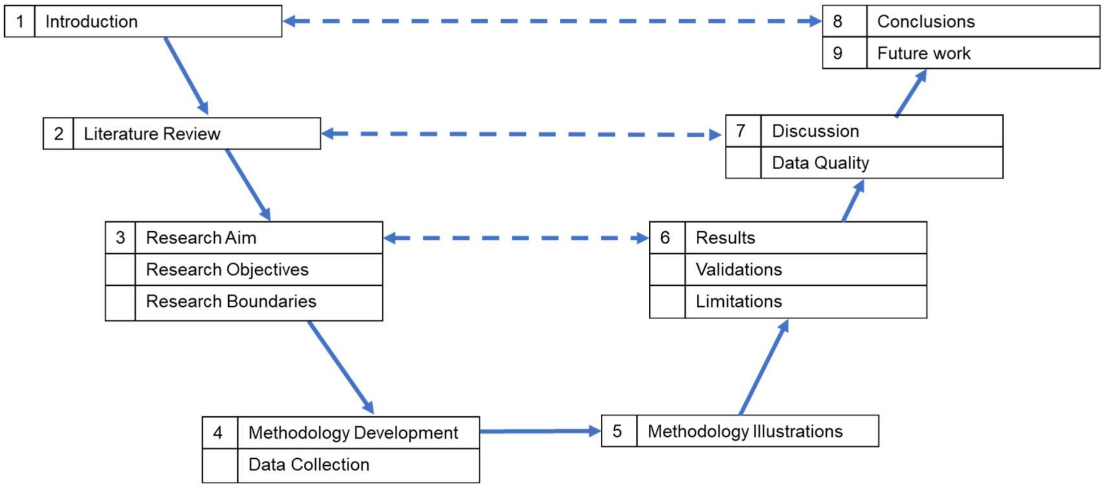


Fig 2: Basic research structure adapted from (Parry et al., 2017)

A structured investigation has been undertaken as outlined in Fig 2 starting with the introduction in chapter 1 which outlines the business issue to be addressed followed by a literature review in chapter 2. The literature review has four key elements: the first element takes up the validation that the hypothesis has not been covered within existing NPD literature. The second element has a focus on fixing the research within a business context. The third element of the literature review seeks to establish which areas of existing literature could be reviewed and drawn together to establish a new NPD methodology tool. This third element introduces mind-maps to explore the potential existing tools which are further explored in the fourth element together with the exploration of existing metadata and potential business impacts. The literature review culminates with the identification of what is missing from the literature in respect to the posed hypothesis. Chapter 3 examines the research aim, singular in this research and the objectives. It starts with the literature review and the hypothesis itself, if the hypothesis is not already covered by existing literature, is the problem of academic creation rather than real? Chapter 3 culminates with the definition of the research scope boundaries.

Chapter 4 starts with validation of the hypothesis using industrial subject matter experts. It explores the nature of the secondary data that is typically available that can provide evidence of the nature of early concept phase uncertainty. Having identified the nature of the secondary data chapter 4 develops the methodology to be used to employ it for maximum impact during the NPD concept phase. To enable a greater understanding of the business risks identified by the new level of NPD metadata, causal loop diagrams, stock & flow diagrams and high-level mathematics are presented to show the potential impact of early knowledge upon the developing NPD. Chapter 4 concludes with the development and definition of the methodology itself. Within its construction, it covers the NPD concepts of carry-over, modified and new features.

Within chapter 5 an illustration of the application of the new NPD methodology is provided and as applied to a common, well-known object – the takeaway paper cup. An additional illustration is also provided based on an actual automotive system.

In chapter 6 the research progresses from the theoretical into the practical with a review of the results, validations and limitations.

Chapter 7 provides a discussion of the findings is presented alongside the development of a practical framework and a proposed timeline for its application with an NPD life-cycle. Also, within this chapter, the practicality of the methodology's application is proposed. To establish that risks could exist is of little intrinsic value, risks need to carry a scale, and the risks are shown by the proposed framework need to be placed within a scale of business risk. A risk index is proposed that can direct mitigation focus on key risks in 'high to low' Pareto order of the risk as applied to the businesses profit line increasing the likelihood of achieving a successful NPD. Data quality is considered, and consideration is given to alternative sources that could be employed to achieve quality data.

Chapter 8 details the researches contribution to knowledge, impact areas and concludes proving the hypothesis. Chapter 9 explores potential further work leading from this research.

Chapter 2. Literature review

The literature review presented in chapter 2 is divided into four distinct elements as shown in Fig 3. It has been necessary to establish if there was potentially valuable new knowledge to be recorded by comparing the research intention against existing new product development literature. It was also essential to establish the proposed research within a business development context. These form the first two elements within the overall literature review. It was then necessary to establish existing materials within literature and physically on the ground if not existing in the literature that could lead to a practical methodology. The fourth literature review element is further sub-divided into specific aspects as identified through element three: mind-maps.

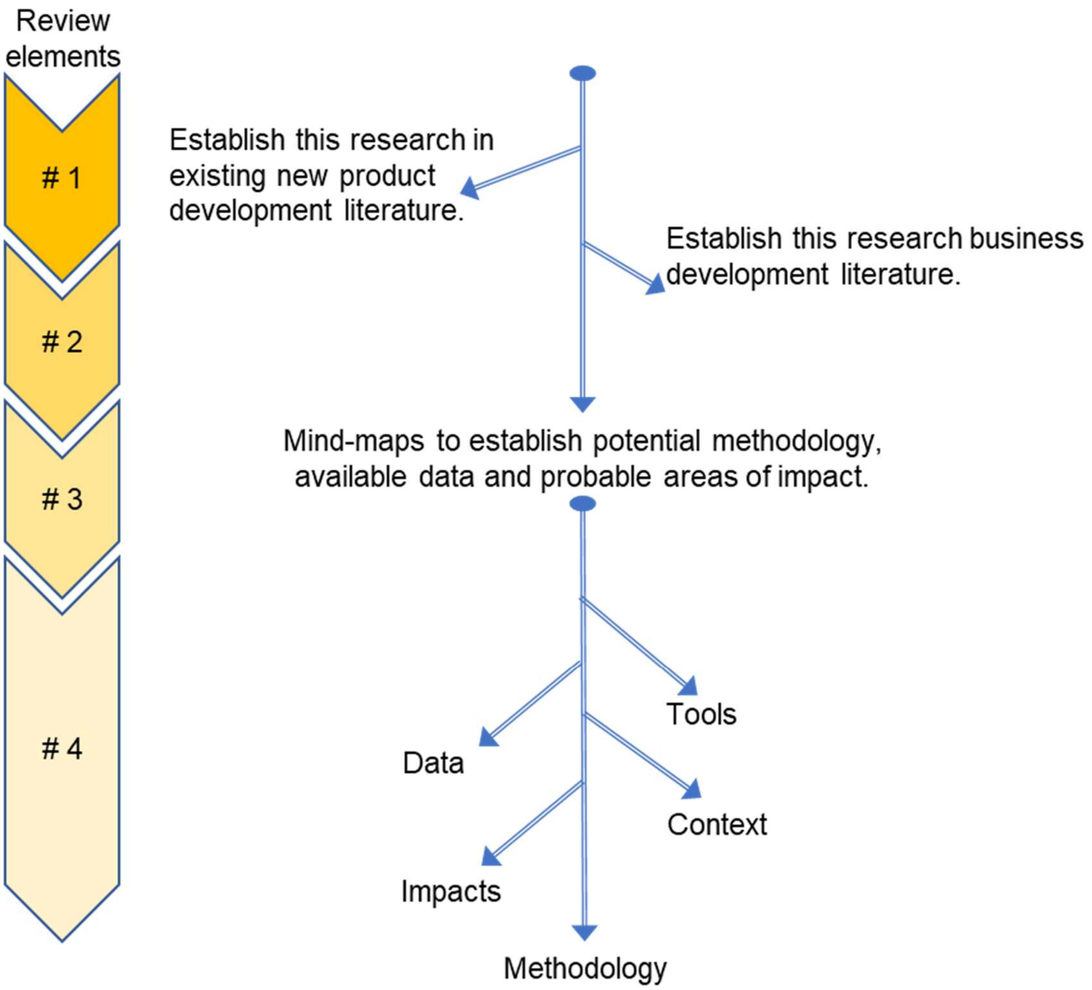


Fig 3: Literature review structure

2.1. Establish proposed methodology within existing literature

Existing NPD and related research covers a vast area, and at first investigation all aspects appear to be fully covered including aspects of the business process. With more than five million google scholar returns for “New Product Development” alone is there new knowledge to be brought to the academic discussion? Books on the subject such as (Mital et al., 2014) do make excellent contributions towards bringing the subject of ‘Product Development’ together. Mital et al., specifically developed their book for undergraduate instruction within the University of Cincinnati. In their book “Product Design” Mital et al., attempt to bring the multi-facets of the subject together with an integrated approach to product design which they illustrate on page 17. The authors, Mital et al., start with the intended users, and concludes with disposal; reuse; remanufacture; recycling but, their presented thinking has the selection of materials separate from the economic analysis and feeding post the product design rather than concurrent or at the concept. On the plus side Mital et al., do include output from ‘disposal’ to material selection. Mital et al., do observe on page 112, “… if the product manufacturing cost can be estimated during the early design phase, designers can modify the design to achieve proper performance as well as reasonable cost at this phase, and designers are encouraged to design to cost.”. Ullman, (2010) is also a teaching text that attempts to address the issues raised in mechanical design. Ullman touches upon the economic and environmental impacts but only to acknowledge their existence. As a result, it is considered to have missed the key points being considered within this research.

Fig 4 shows a Venn type diagram constructed from the existing literature coverage

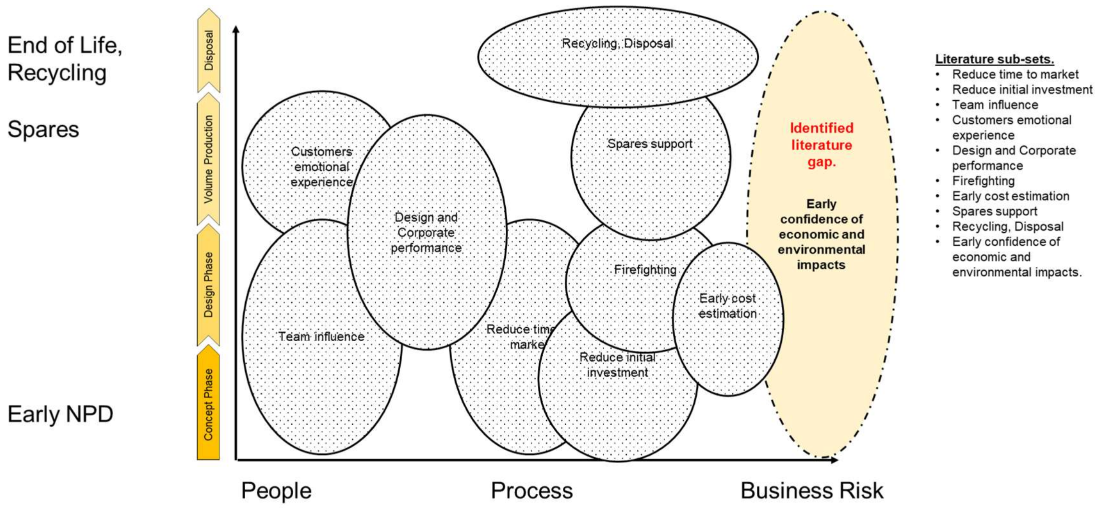


Fig 4: Literature coverage - identification of the existing literature gap.

The physical size of each set does not attempt to represent the quantity of literature on a specific area; it merely indicates the nature of the coverage (X-axis) against the NPD time-line (Y-axis).

What has been noted is that as the nature of coverage (X-axis) progresses from People and Process towards Business Risk, the research coverage reduces. There is coverage of people; NPD teams and customers included, NPD process throughout the NPD lifecycle have literature coverage. Some coverage of early cost estimation but the authors 'early' is post the concept phase of the NPD. There is a lack of literature that attempts to establish early confidence of economic and environmental impacts for an NPD during the early concept phase. This lack of coverage highlights the gap in the literature and is expected to correspond to the known gap in the practical application which has been confirmed by "Subject Matter Expert" (SME) witnesses from industry. Within the context of this research, economic and environmental impacts means; the identification of high usage of high cost tier 1 materials; the high usage of economically volatile tier 1 materials; the imbalance that might exist between tier 1 materials and sales revenue currencies; the achievement of preference market requirements due to tier 1 material sourcing; the achievement of recycling targets as required by legal statutes.

Areas of research that contributed to Fig 4

Some noteworthy areas of tangential research that form the data sets of the Venn diagram shown in Fig 4 and within the general scope of NPD are:

a) NPD Teams and their influence has formed a subset of research with team learning being the focus of (Akgün et al., 2007). In Akgün et al., study, they concluded that their "… study empirically demonstrated that team improvisation and unlearning provide team flexibility in turbulent environments and impact new product performance via knowledge utilisation and implementation". The study is important to the overall body of knowledge relating to NPD's but not related to the aim of this research. Leban and Zulauf, (2004); Magni et al., 2009) have focused upon the influence afforded by the leadership of the NPD team. The pre-existing organisational strategy is a cause for improvisational constraint according to (Cunha et al., 2012). In (Leonard and Sensiper, 1998) the authors look at the role played by tacit knowledge and innovation. Bai et al., (2017) studied the organisational structure of the enterprise and concluded that it has an impact on team performance.

b) Published research also exists that seeks to introduce the emotional experience felt by the customer into the NPD design process eg. Akgün et al., (2009); (Yoon et al., 2014; Farrugia, 2016; Driskill, 2016). In the study presented by Yoon et al. the authors concluded that “In this paper, we mainly gave attention to nuances between positive emotions considering that people involved in product development usually intend to evoke positive emotions with a new product and distinguishing positive emotions require thorough understanding of emotional experiences. During the interviews, designers and user researchers stressed that distinguishing nuances between negative emotions is also important to get insights into users’ demands and desires.” The area of study has a contribution to NPD development knowledge but is not contextually aligned with the ‘knowledge space’ of this research.

Gnanapragasam et al., (2018) studied the UK customer base for desirable preferences across eighteen product categories. Their findings highlighted consumer desire for; longevity and reliability when undertaking new goods purchases. Cars were included in their study. Something that is notable from their summary of important purchasing factors is that of the eighteen product categories only Cars and Electronics goods show ‘Brand’ identification as very important all other categories have it as moderately important.

c) The effect of firefighting within the NPD has been reported by (Nelson, 2001). In summary, the observation is that once firefighting has been initiated within an NPD, the firefighting approach becomes a self-fulfilling activity.

d) Molcho et al., (2014) have considered part cost estimation during the early phases of an NPD. Dewhurst and Boothroyd, (1987) also consider early cost estimating but their early is post the initial design phase and so late compared to a concept phase framework which is the focus of this research.

e) The relationship of design to corporate financial performance has also been investigated by (Hertenstein et al., 2005). Their research concluded that there is a strong relationship between good design and financial performance. Unfortunately, their conclusions are drawn from a comparison of Industrial Design expenditure as a proportion of profit. As such it assumes that all expenditure has a positive contribution towards the NPD outcome. Low expenditure with a highly inspired and focused design team that does not have to repeat work can produce surprising results of low-cost design.

f) During the volume production phase of an NPD, pre-Disposal, spares support for an NPD can consume a considerable amount of; production resources to provide spares as required; cash to provide spares from stock and on demand. NPD based research has been applied to this aspect by (Shenyang et al., 2017; Qian et al., 2017) have both specifically researched the forecasting of spares. According to Shenyang et al., "Only through in-depth study of the spare parts consumption rules of the mutual support system, can we explore further the equipment management methods and improve the equipment's impact rate level continuously. Therefore, it is of great significance to master the spare parts consumption law of the mutual support system.". The paper by Qian et al. concludes, "… through analysing the factors such as the failure rate of equipment, the number of equipment, the number of equipment units and the training time of the next year, the paper obtains the calculation method of the quantity of equipment unit minor repair consumption, the quantity of medium repair consumption and the quantity of overhaul consumption." Both papers in their way contribute to aspects of NPD knowledge but neither seek to explore the knowledge space intended to be occupied by the research undertaken within this thesis.

2.2. Identification of literature required to deliver the new methodology.

Fig 4 (pg 8) showed the identification of the existing literature gap, early confidence of economic and environmental impact. The identified literature gap defined the research scope for the literature review and resulted in a mind-map exercise being undertaken to establish the data that would be required to answer the intended research aim.

The mind-map shown as Fig 5 seeks to explore the current methodology, tools and data sources are shown on the right-hand side. On the left-hand side is where the proposed research is undertaken and presented within this thesis. As shown in the mind-map, methods such as SCE exist on both sides, but the metadata below the estimate is used via an allocation method to feedback into the usage of parametric cost estimating on the left-hand side. Note: in the upper-centre of Fig 5 there is a reference under engineering to Unique System Code (USC). USC will be further introduced in chapter 4 of this thesis, but it should be thought of as a codified reference for a part within a higher-level system as defined by engineering. The feature is a similar codification used by marketing. The two coding systems have a many to many relationship.

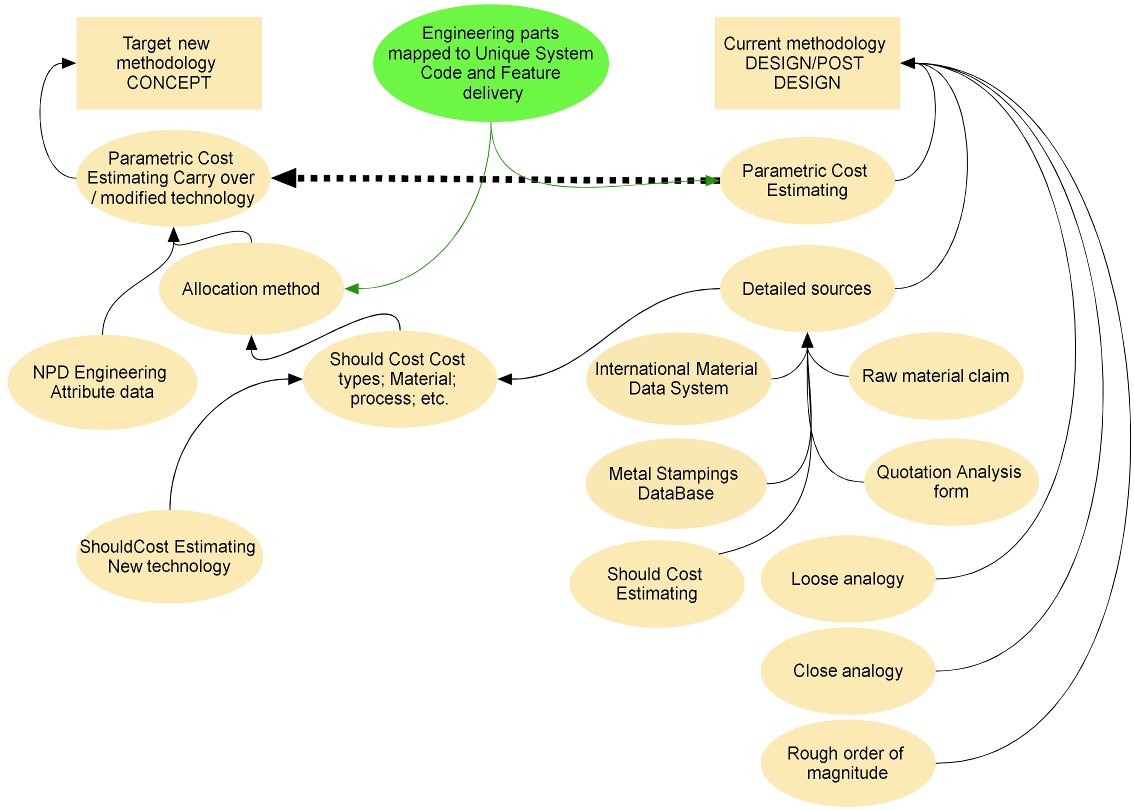


Fig 5: Proposed methodology mind-map.

Fig 6 shows the mind-map of the possible uncertainties, business risks that are

Fig 6: Mind-map of the requirements to cover the included scope of uncertainties and business risks.

informed by the new metadata-rich methodology output.

The inverted triangle (centre top of Fig 6) indicates the new metadata-rich output that might be expected to result from the mind-map shown as Fig 5. The new metadata flows around the six main targets for business risk associated with tier 1 material costs; Economic material volatility; NPD manufacturing processes; Preference markets; Currency; Import duty; Recyclability. The tier 1 areas previously highlighted.

Progress has also been achieved by reviewing the types of secondary data already in use to identify the tier 1 material content and its eventual adherence to the data mind-map shown in Fig 6 including recyclability legislation requirements at the NPD End of Life (EOL).

Fig 7 shows the mind-map of the anticipated pre-existing tools and the space where new methods would be required to be drawn together to satisfy the delivery of NPD data. The available tools are dependent upon the point in time within the NPD time-line, and for this research, this is defined as the concept day plus one. Therefore, the literature review builds from existent concept NPD tools and how these can be utilised to provide early confidence of economic and environmental impact.

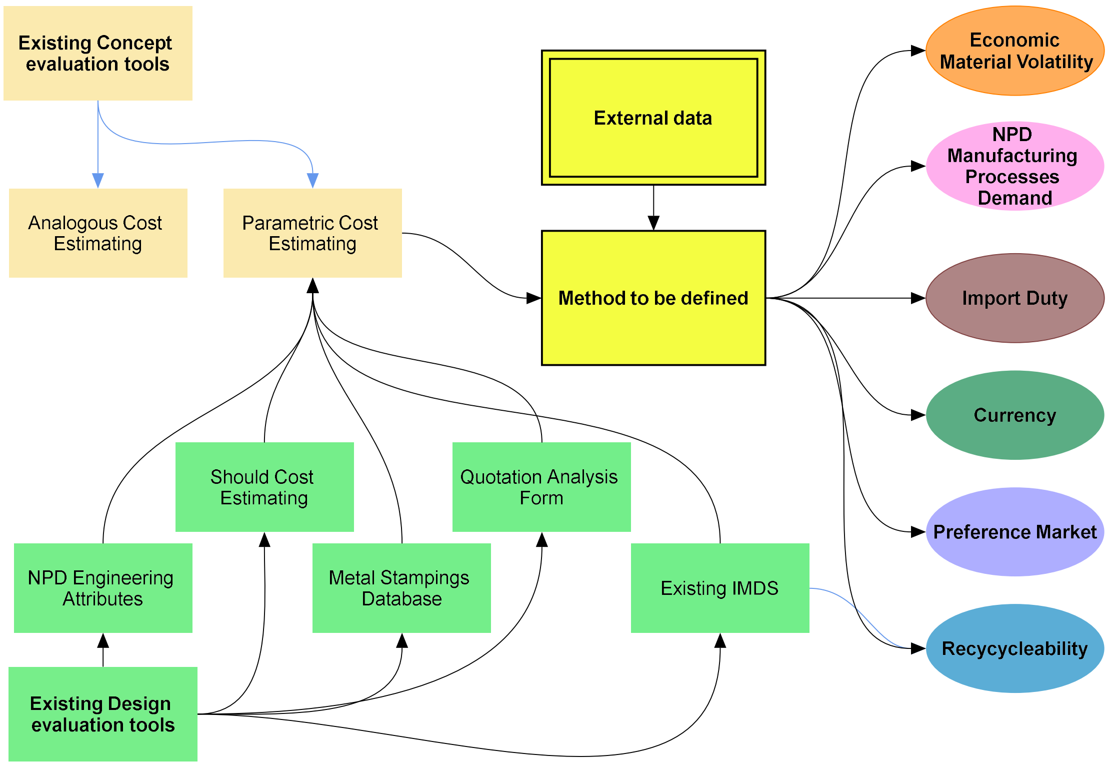


Fig 7: Mind-map of the anticipated pre-existing tools and the space where new methods would be required to be drawn together to satisfy the delivery of NPD data

To establish early confidence of economic success there is a need to have the early creation of a cost estimate, and that in some way that cost estimate would need to have a bill of materials as a basis. Progress has been achieved by reviewing existing cost estimating methods. Specifically, their application to early within the NPD timeline, their ability to provide a detailed structure that would lend itself to the creation of a bill of materials that could be used to examine the economic stability of the initial cost estimate for the volume production phase and the meeting of environmental requirements during the disposal phase.

In between the starting position of existing NPD tools and existing secondary data that informs upon recyclability other tools, techniques and data will be explored to enable the two potential knowns to be joined with a structure and robust new method.

In the following sub-section, 2.3 to 2.4 each of the potential tools and methods that are required to achieve a successful conclusion to the research aim are examined in the literature. 2.3 to 2.4 review specific tools and methods that have been employed in the development of the methodology. Section 2.5 reviews the context behind the research while section 2.6 looks at some of the impacts that are exposed by the application of the method. In this respect, the section follows the mind-map presented as Fig 7. Section 2.7 seeks to explore what is missing from existing literature.

2.3. Tools.

In this section existing cost estimating tools are examined for their current practical use and potential to provide a basis that can be applied to the determination of a research solution.

Cost Estimating techniques/method.

Existing literature contains reviews of cost estimating methods. Trivailo et al., (2012) discusses hardware cost estimation methods as used in space mission planning. In this paper Trivailo et al., review several methods together with relevant commercial software that has been developed to assist. The authors also review the relative usage of the different headline methods across the timeline of a project. Other papers such as (Meisl, 1988; Roy, 2003 and Farr, 2011) also undertake similar attempts to position the usage of a method along the timeline.

Fig 8 shows a summary of the high-level method groupings laid along an NPD timeline of their standard application.

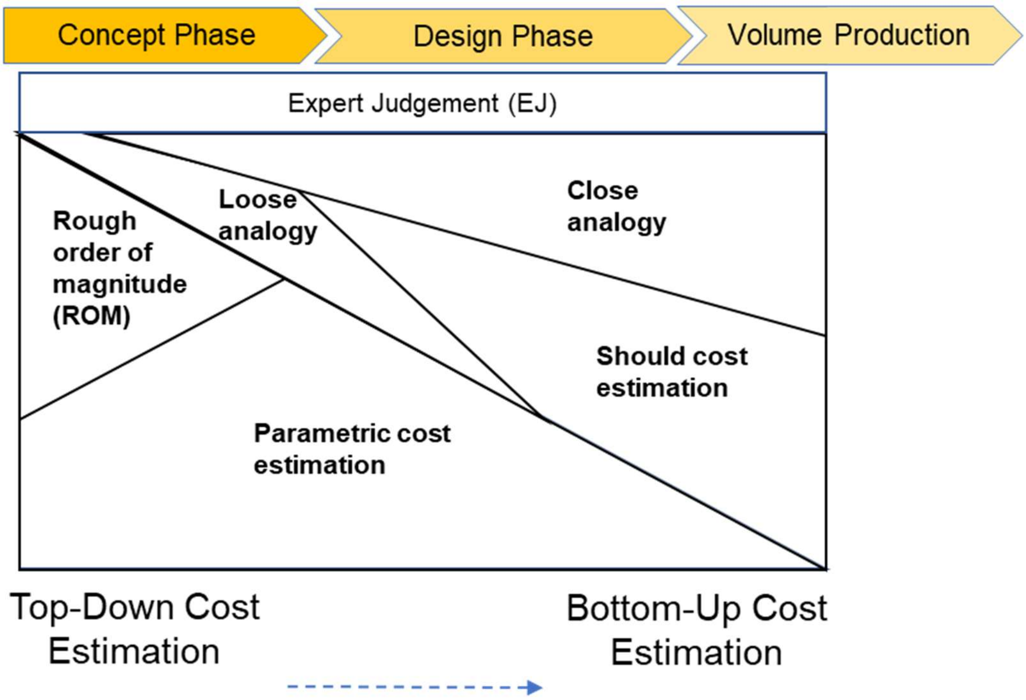


Fig 8: Application of cost estimating methods through the NPD process. (Adapted from Trivailo et al., 2012)

Of the six methods shown in Fig 8, four are qualitative. To achieve a basis from which a bill of materials could be created a quantitative method will need to be adopted. The only existing cost estimating method that is likely to provide a quantitative basis is Parametric Cost Estimating (PCE).

Mirdamadi et al., (2013) also provide classification and a comparison cost estimating method. Fig 9 shows the summary of cost estimation methods cited by Mirdamadi et al. The significant classifications align with those presented by Trivailo et al.; parametric; analogy and analytical being represented by should cost estimating in Fig 8.

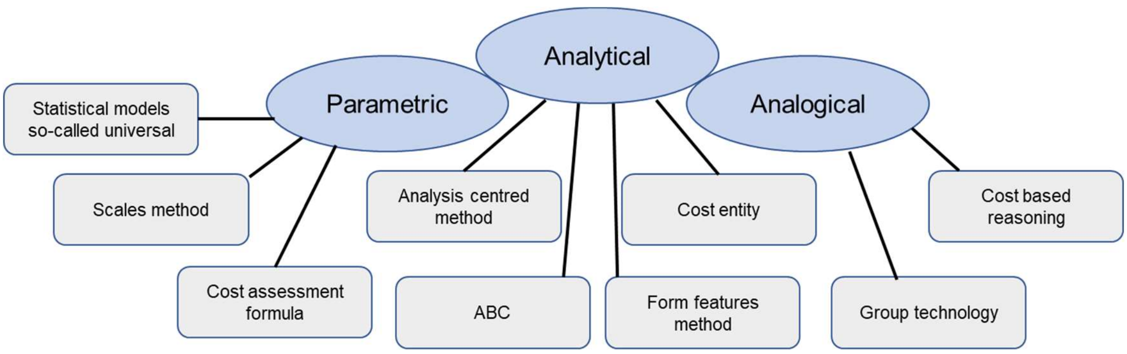


Fig 9: Cost estimation methods classification, reproduced from (Mirdamadi et al., 2013).

Fig 10 has also been redrawn from Mirdamadi et al. Here the authors have taken their interview data and generated a comparison of the significant method classifications. Table 1 provides the legend to the radar diagrams scales. Table 2, which has also been reproduced from (Mirdamadi et al., 2013) shows the conclusions drawn by the authors as far as the key capabilities and difficulties in applying the major classifications.

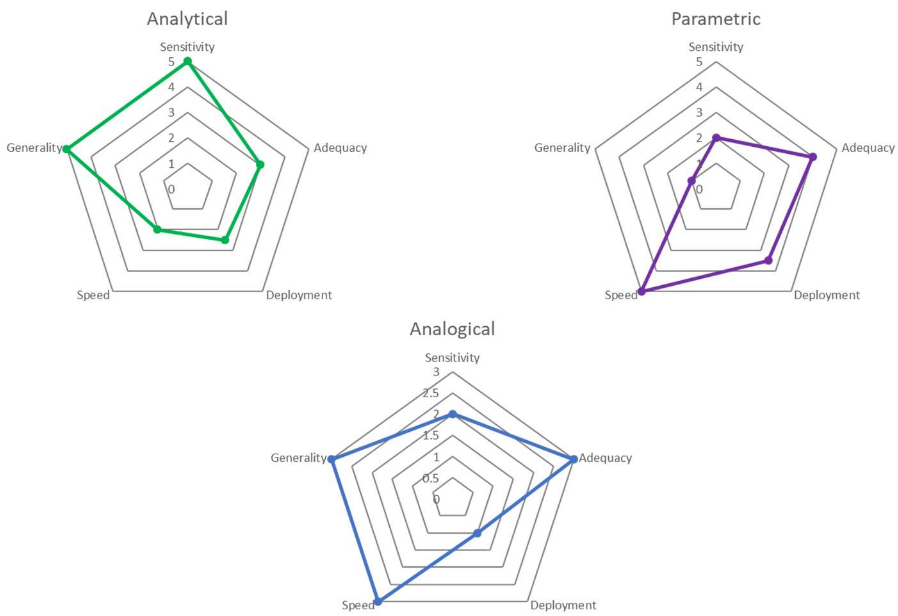


Fig 10: Comparison of three cost estimation methods, reproduced from (Mirdamadi et al., 2013).

Table 1: Legend supporting Fig 10.

Rating.	Description.
Sensitivity	The sensitivity of the assessment (repeatability and robustness): the ability of the method to integrate and consider the variations of the input data.
Adequacy	Adequacy of the evaluation (precision): the ability of the method to give accurate results considering the final product cost.
Deployment	Deployment: the difficulty of formalising data preparatory for the evaluation of cost, usually performed by experts.
Speed	The speed of estimation: includes both the computation time and the time required to model a new problem.
Generality	Generality: scalability of the method allows measuring the performance indicator rather than only financial dimension.

Table 2: Major method classification summary reproduced from (Mirdamadi et al., 2013).

Major classification	Description.
Parametric	although accurate and fast to use, in their range of validity they are limited by restricted generality.
Analogical	these methods are useful, but the preparatory phase (enrichment of knowledge base, parameters discriminating) is long for the results. This approach seems impossible to automate in an optimisation process.
Analytical	although the estimation process of these approaches is quite long because they generate and analyse all the operations necessary for obtaining a product, they remain attractive because of their flexibility and accuracy. Moreover, thanks to this generality, the cost evaluated can support not only the financial dimension. Indeed, variations can be handled by this approach.

Parametric Cost Estimating method (PCE).

Most researchers, including (Watson and Kwak, 2004), attribute the origins of PCE to T. P. Wright who described learning curve theory, a paper that was published in the Journal of Aeronautical Sciences, 1936. Wright, (1936). Originating from a joint government and industry initiative is a reference manual on PCE is the Parametric Cost Handbook, (Brundick, 1995).

PCE uses statistical methods in combination with a company's existing cost data to establish trend data for a specific functional requirement of a future or concept based on regression analysis of existing data; these are generally referred to as Cost Estimating Relationships (CER).

At their simplest CERs can be regression analysis as shown in Fig 11. It should be noted that CERs may not be straight lines, they can be curves and they may involve step changes.

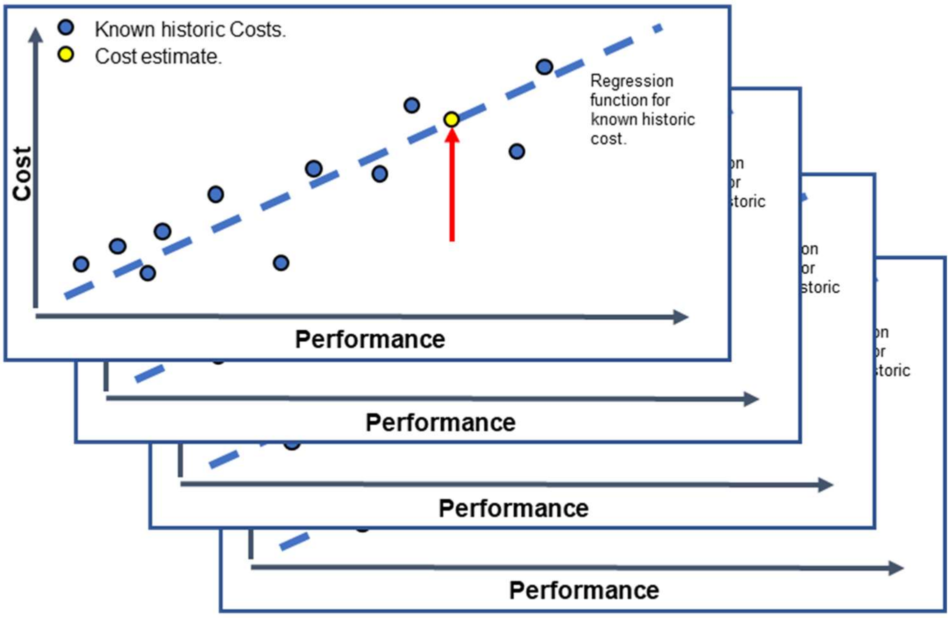


Fig 11: Parametric Cost Estimating CERs: one per Unique System Code-feature combination.

As PCE is a statistically based method, each CER will contribute a secondary outcome. Associated with statistical results is a probability of that outcome being true given the quality of the original data. The probability of the CER is known as Correlation or R^2. If the NPD product is deconstructed into smaller Unique System Codes (USC) sub-sets, then each USC can be compared for relative probability allowing the precise identification of weaknesses in the NPD confidence. Through the analysis of R^2 a source for the subsequent focus of additional research to reduce those specific weaknesses. This correlation property is likely to form a key indicator in determining the quality of any resulting answer gained from PCE and underpin the targeting of resources during the delivery of an NPD.

At this phase, PCE is however only predicting what might occur if engineering and commercial conditions remained the same as current conditions. In the latest evolution of PCE Time Series Forecasting and Phenomenological projections are applied to project the initial answer to forecast against a future delivery date.

Shermon, (2009) details much of the PCE method which is also described in (Trivailo et al., 2012). Watson and Kwak, (2004) however additionally considers issues in accuracy, which will be particularly crucial to this research. Watson and Kwak draw specific attention to the susceptibility of PCE to; changes in project scope; changes in design standards; incorrect unit cost/quantity assumptions; unforeseen problems in implementation. Also, they draw attention to issues resulting from; who; how; prior knowledge; considered in scope factors. Despite these potential issues the authors consider that PCE is worth pursuing.

In the cost estimating world, much has been documented about the application of parametric methods when applied to the aerospace, defence, construction and other industries to assist with the early evaluation of NPDs. Within the automotive industry, there is no evidence of parametric methods being applied, as confirmed by (Ibusuki and Kaminski, 2007). Instead, the industry prefers to use analogous methods during the early phases of an NPD. This analogous approach does not provide the quality of information required to quantitatively reduce the uncertainty during the early phases of an NPD.

Where the automotive industry, including JLR, differs from other sectors is in its widespread application of Should Cost Estimates (SCE) during the design phase, as evidenced by various sources such as (Roy et al., 2005; Ibusuki and Kaminski, 2007 and Backlund, 2013). Should costs incorporate a significant amount of detail about materials, processes and regional costs simulating the costs incurred by the supply base. Contextually and historically, should cost estimates are useful in the later design and delivery phases as indicated by Fig 8. In this historical timing, they are used to support structured negotiations rather than being a validation of the cost for NPDs. The cost management applied to the NPD is prioritised on the data provided by the tier 1 supplier in a Quotation Analysis Form (QAF).

JLR has already internally proved, via a Proof of Concept (POC), that it is possible to apply parametric principals to automotive NPDs, but this remains unpublished. JLR's successful POC of Parametric Cost Estimating (PCE) will be referenced within this research, but the POC does not form the basis or the aim of the research.

2.4. Data.

The research needs to build upon a foundation of existing data, pre-existing secondary data. In this section, a review of the secondary data is undertaken that has been identified and considered relevant to the research.

Should Cost Estimating method (SCE).

As a tool, Should Cost Estimating (SCE) relies upon a design to exist for a part. In this exploration, however, it is being treated as a data source rather than a tool. It uses Activity-Based Costing (ABC) methods to cost a detailed manufacturing process plan (Rush and Roy, 2000) does not reference ‘should cost’ estimates but does discuss ‘detailed cost estimates’ as being based upon ABC. A similar discussion takes place in (Johnson and Kirchain, 2011) however here the authors refer to it as ‘Generative Cost’ but still builds it up by looking into the detailed cost incurred by low-level cost drives such as salary and investment recovery. Investment recovery within SCE is unusual when applied to automotive. Automotive SCE includes the investment recovery of presses and injection mould machines. Adaptive tooling investment such as press tools, mould tools, are directly funded by the automotive OEM rather than being recovered through the piece cost. This mechanism is used by automotive OEMs to avoid the creation of contingent liabilities should the amortising volume of the part not be realised.

Roy et al., (2011 undertake a detailed description of the Should Cost Estimating (SCE) method as applied within the automotive sector. Within the paper, they present a generic breakdown of the cost elements, detailed deconstruction of each element and an overview of the cost elements included within the rate construction. A generic should cost structure is shown in Table 3. The precise detail will be dependent upon the part or assembly being considered. Some will be based upon the weight of material being processed; these will typically be castings and forgings. Others will be the weight of material and time-dependent processes. Within the automotive sector, it would be unusual to include the amortisation of specific tooling unless the component is a forging where to tooling has a high wear rate. In general, within the automotive sector, the component-specific (adaptive) tooling used at the tier 1 and below is OEM direct funded and known as vendor tooling.

Table 3: Generic Should Cost structure.

Cost element		
1 Bought out parts (Tier 2+)	a	
2 Raw Materials	b	
Overheads on Materials	% on (b)	
Resale of In-process waste	-c	
3 Tier 1 added value	d	
Direct labour cost		
Indirect labour cost		
Machine/facility cost		
4 Tier 1 general overheads	e	
Design and R&D		
End item scrap		
Logistics costs		
Sale, marketing and general admin		
5 Tier 1 profit	f	
Estimated or analysised Part cost.	**Σ(Above)**	

Nb: a to f represent incurred or developed costs associated with each element of the SCE.

Roy et al., (2011) confirms that the SCE method requires a design to exist. The paper also confirms the need to identify the manufacturing process details; bought out materials; raw material; manufacturing processes; general overheads consistent with the generically incurred for the tier 1 suppliers location and size as well as the industrial sector that they operate within. An acceptable profit margin will also be allowed.

Other published authors also confirm the cost estimating methods. In a book (Farr, 2011), Farr provides discussion and illustration of several cost estimating methods used through the life cycle of a project. Farr describes various costing methods and evaluation methods and includes a comparison between critical methods ‘Should Cost’ however is referred to as ‘Detailed Engineering Build Up’.

Quotation Analysis Form (QAF)

Academic literature does exist relating to Quotation Analysis Forms (QAF), but it is minimal. Other than published work by this thesis author, there are only three that show since 2014, all in German. Cranfield University has two PhD theses that include discussions on QAFs dating back to 2006 & 2009; (Oduguwa, 2006; Mishra, 2009). Mishra only provides a passing mention of the QAF as a tool that can be used within the OEM Tier 1 supplier relationship. Oduguwa provides an insight into the high-level construction of the QAF but very little detail. Oduguwa does show a redacted QAF in his appendix E. Because of the lack of detail expressed in these theses there is a need to review alternative sources such as professional bodies.

As leading professional bodies both Association of Cost Engineers (ACostE) and Chartered Institute of Purchasing & Supply (CIPS, 2002) provide sample forms and instruction on their completion. ACostE provides a background discussion within its (ACostE, Professional Development Learning 2007). Within the learning presented by ACostE is a noteworthy slide as it offers clarification of what a QAF is and is not, it is included as Fig 12.

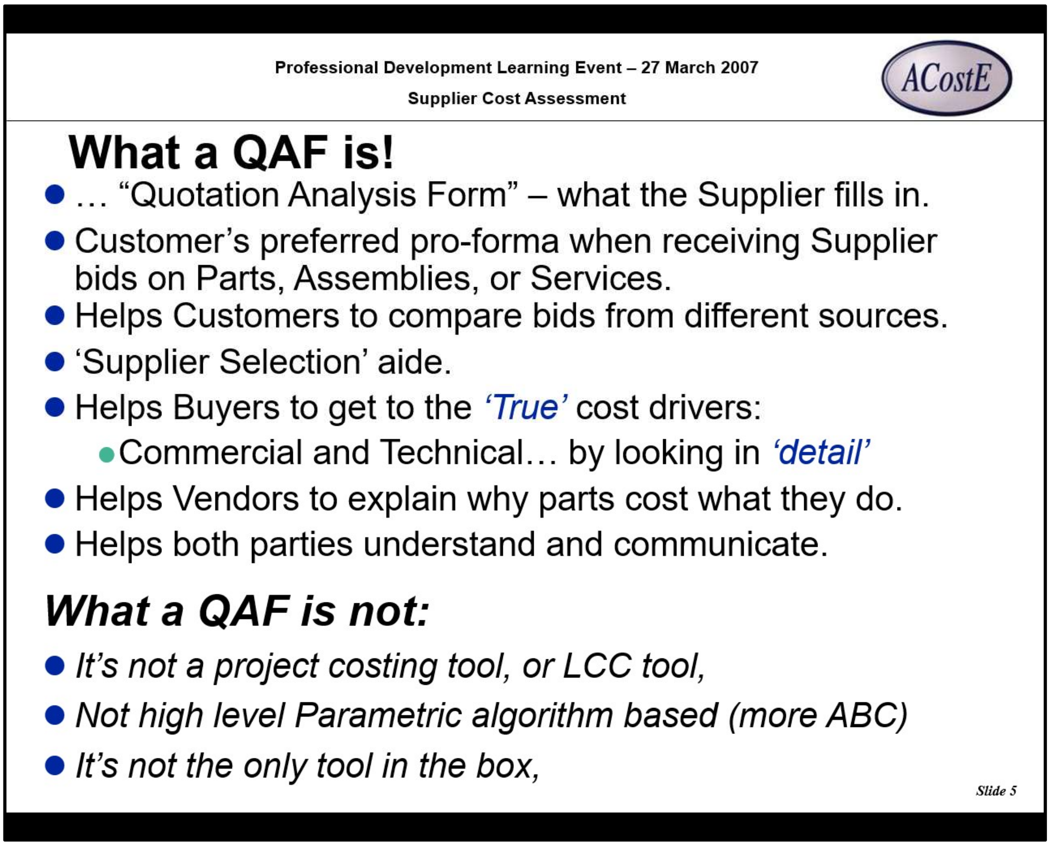


Fig 12: ACostE QAF 'is and is not' slide. (ACostE, Professional Development Learning 2007)

The CIPS sample excel form can be found at CIPS, (CIPS, 2002). ACostE has a very similar generic QAF available, (ACostE, QAF, 2007).

Metal Stampings Database (MSDB)

Metal Stampings DataBase (MSDB) has not been found in context in any academic literature. The fact that MSDB does not occur in literature is not surprising as it is a bespoke development of Ford Motor Company[1] and used to consolidate data to support internal stamping operations.

NPD Engineering attributes.

NPD Engineering attributes have contextual inclusion in academic literature. The contextual usage being addressed here is a relative measure of the performance of the vehicle against a predetermined set of characteristics. In themselves, the characteristics are not unique, but the relative measures and the relative weighting between characteristics provides an OEMs identity through performance and emotion.

Kim and Wilemon, (2003) approach the contextual subject in their use of attributes as a contribution to the measure of NPD complexity. A cited reference by Kim and Wilemon, (Downs and Mohr, 1976) creates discussion around primary and secondary attributes coming extremely close to the contextual usage of attributes within JLR.

International Material Database System (IMDS)

The International Material Database System is a European development between Hewitt Packard (HP) and several European automotive OEMs. The objective was to create a shared database to record the materials used in and the quantities of the materials that contribute to the kerb weight of the vehicle at the point of recycling. In 1997 the creation of IMDS was deemed necessary to allow the industry to meet the requirements of was new legislation relating to the recyclability of the products being offered, (DXC International Material Data System (IMDS), 2017). IMDS itself contains a unified material classification system and is filled in by tier 1 suppliers rather than the OEMs making the output as far as possible independent of the OEMs although the OEM does need to maintain the Bill of Materials (part numbers and quantity of parts) required to create a viable OEM product. Considerable background on IMDS can be drawn from (DXC IMDS Create MDS, 2017). In this document DXC talk through the underlying rules to be followed to both use and create a material within the IMDS system.

[1] Ford Motor Company (FMC) all rights acknowledged.

In common with QAF, IMDS does get a mention within academic literature, but the papers that exist seek the potential application of IMDS rather than an exploration of what it is. A paper authored by (Du et al., 2015) confirms that it used data drawn from IMDS. In their paper, they confirm that IMDS contains "… hundreds of thousands reported data sheets of car parts (collected data)". Andersson et al., (2017) discuss the implication of the European recycling target, 95% by weight. Andersson et al. references to IMDS are to cite IMDS as the source of data being used. Tarne et al., (2017) also mention that IMDS exists, that it is used and that it is used by the OEMs to identify the materials that they build into their products and as a defence against the legislative requirements. To understand the origins of IMDS, it is necessary to explore non-academic sources.

Cullbrand and Magnusson, (2012) make some critical observations about the potential quality of the data held in the IMDS database from which they sourced car part data. "The IMDS offers the opportunity to access and create comprehensive and detailed information of the materials contained in vehicles. However, the system relies on the suppliers' declaration of material data, with reporting time lags and only controlled by the automaker OEM's by random sampling.". They present a critique of the database in some detail. A significant concern identified by Cullbrand and Magnusson is that the use of the data is itself restricted, an OEM is not allowed to make any commercially directed use of the data contained in the database. A situation that has been confirmed through JLR sources.

In a more recent paper from (Field et al., 2017) they also reference the quality of the IMDS data. Their research and conclusions, however, appear to have been hindered by a lack of understanding between the Ford part numbering system and the delivery of a customer feature. The alignment of appropriate parts to achieve a specific feature uses a Unique System Code by Feature (USC-f).

> *The implication of the restrictive terms and conditions of usage of IMDS data may imply that it cannot be used to inform a methodology that is directly feeding an NPD development. However, if the terms and conditions are intended only to protect the tier 1 supplier from commercial pressures applied by the OEM, then the data may be usable. Verification has been requested with direct contact to DXC-IMDS, but only an acknowledgement of the contact has been received to date. The email to DXC is included in Appendix 8.*

Composition Analysis.

Academic literature does exist on ‘composition analysis’, but it is directed to Mass Spectrometer of materials and even financial statement fraud detection. Composition analysis, as required within the proposed methodology, is being applied to materials but rather than being a ‘tool’ based method it is a mostly paper-based or spreadsheet and internet-based data alignment process.

Contextually, composition analysis is taking the material as declared in the source data such as an SCE, QAF and raw material claims and identifying its chemical composition[2].

No contextually relevant literature has been found. The method is discussed in more detail in chapters 4 & 5.

Allocation method.

Within the context of this research allocation method is much simpler than that found through a literature search. There is only a requirement is to ensure that the amount of an SCE or QAF cost type and sub-metadata (type and grade of material) assigned to the delivery of a feature is appropriate. Allocation methods found in literature want to complicate this by seeking an optimisation goal. Examples of these include: (Federgruen and Zipkin, 1983; Merkhofer, 2002; Heragu et al., 2005; Busenbark et al., 2016).

There is a close alignment between the required allocation method and Function Analysis System Technique (FAST), a component within Value Analysis (VA). Within VA the cost contributed in the delivery of a feature is assigned through analysis of features associated with the part or system; if a feature does not require a cost incurred in the delivery of the part the cost incurred must be assigned to the delivery of a different feature to which the part contributes, (Ibusuki and Kaminski, 2007; Terem et al., 2016; Babu et al., 2016). These papers present FAST using its accepted narrative of cost allocation to ‘function’. Within this research and application of the FAST method, the cost allocation is against the deliverable desired feature rather than a deliverable function. It should also be acknowledged that the inclusion of an allocation method such as FAST introduces a degree of qualitative rather than quantitative data. The resulting subjectivity being subject to choose should mean that any output needs to be stress

[2] The contextual composition analysis presented in the research was specifically created to answer a business need by the thesis author in 2007. Its development used raw material claim data, internet sources and JLR budget volume data.

tested to ensure that the output is a reasonable representation and sufficiently accurate for analytical purposes. Ibusuki and Kaminski, (2007) substitute the classical FAST allocation of cost by creating specific cost estimates, but as confirmed in their paper the costs were ultimately allocated as a proportion of the individual parts contribution to function delivery.

Cost estimating of new technology.

The contextualised interest in cost estimating of new technology is to obtain data that may contain uncertainty, business risk. Establishing what is being proposed by ‘new technology’ is the initial challenge that needs to be undertaken. Several authors have commented upon the physical actions that might be involved. In (Roy et al., 2005) the authors propose that new technology can be sub-structured into three categories; new to the market, new to the industry, new to the organisation. To this short list of ‘new’ (Schröder et al., 2015; Baumers et al., 2016), deal with the challenge of the redesign of parts to take advantage of the new manufacturing technology, (Hällgrena et al., 2016) specifically consider the adoption additive. Few papers attempt to deal with the introduction of new technology for the delivery of a deliverable feature. Roy et al., (2005) touches upon it when reviewing the identifiable usage of PCE methods as applied to new technology appear to make a ‘leap of faith’ in its application to ‘proton exchange membrane fuel cells’. Minkiewicz, (2011) has published much of the high-level supporting data for the proton fuel cell referenced by (Roy et al., 2005) in a PRICE Systems whitepaper.

Rogozhin et al., (2010) takes a specific look at the automotive sector drawing data from Daimler Chrysler, Ford, GM, Honda, Hyundai, Toyota and VW. In this paper, the authors explore technology complexity, innovation scope and their combined impact on indirect costs by way of a multiplier. Banazadeh and Jafari, (2012) review the application and history of Complexity Index Theory which was put forward by Bearden in 1986. Complexity is also a theme taken up by (Griffin, 1997). Griffin argues that starting from a clean sheet is not always practical due to the extended timelines that it tends to produce, evolution is the more practical way.

Burchholz, (2014) takes an entirely different approach to the problem of cost estimating new technology. In Burchholz’s paper, he advocates a method reportedly used by Japanese Original Equipment Manufacturers (OEMs), involve suppliers early in the development process. Burchholz goes on to argue that the ability to achieve a successful outcome of early engagement is dependent upon the relationship that has been achieved between OEM and Supplier. In the author's experience, as with most relationships, there are both good, and bad aspects to be considered. Experience gained at JLR has indicated that early engagements with a supplier can lead to good technical outcomes but where the supplier is costing for new technology the quotation needs to be analysed to remove any premium loading simply because it is new technology.

Albers et al., (2014) explore the transfer of technologies between industries as a means to progress the introduction of new technology into an NPD. The authors developed their research with application to the automotive sector. Within their research they identified four ‘barriers’ to technology transfer; not knowing; not wanting; not capable, and not allowed. Once these barriers have been overcome, the authors claim that the transfer of technologies can be achieved. Melander and Tell, (2014) also propose collaboration with pre-existing suppliers with specialist knowledge to gain a competitive advantage. In their paper, they present a sequence of; Innovation, uncertainty, and supplier selection. The researchers stress the need to avoid relationships where there is a technology monopoly with a single supplier. They also stress the need for buyer–supplier collaborations and joint co-design process and commitment to the relationship and the NPD.

Patent Analysis is another method proposed and used by academic authors and OEMs alike. Patent analysis and Patent Co-citation analysis being presented in this space by (Faria et al., 2014; Valverde et al., 2014; Castriotta and Di Guardo, 2016). Other methods are also available such as social media analysis; this tends to be more appropriate to short-term, one to two-year outlook, (Eckhoff et al., 2015). The search within the context of the automotive industry should not stop at the patents taken out by automotive OEMs and their traditional supply structure base. The search needs to be extended to incorporate: audio/visual, electronic gadgets, furniture, and anything being covered in social media. The difficulty is that merely because a patent has been taken out does not mean that it will deliver at volume in the short term. All trend indications need to be assessed against ‘Technology Readiness Level’ (TRL) and ‘Manufacturing Readiness Levels’ (MRL) capabilities.

Several papers and reference texts do exist on the subject of TRL and MRL, (Pretorius and Wet, 2000; Sauser et al., 2006; Bayazit and Karpak, 2007; Mankins, 2009a; Mankins, 2009b; Parry-Jones, 2011; DoD, 2011). Parry-Jones, (2011) is the most contextually relevant to this body research as it directly relates to TRL & MRL application within the Automotive sector. Parry-Jones lays out the two readiness levels side by side with gateway achievements so that the specific differences can be observed. MRL does not start with MRL-1 until TRL has achieved TRL-2, but MRL inserts additional steps once TRL-8 has been reached inserting MRL-7 through to MRL-9 before both achieve full readiness level 10.

No matter how it was informed the introduction of a new technology, any type and source is through adding complexity weightings into PCE, an SCE assessment and or QAF. The source and degree of readiness may give rise to additional business risks that are outside of the scope of this research.

Evidence for historical risk.

The focus of the research presented in this paper is to prove/disprove the hypothesis that 'uncertainty' is present in the results from a parametric cost estimate. It is proposed that some significant uncertainties can be identified using the secondary data that was used to create the Cost Estimating Relationships (CER), regression lines of the PCE. Of particular interest will be the identification of uncertainties such as 'volatile materials'. Other uncertainties could be explored using the same methodology such as less than favourable commercial relationships including currency, capacity, poor sourcing balance and even the impact of late risk driving up actual costs as identified by (Joumier, 2017), this was also discussed by Edwin Dean in his 1993 paper, (Dean, 1993). In Dean's paper, it is known as the Freiman curve. In short, the Freiman curve as shown in Fig 13 depicts that there is an optimal time within an NPD to both complete an estimate but more importantly to agree on the costs with a tier 1 supplier. Either side of this optimal point and the cost risks to the NPD and the business increase. Fig 14 has been adapted from Joumier's 2017 paper when PCE methods are employed in isolation using only actual historical cost data the impact of late risk resulting in premium cost build up over time creating an inflated estimate.

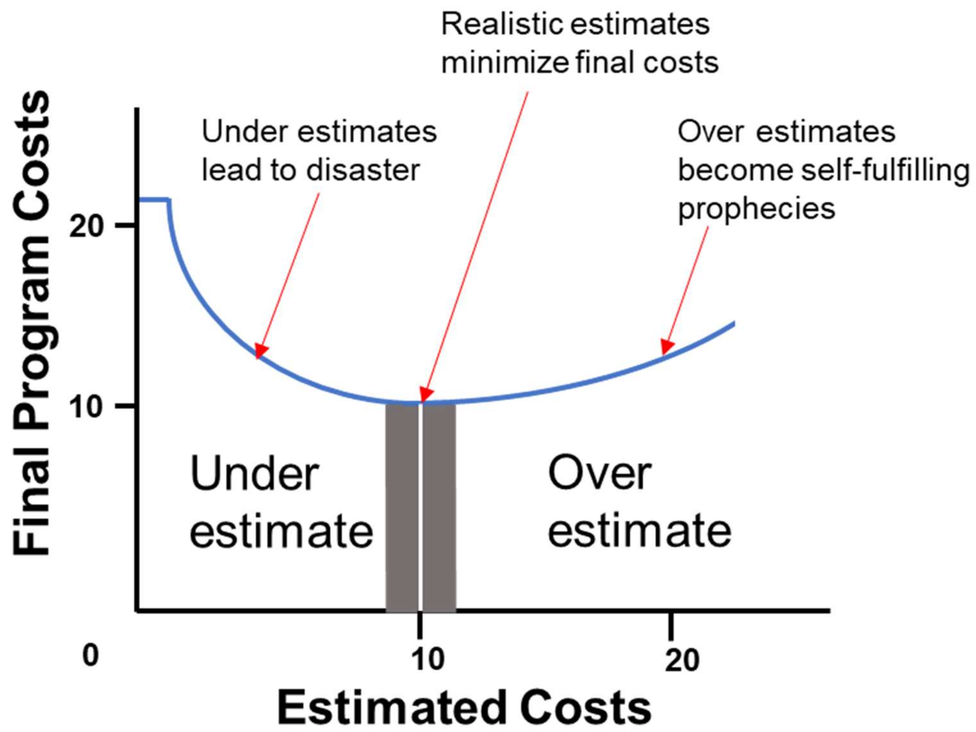


Fig 13: Freiman Curve, (Adapted and redrawn from (Freiman, 1983).

Frieman's observations on an NPD have an indirect consequence upon the research presented in this thesis. Frieman's observations demonstrate the embedded risk that will flow through into the data usage within the PCE cost estimating method. Data drawn from the business records of previous NPDs are most likely to either too high or low. By implication, it would be better to utilise an SCE, or other detailed source data feed in the PCE CER development.

Current PCE practice is to use the known historical and current cost data as the source data behind the CER development. Fig 14 shows the potential impact of the data from NPD 1, estimate + risk, has on the potential estimate of NPD 2, NPD 2 will already have a measure of risk embedded in it. Over several NPD's the PCE derived estimate becomes overinflated as a result. The data feeding Fig 14 assumes constant engineering and economics across NPD 1 to NPD 4.

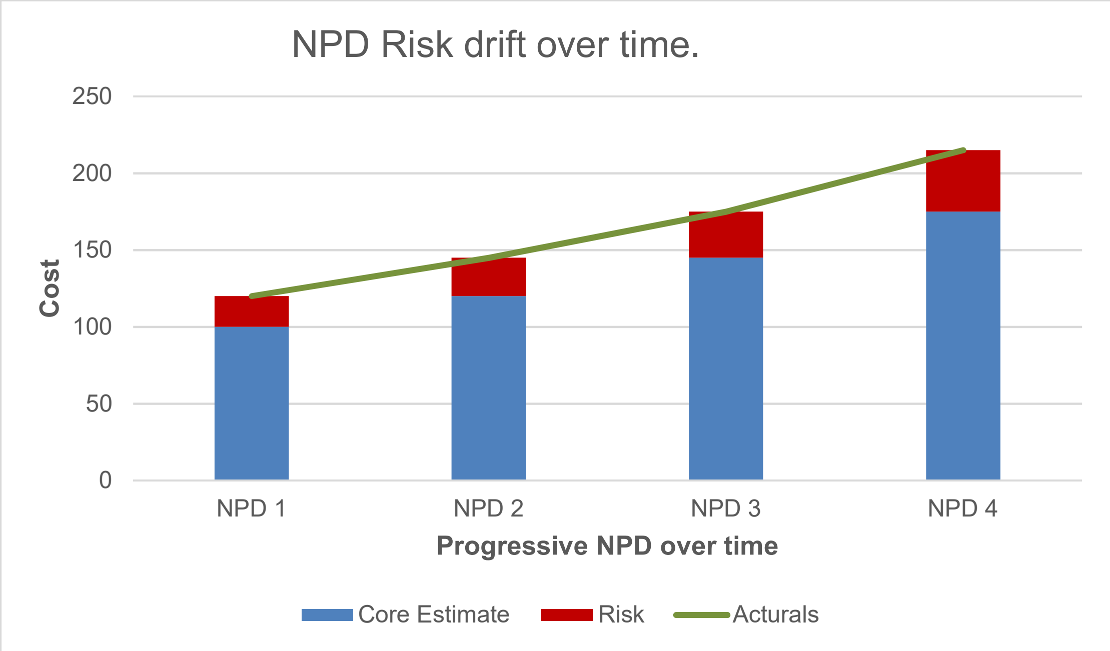


Fig 14: NPD Risk drift over time.

In Fig 15 an indication of the usage of PCE and SCE source data is provided. The programme target is provided using historical cost data relative to the expected NPD revenue. For this illustration programme target cost in Fig 15 has been set at 24,000 in all cases. Roy et al., (2005) refers to the derivation of the programme target cost. In summary, it is the expected revenue per unit multiplied by the historic business cost structure percentage an example of which is presented in Table 6 (pg 53) Where the cost structure percentage is the historical cost expressed as a percentage of the historical revenue.

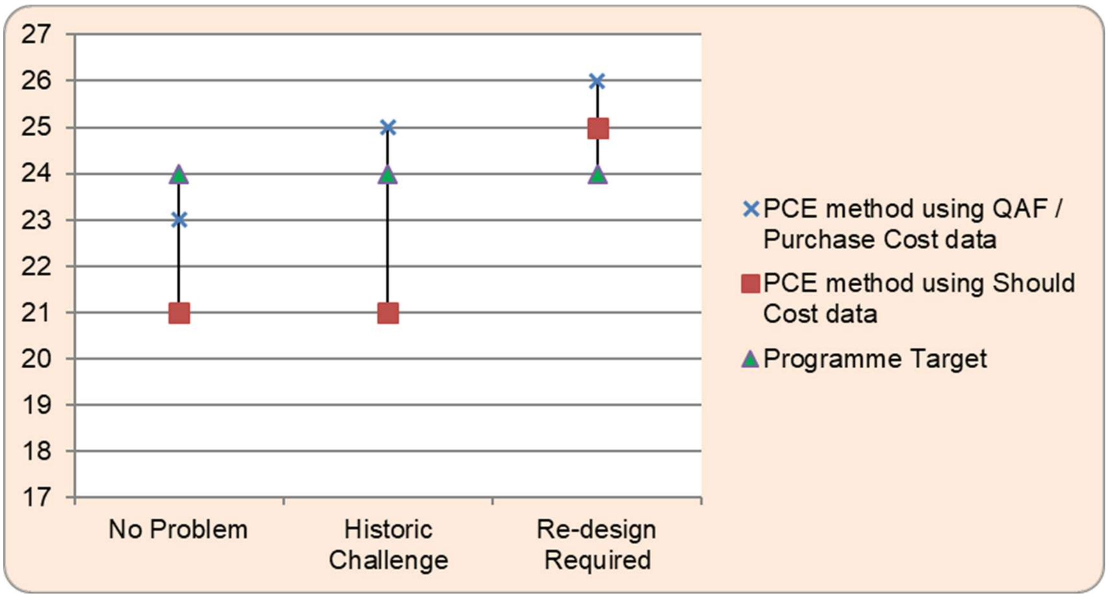


Fig 15: Review of the implication of using PCE with Purchase or SCE source data for NPD evaluation. Adapted from (Mills et al., 2016)

Fig 15 Includes three critical threads of NPD data; Programme target; PCE method using QAF / Purchase cost data; PCE method using Should cost data. The difference between the two PCE based data should be explained.

- **PCE method using QAF / Purchase cost data** – The data has been generated using PCE with the CER populated using historical purchase price data such as order prices and QAFs.
- **PCE method using Should cost data** – The data used to create the PCE CER is sourced from SCE data and is therefore considered to be a normalised data set with historical risk and other historic commercial issues eliminated. An evaluation of the cost to deliver the required design.

Parametric Cost Estimating in conjunction with 'Should Cost Estimating.

Attempts to join the parametric and should cost methods are not new. Langmaak et al., (2013) explores the joint application of these methods within Rolls Royce to produce a scalable blisk manufacturing model. The model, however, is limited to bladed blisks within the aerospace industry. Qian and Ben-Arieh, (2007) also combined the methods, but their resulting approach was limited to the estimation of the machining required to produce a simple cylindrical component.

Where these prior applications of combining parametric and should cost methods differ from the combination being made within this research are that prior combinations limited themselves to the validation of cost during the design and volume production phases of the product lifecycle. The research presented in this thesis seeks to employ detailed sources such as should cost data to identify and quantify uncertainty highlighting areas to mitigate the uncertainty into manageable risk or opportunity.

Parametric cost estimating methods have rarely been applied within the automotive sector the method being the province of the aerospace and defence sectors. The automotive sector has historically preferred Should Cost Estimating (SCE), but in recent years a proof of concept application of PCE has been successfully achieved within the automotive sector. Application of PCE has the potential of providing very early indications of NPD cost, but within the resulting output of the PCE, the tool hides uncertainty.

2.5. Context.

In the following brief section literature relating to the contextual application of this research is examined. Areas covered include the nature of uncertainty, business risk and rapidly changing markets.

The nature of uncertainty.

In Cost Engineering confidence is typically understood, in its negative connotation, as uncertainty. This fundamental proposition is supported by several references which introduce uncertainty about confidence levels for example; (Kechagioglou, 2005; Lee and Dry, 2006; U.S. Air Force, 2007; GAO, 2009; Schuliz et al., 2010 and Department of Energy, DOE, 2011). Of the numerous papers in the field, few consider the relationships between cost, confidence and uncertainty; (Department of Energy, DOE, 2011) is an exception. No papers have been identified that specifically address or link directly to the early reduction of uncertainty within NPDs within the automotive sector.

Most cross-industry studies have focussed on identifying and analysing techniques aimed at reducing or managing uncertainty. Papers by (Cleden, 2009 and Boness et al., 2011) consider the lack of initial understanding of development and or project brief. Boness et al. researches this explicitly in the software industry. Frishammar et al., (2009) and (Lenfle and Loch, 2010) effectively review dealing with uncertainty through the managed application of trial and error. Joint Confidence Levels (JCL) within the aerospace industry are the subject of papers by (Marion and Meyer, 2011; Management and Shuttle, 2012 and Nair, 2013) propose dealing with uncertainty through the early application of cost engineers alongside the design and development engineers. It could be argued that this recommendation of early alignment is closely allied to the research presented in this thesis.

Walker and Weber, (1984) do consider uncertainty within the automotive industry, but this is the uncertainty involved in make vs buy decisions which are typically undertaken during the latter half of any NPD. Terwiesch and Loch, (1996) consider the levels of rework in downstream activity when uncertainty is not addressed in the early phases of an NPD. Their findings support this research in that they identified that considerable waste was taking place due to reworking because of poor definition, but their investigation was significantly downstream of the early concept phase with the result that their work is not material to this research. Chalupnik et al., (2009) looked at the uncertainty of the process of product development, proposing a framework that could be adopted. The Chalupnik et al., paper is interesting although its application is significantly past the concept phase of an NPD and the primary focus of this research.

The findings of (Chwastyk and Kolosowski, 2014) are precisely aligned to the challenges faced by the automotive sector and show that the automotive market has moved from ‘manufacturer lead’ to much more ‘fashion lead’. Bloch and Richins, (1983) and (Sheller and Urry, 2000) re-emphasise this, showing that if a product arrives or is delivered late, then the market would move on. Cost-effectiveness is required by the end-user and the customer. In the sector within which JLR operates, the customer has the choice to walk away, and the cost is a significant success factor as shown by (Jin, 2004). The accuracy of information to support and inform the business at the point of, or before taking, any decision or commitment of funds, is critical to successful delivery. The current problem is that the approach to NPDs within the automotive sector leaves the achievement of quality and accurate information too late in the delivery cycle to allow clarity around the uncertainties and time to effectively undertake mitigating actions.

Although drawing upon the aerospace industry (Masood et al., 2014) sum up uncertainty as “an issue of confidence in decision-making which is caused by the difference between the amount of information or knowledge required to perform a task and the amount of information or knowledge already possessed by an organisation.”. Masood et al., make observations that appear to align with the stated aims of this research within the automotive industry. Masood et al., illustrate the problem as adapted in Fig 16. Ignorance is associated with high levels of uncertainty and low understanding of business risk. With increasing understanding, the uncertainty reduces transitioning into higher levels of certainty around business risk.

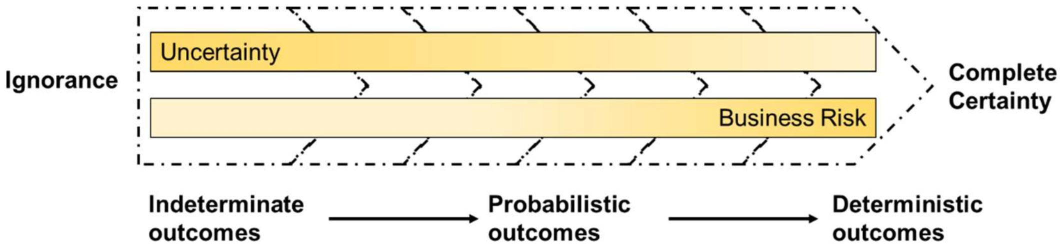


Fig 16: Transition of Uncertainty to Certainty. (Adapted from Masood et al. 2014)

This research aims to establish a methodology to identify the uncertainty surrounding NPD tier 1 Materials, manufacturing processes, currency, importation duty and preference markets. With the aim of allowing these uncertainties to be converted either to deliverable opportunities or mitigate risks as early as the concept phase of an NPD. For the research being undertaken and presented within this thesis there are two aspects to uncertainty; what is likely to be in the NPD driving cost during the volume and disposal phases; how stable is the cost of that cost driver?

Business Risk.

Business risk occurs in many forms. Several forms have been covered within academic literature; Influences on market performance is addressed by a few researchers, (Liu and Atuahene-Gima, 2018) take an interest in the effect of dysfunctional competition upon product performance. Their research indicates that competitive strategies (cost leadership and differentiation can retain product performance. Chen et al., (2016) also report on NPD performance in the marketplace. They conclude that NPDs with high levels of service innovation, market-linking and market turbulence exhibit the best NPD performance. The conclusions drawn by (Chen et al., 2016) are firmly supported by a Swedish study by (Linton and Kask, 2017). These papers in literature demonstrate the business risk due to a failure to recognise customer and market conditions with the potential of lack of NPD sales.

Risk also exists within the material supply and procurement, a series of which (Cube et al., 2016a and Cube et al., 2016b) define as; procurement in supply chains; supply risks; and monetary risk quantification. The paper 2016a takes a focus on monetary risk and proposes a checklist to ensure that an informed and appropriate decision is achieved. Fig 17 is recreated from this paper and attempts to model the delicate balance that exists around supply risk.

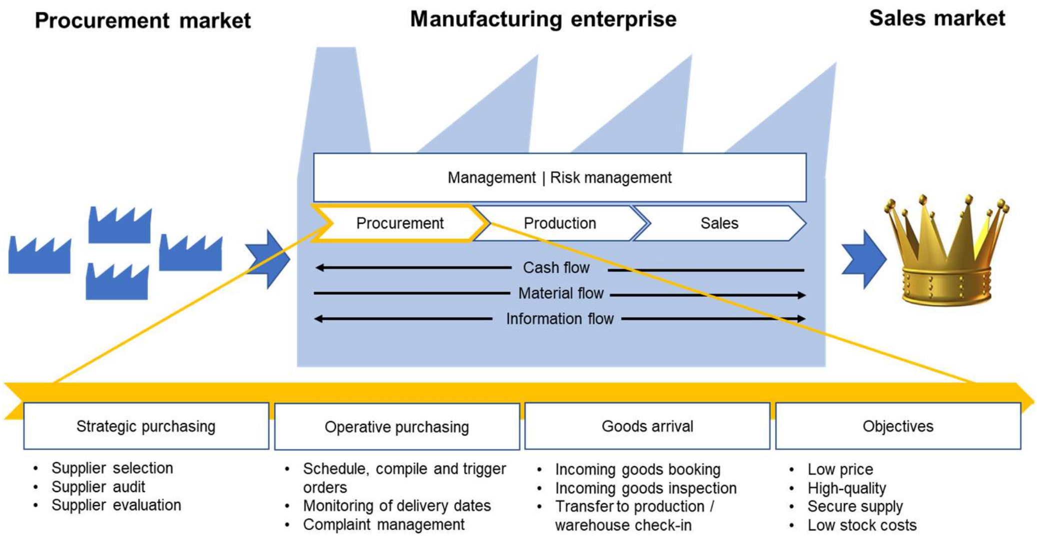


Fig 17: Procurement in the context of supply chains, (Cube et al., 2016a)

2016b also researches solutions to the monetary quantification of supply risk but takes a more quantified approach to the solution with the introduction of statistical analysis and simulation stressing using Monte-Carlo simulation.

Poor NPD team preparation as a source of business risk is covered by (McDonough III et al., 2001). Their key conclusion is that global team performance is also lower than the performance of virtual or collocated teams and this is suggested to be due to greater behavioural and project management challenges.

Authors (Grunert and Trijp, 2014) pay attention to customer-oriented NPD seeking to clarify the factors for success. Within their paper, they consider the customer's willingness to pay. They conjecture that the potential customer knows the average price for existing products in the market and what they might get for their money. If the customer is confronted with an NPD of excellent specification that covers an existing products specification and cost equal or less, then the NPD will take volume from the existing product offering. The business risk here is that the product substitution could result in a successful NPD but with an overall adverse profit outcome.

For the research being undertaken within this research, there is an interest in the economic risk associated with the probable materials and processes that can be identified by using the SCE or other detailed source metadata. A physical NPD will enviably require resources such as materials and processes. Materials can have a high cost per unit and either a high or low total unit usage. Either way, in themselves, if they were planned for, they do not form a risk. The risk occurs when a high-cost material with a significant usage is identified and was not planned for, or a planned for cost has significant volatility.

Rapidly changing markets

The timeline against which the automotive sector responds has changed over time. The current timeline is shown in Fig 1. As indicated the Concept and Design phases change duration subject to the type of NPD being undertaken. Small ‘facelift’, model year or legal projects can be just one and a half years while a large all-new vehicle project can take six years.

Creating an NPD that will achieve a lifetime profit is no longer at the behest of the Original Equipment Manufacturer (OEM). Several authors have reflected that even the automotive sector is driven by a fashion-based effect. Bloch and Richins, (1983) and (Sheller and Urry, 2000) re-emphasise this, showing that if a product arrives or is delivered late, then the market would move on. Cost-effectiveness is required by the end-user and the customer, and in the sector, within which JLR operates, the customer has the choice to walk away, and the cost is a significant success factor as shown by (Jin, 2004). The accuracy of information to support and inform the business at the point of, or before taking, any decision or commitment of funds, is critical to successful delivery. The current problem is that the approach to NPDs within the automotive sector leaves the achievement of quality and accurate information too late in the delivery cycle to allow clarity around the uncertainties and time to effectively undertake mitigating actions.

Fast changing markets and short product life-cycles are considered by (Keddis et al., 2015). They consider manufacturing systems rather than NPDs but conclude that designed in flexibility within the technology should be a requirement of the design. This theme is also taken up by (ElMaraghy and ElMaraghy, 2014) although they focus on customers’ demand for new product functions and features, different regional requirements, and a large number of market segments having different needs. They conclude that the customer's requirements have been met through the availability of alternative materials, continuous innovation and competitive costs.

At a FACTON User conference, 29th November 2018, (Kardos, 2018) confirms that there is a “… trend towards individualised products”, that “individualised consumables and commodities lead to ‘mass customisation’ and that a markup of 20-30% is accepted.”. Kardos also confirms that “product complexity has changed dramatically over time and is now increasing significantly.”. Whilst Kardos is not directly employed by an automotive company he is however employed by a subsidary of PORSCHE

2.6. Impacts.

In the following sections of this literature review some specific business risks are explored; price volatility; recyclability. A review is also undertaken into the potential impacts of material and process substitution. An impact review is felt to be essential to ensure the identification of the metadata required for success and how the resulting new data may be applied to improve NPD profitability.

Price volatility

The price of raw materials as commodities; steel scrap; aluminium; lead; copper; including alloying elements such as nickel; chromium, can and do vary over time. In most cases, the price is stable enough that it can be priced for in the product with the variation in price being absorbed against the NPD profit margin. In some cases, however, the price is not stable and due to market forces is volatile. In these cases, the point in time price change if a price rise against the NPD commodity baseline will erode the NPD profit making profitability unpredictable. Greinacher et al., (2016) look specifically into the implications of globalisation, growing environmental awareness as well as rising and volatile resource prices contribute to an increasingly uncertain business. They explore improvement strategies that counter the effects of the external pressures that cause to price volatility. They identify five groups of volatility drivers and 21 change drivers, concluding that each situation requires a tailored solution.

In a paper by (Janzen et al., 2016) the authors consider why commodity prices move even when supply can meet the needs of demand. They specifically study cotton pricing but, cotton is only being used as an illustrating commodity, it could be any traded commodity. They conclude that the price rise in 2008 was mostly due to market analyst’s speculation alone and not down to the realities of supply.

Contextualising price volatility within the environment of manufacturing.

For this thesis, the measure of the volatility in the historical price of an element is calculated as the percentage difference between the Maximum and Minimum price (USD/kg) over the past five years, relative to the Minimum price.

$$\text{volatility (\%)} = ((\text{Maximum price} - \text{Minimum price})/\text{Minimum Price}) \times 100 \qquad (1)$$

Within an application to an NPD where it is normal to adopt a baseline value against which everything is measured the baseline value is adopted as the Minimum price in the volatility (%) equation. This more simplistic calculation is in use within such sources as GRANTA[3] and made available through personal correspondence (Petruccelli, 2017). In truth, it measures the change in price amplitude over time.

More complex calculations are in general use within the commodities industry and evidenced in literature within papers such as (Chapman et al., 2013). The formula that is applied for stock and commodity prices and used by the Chicago Mercantile Exchange (CME) and by European Commission commodity price analysis is

$$Volatility = \sigma\left(ln\frac{P_t}{P_t - 1}\right)\sqrt{T} \quad (2)$$

$$\sigma = \sqrt{\frac{1}{T}\sum_{t}^{T}(P_t - P_{mean})^2} \quad (3)$$

Table 4: Legend for equations (2) & (3)

Legend	Description
σ	Standard deviation of prices
P_t	Price at period *t*
T	total number of periods
P_{mean}	The mean price

[3] GRANTA is wholly owned by Granta Design Ltd all rights acknowledged.

Volatility risk level.

Based on work undertaken by GRANTA[4] made available through personal correspondence (Petruccelli, 2017) a table of risk has been provided as shown in Table 5.

Table 5: Volatility risk levels

Volatility risk level	Volatility (%)
Very High	>400
High	300 - 400
Medium	200 - 300
Low	100 - 200
Very low	<100

Within the context and application of the research undertaken in this thesis, the risk levels should be adjusted to the requirements of the NPD.

Recyclability.

This research thesis is not intended to become a thesis on recyclability, but there are recyclability challenges that can be addressed at the concept phase of an NPD if the necessary data is available. Inclusion within this research thesis is to draw attention to the need to cause the required data to be made available during the concept phase of an NPD.

Several authors have considered the state of current recyclability, culminating in the view that we are far from achieving a Circular Economy (CE). Dutta et al., (2018) assert that to achieve CE there is a need to address the restrictions to recycling such as product design, recycling methodologies, process thermodynamics, economics, and social behaviour. Lack of establishment of CE is seen by some to be due to failure by the NPD community to specify recycled materials. The NPD community claiming a lack of supply and stabilised specification. The consequence is a lack of demand and a failure to generate the economic environment to invest in recycling facilities or the technology required to recycle waste materials. Ritzén and Sandström, (2017) go further and assess that there are internally created barriers to the establishment of circular economies. Financial - minimal immediate financial benefits, Structural - a lack of clarity across business domains leading to a lack of clear reasonability, Operational –

[4] GRANTA is a source of Price volatility data and other data such as composition and origin. Total Materia is another shelf source for this data.

Infrastructure and supply management, Attitudes -Perception of sustainability and risk aversion, and finally Technological – Product design and a lack of integration into production processes. Unfortunately, Ritzén and Sandström do not include a clear direction of how this CE introduction stalemate can be resolved. Dieterle et al., (2018) also discuss and present argument on the circular economy but bring an additional tool to the analysis – life cycle gaps. One of Dieterle et al. 's conclusions is that the need is to increase the degree of recycling and not just reduce the total usage of materials.

Other than the social and moral pressure to achieve recyclability at the End-of-Life Vehicle (ELV) the current NPD motivation is driven by legislation. As shown in Fig 4 (pg 8) has focused on the NPD timeline from concept to end of volume production. The focus is rational because historically this is where the OEMs incur direct impacts to its accounts through achieving a profit-generating NPD through the original retail, but today's products also need to establish recyclability at the end of their life. Example legislative recyclability is presented in European Commission papers. DIRECTIVE 2005/64/EC, (2005); (European Commission, 2016). (Soo et al., 2017) undertake a comparison of differing international recycling legislation between Australia and Belgium.

Several papers discuss the means through which both current and known future ELV materials could be recycled. Gaines, (2014) argues the recycling case for lithium-ion and other battery's and materials from the automotive industry; the author also discusses; Lead-acid; Nickel-metal-hydride; recovery of other valuable metals such as copper, cobalt, nickel and iron recycling. Concern about lithium-ion supplies is expressed by (Sonoc et al., 2015) argue that without a sustainable lithium-ion recycling that the lithium demand due to electric vehicles will exceed supply by 2023 but, it must be assumed that Sonoc et al., were not aware of the evolving lithium sources such as those identified in (Bell, 2017). In a paper (Natkunarajah et al., 2015) the authors argue that the better recycling method is automated disassembly leading to a higher total yield including the electronics rather than just the underlying materials. The growth and use of composites have been a concern with significant effort to recycle aircraft composites which have been an increasing concern with composite growth in automotive NPD. The recycling of composites gets specific attention in several papers, (Jiang et al., 2017; Holmes, 2017). Classic precious metal recovery; Gold; Platinum; Palladium, get the attention of (Inoue, 2015). Automotive tyres at the end of life receive the attention of (Marconi et al., 2018) who present research to recycle the textile fibres from tyre into reinforcement in other automotive plastic products such as bumper covers.

Improvement in the early introduction of design for disassembly and or recyclability is argued by several authors. Within the design for recyclability papers (Soo et al., 2016) study automotive door recycling and are concerned by the mixed materials that need to be dealt with. (Wang et al., 2017) argue for selective disassembly planning for the end of life product. Their focus is on designing the NPD to accommodate the current disassembly methods that are available. A paper presented by (Tian and Chen, 2014) review Life Cycle Assessment (LCA) and state but do not attribute the claim that "carmakers have developed their own LCA database. However, LCA is difficult to apply in practice because of data limitations. In the life-cycle analysis of automotive materials, energy consumption should be reduced in each stage, material recycling should be increased, and a balance between the use of recycled materials, applicability, and cost should be implemented". Tian and Chen also review dismantling and recycling of ELVs making the point that welded components establish disassembly issue. The process of welding shows in the detailed data (metadata) under discussion within this research and could be specifically targeted to facilitate Design for Disassembly (DFD).

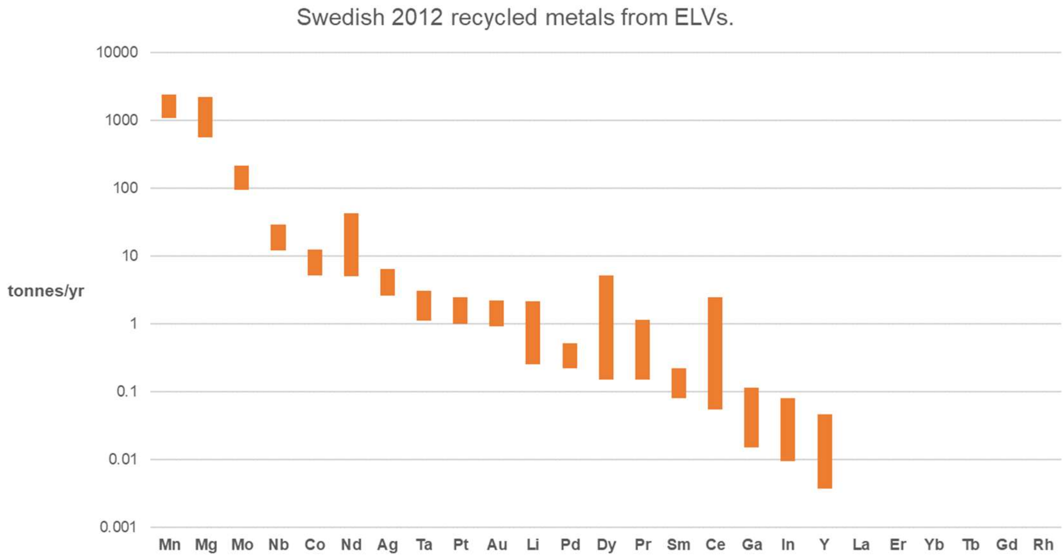
Literature establishes a clear need to be aware of the materials planned to be consumed once the NPD enters the volume phase. The potentially restricted availability will become a factor in their long-term cost volatility as well as in the NPDs ability to meet recyclability legislation.

> The challenge that needs to be addressed therefore is what materials are likely to be in the NPD product and can any of them be substituted to use recycled materials?

In the paper already introduced under section 2.4 IMDS (Andersson et al., 2017) elects to focus on the materials in an automotive product but more specifically the current ability to dismantle and recycle them within Sweden. In this paper, Andersson et al. conclude that greater effort is required to effectively recycle some of the materials being found in the modern automotive, materials that are already considered to be globally scarce.

Du et al., (2015) offer a comparative evaluation of automotive passenger vehicle material from across five published research studies; (Alonso et al., 2012; Cullbrand and Magnusson, 2012; Widmer et al., 2015), from across four countries; Japan; Sweden; Switzerland and the United States of America and focus on 25 metals. Two more papers were cited as sources by Du et al., (MOE, 2009; MOE, 2010) these have proved to be unobtainable. Du et al. concluded that most metals were represented across the spread of represented vehicles. An accurate analysis of the spread, however, was not possible due to the differing specification of the represented vehicles.

Fig 18 shows the scarce metals found in the Andersson et al. study of 2017. The figure is split into two halves. The top half is a graph showing the tonnes per year of each observed metal for a group of 3 Volvo products that were being recycled in Sweden during 2012. The lower half shows the mixture of higher-level metal alloys and vehicle systems against which the scarce metals were found. The declared source of the data is (Cullbrand and Magnusson, 2012); Volvo IMDS. Andersson et al.,'s studies the objective was to review Sweden's recycling industries readiness to recycle these End of Life Vehicles (ELV) products. They concluded that Sweden's recycling industry could not cover all recycling requirements.



Steel alloys	Mn		Mo	Nb	Co																				
Aluminium alloys	Mn	Mg																						Gd	
Magnesium alloys		Mg																							
Nickel alloys				Nb															Y						
Lubricants											Li														
Catalytic components									Pt			Pd				Ce				La					
Electric, electronic & magnetic components	Mn				Co	Nd	Ag	Ta		Au	Li	Pd	Dy	Pr	Sm		Ga	In	Y	La	Er	Yb	Tb	Gd	Rh

Fig 18: Scarce metals consumed within Automobiles and Swedish recycling data recreated from Andersson et al., 2017.

Within the context of this research, the data presented by studies such as Andersson et al. shows that there is a need to understand which scarce metals are already being included in current products that might become component part and technology donors for an NPD. The early identification, at the concept phase of an NPD, allows an improved recognition of what needs to be recycled either in the disposal market or transported to a suitable facility in another country. Having been identified pre-NPD design phase it also allows the scarce metal and other materials to be designed out if possible.

The data collected by Cullbrand and Magnusson included both recycling activity within Sweden, where metals were used within the sample cars and the amount used per car. The amount used measured in g/car is shown in Fig 19 and is recreated from the source data made available through Andersson et al.

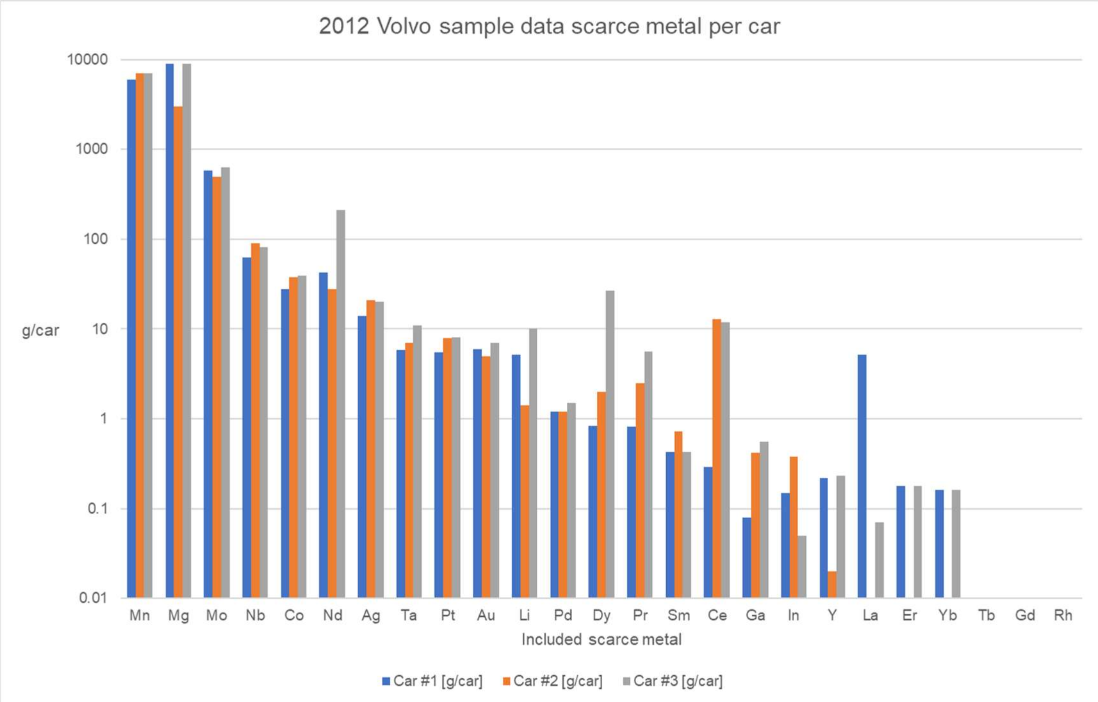


Fig 19: 2012 Volvo sample data scarce metal per car.

There is a historical example of a specific alloying element being targeted. Hexavalent chromium (CR6 or CR(VI)) was identified as a highly toxic metal, and in July 2003 a European directive came into force permitting a maximum content per vehicle of 2 g Cr(VI) will be authorised per vehicle in corrosion-preventing coatings of critical components. Séby et al., (2003) report their study to identify the CR6 in a vehicle. While Séby et al., focused on the identification of CR6 inclusion the automotive industry engaged in its exclusion.

> *Supplementary data associated with Andersson et al. paper that has been used to recreate* Fig 18 & Fig 19 *can be found, in the online version, at* *http://dx.doi.org/10.1016/j.wasman.2016.06.031*.

While it may not be evident from academic literature there are several implications to an NPD with a heavy material dependency:

i. The initial cost of the material.
ii. Price Volatility of the material.
iii. Creation of circular economies and a draw on the creation of an extended recycling industry.
iv. Achievement of legislative recyclability targets.
v. Land Rovers owner's manual, (2017) shows an additional self-imposed dependency relating to - "**END OF LIFE (ELV).** Within certain markets[5], Jaguar Land Rover has established a comprehensive plan to meet vehicle recycling requirements and End of Life Vehicle (ELV) legislation. In accordance with the applicable market directives and local legislation, Jaguar Land Rover takes back all on-sale vehicles and vehicle starter batteries, regardless of the date of a vehicles first registration, at the end of their life. Items taken back are treated in an environmentally responsible manner.".

Material and process substitution.

In a paper by (Buchert et al., 2015) the authors consider the product designers need to recognise the interrelationships of product attributes, economic, social, and environmental impacts. They propose the application of a shifting multi-criterial quantitative analysis during the early development of an NPD. At the core of their recommendation is that Pareto-optimal decision-paths for the selection of materials and process alternatives throughout the life-cycle are included in the concept phase decision making. A bicycle frame is used to illustrate the beneficial outcome.

Material substitution does not need to be a total change of material class, i.e. composite instead of steel; material substitution can be much lower key. In the case of carbon composites recovered carbon fibre recycled substituted for virgin carbon fibre. In (Oliveux et al., 2017) the authors claim that the materials made using recycled carbon fibre showed excellent properties in comparison to virgin fibre. This evidence has the potential to stimulate the circular economy as already proposed in section 2.6. The authors do provide a note of caution, to achieve success the recovered fibres need to be clean and correctly aligned no defaults such as fluffy fibres. They concluded that the recovered fibres could be used to replace discontinuous virgin fibres, and even continuous fibres applied to a complex shape. Also, they assert that the use of the recovered fibres would deliver a lower price.

[5] Through personal communication it is understood that this policy applies to European markets.

A paper by (Witik et al., 2011) looks at the progressive introduction of lightweight materials in automobile applications, their recommendation is that caution should be exercised when making material substitutions. The authors concluded that lower performance materials such as sheet moulded compounds produced a better over-all lifetime cost when compared to lightweight materials using carbon fibres or magnesium. However, they did recognise that the use of lightweight materials had led to reduced consumer costs through lower fuel consumption. Denzler and Wiktorsson, (2016) also consider the introduction of new product, technologies and materials into existing automotive applications. The authors made two critical observations; it is not always possible to describe the impact of a material change upon the manufacturing process; and the need to show both the positive and negative impacts on the production system resulting from the product change – in this case material substitution.

The clues that can be provided by a better understanding of the manufacturing processes involved in the tier 1 supply chain can be used to directly inform the capability to achieve a Sustainable Manufacturing (SM) strategy. Achieving SM is a desire invoked by the United Nations (UN) in 2015 and followed up by (Barletta et al., 2018). In their paper, they provide a methodology to identify the opportunities and realise sustainable manufacturing, minimising adverse environmental impact, conserving energy and natural resources.

In a paper by (Kasper et al., 2016) the authors recognise that basic material selection is typically a complex 'hands-on' activity. They recommend an overall material-oriented development methodology which features material selection method that takes the product, production process and material information into account in an integrated way. Cost and environmental issues associated with the material selection appear to have been missed from the published method, but the method appears to be adaptable to accept their inclusion.

2.7. What is missing from existing literature?

Of the methods that are required to deliver the new hybrid methodology proposed by this research and indeed the data types, there is some pre-existing coverage in literature. What is missing, therefore, is something other than coverage of the individual methods themselves. The aspects that are missing from the existing literature are, the comparison of methods when shifted within the NPD timeline and an understanding of what is lost during the existing application of the PCE method.

Deficiencies of current methods and tools

Currently applied PCE methods provide an answer to the cost of an NPD during the evolution of the NPD, but the quality of that answer can be like the damping provided by a spring and damper assembly at an over-damped setting. As shown in Fig 20, the Should Cost Estimate (SCE) line starts late and only slowly rises to the final answer as

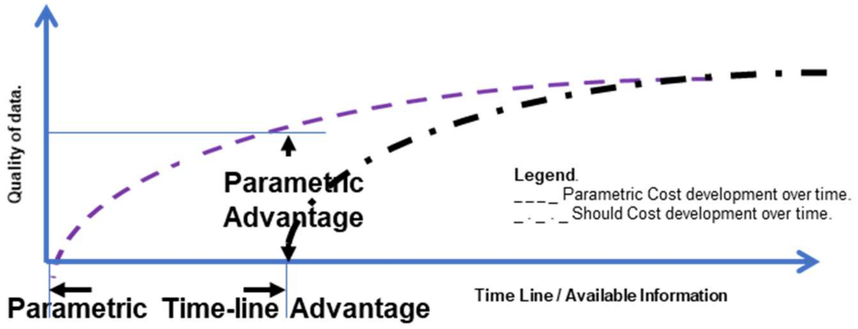


Fig 20: Parametric advantage - Adapted from Sherman, (2009).

the detail design matures. The cause is because SCE costing methods require a design to exist, and the design takes time to mature. SCE is the quantifiable method widely adopted by the automotive and white goods industry. Once defined SCE provides a very high quality of cost estimate being able to reflect several key manufacturing and sourcing decisions. Other methods do exist such as also shown in Fig 20, Parametric Cost Estimating (PCE). PCE is widely adopted by the aerospace and defence industry. PCE can provide a quick statistically based answer where historical data exists.[6]

Fig 21 shows the experience of JLR to the POC application of PCE to the seat systems. The financial uncertainty at the early phases of the NPD is relatively high at more than ±15%+ improving through the NPD delivery over time, as shown by the outer cone. The inner cone shows the uncertainty achieved after the application of PCE as being reduced to ±5%. The full detail of this POC study is not available outside of JLR.

[6] It has recently been applied to an automotive application at JLR (Mills, 2015) and it is from this proof of concept application that this PhD will build.

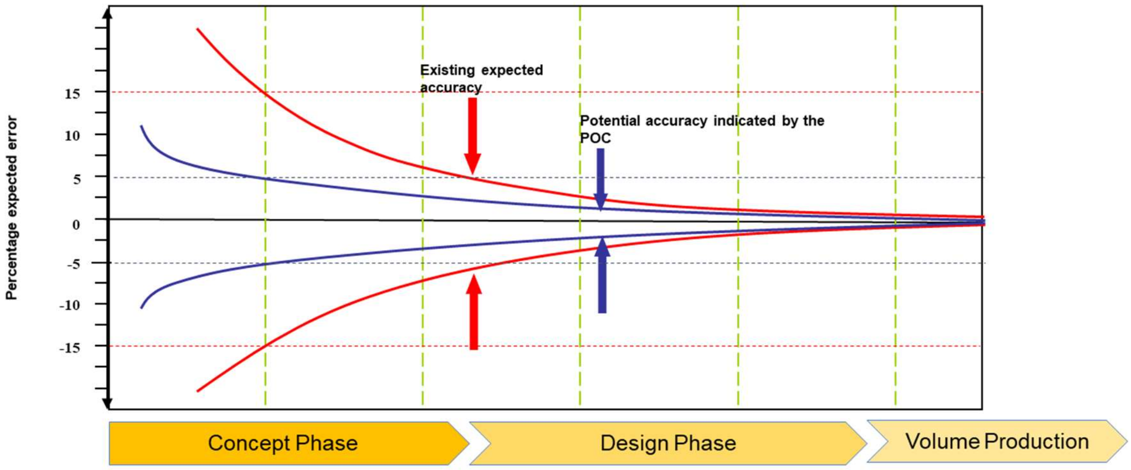


Fig 21: An illustration of the impact of PCE

JLRs application of PCE is limited to tier 1 material costs and investment costs. JLR has noted that the output of the PCE is very coarse, several business-critical aspects of the historical data has been 'normalised' out. Normalisation has the effect of creating an answer but hiding the potentially damaging information that could put the success of the NPD and business at risk. Within this research, there is a focus on creating a methodology to re-establish the detail of the material costs within the PCE to allow mitigating action to be taken early in the NPD timeline. The focus of the research will be upon the tier 1 supplier costs which within the automotive sector are known to equate to between 45% and 65% of the total revenue that will be achieved by the NPD. Boothroyd, (1988); (Mills, 1991). Other potentially exciting data analytics include manufacturing processes, currency, importation duty and preference markets will be discussed, all of which are aspects of early NPD uncertainty that the proposed framework can uncover allowing mitigation of business risk to be undertaken.

Need to reduce environmental impact

The literature review of recyclability, section 2.6 (pg 37), has shown that current literature does not reveal research that allows early identification of the recyclable materials and adjustment of the consumed commodities. The focus of historic literature is on achieving an understanding of the materials at the NPDs end of life that will require recycling. The research material presented in this thesis has the potential to identify the probable materials that will be included within the product resulting from the NPD and therefore insight into the potential adherence to a legislative requirement. However, achieving the legislative requirement is only one potential outcome. The business and environment gain the opportunity to undertake early redesign to avoid the use of environmentally damaging, increasingly scarce and costly materials.

2.8. Chapter 2 summary.

The broad review of NPD and associated literature as illustrated by Fig 4 (pg 8) has shown that a literature gap exists in business risk. A more specific literature review focusing on NPD activity to understand business risk showed that interventions exist but not configured towards delivery at concept phase of an NPD. A determination of how this gap in existing literature might be closed has been undertaken. While PCE methods have been applied at the concept phase of an NPD, the metadata held within the detailed sources informs the normalised input to the PCE has never been recorded within the academic literature as being used to inform the identity of commercial uncertainty and business risk. To explore the introduction of new technology literature has been reviewed to provide insight into the impact of industry cross-over; patent analysis; technology and manufacturing readiness levels. Ultimately though, the introduction of new technology within the context of this research is through either an estimate; PCE; SCE and or a QAF. The contextual application of the proposed hybrid methodology has been presented with a literature review of; uncertainty; business risk and rapidly changing markets.

The IMDS literature presented by (Cullbrand and Magnusson, 2012; Andersson et al., 2017) indicates that using IMDS data as a source to determine the resulting recyclability is viable but doesn't cover its appreciation during the concept phase of an NPD. Alternative detailed data sources do exist in the form of SCE & QAF data but would require a potentially incremental processing using composition analysis, a process that if the IMDS data has been fully completed should not be required. The data sources do present some differences; IMDS presents kerb weight while SCE & QAF data present gross material usage. Kerb weight drives recyclability requirements while gross weights drive cost and total usage.

As far as the aim of this research is concerned the (Cullbrand and Magnusson, 2012; Andersson et al., 2017; Du et al., 2015) papers have shown a linkage that materials used in a car can be identified down to the composition elements. These papers have also put forward evidence that there is increasing use of rare metals particularly with the increasing rise of Hybrid and electric vehicles. This rise in the demand, based on historical commodity price, will give rise to price rises and price volatility. Once identified their total usage can be defined but also their price volatility can be explored and mitigated if required. The key that is being explored is given what is known during the concept phase can a reliable forecast be achieved of volume production business risk for the NPD that can be relied on?

The presented literature review has revealed existing NPD literature and determined that it is a highly researched area. However, the principle area of interest for this research;" … that by quantifying commercial uncertainties and addressing their impact at the concept phase early confidence that once in volume production the risks to New Product Development (NPD) profitability due to volatile economic forces can be reduced." remains undocumented in academic literature.

Chapter 3. Research aim and objectives

This chapter presents the aims, objectives and critical research methodology applied to this research. The chapter explains the rationale behind the decisions taken in establishing the research strategy: Section 3.1 will address the aim of this research and how it will meet the hypothesis. Section 3.2 will lay out the objectives that need to be addressed. The approaches that were adopted will be discussed together with a review of alternative approaches and decision rationale. Section 3.3 presents an overview of the method followed for each step as required to deliver the research objectives. Section 3.4 addresses the specific issue of access to supporting data. The chapter concludes with a summary of the aim, objective and method.

3.1. Aim

This research aims to design and test a new and original approach to identify uncertainties at the early concept phase of an NPD allowing the uncertainties to be translated into mitigatable risks ahead of and during the later volume production and disposal stages.

3.2. Objectives, adopted approaches, review of alternatives and decision rationale.

The initial objective of this research is to verify, through a literature review, that there is a current gap in the published records that is specifically addressing the determination of uncertainties established during the concept phase of an NPD.

> The results of the literature search have been presented as a Venn diagram showing the impact areas already covered by literature against a Y-axis of NPD lifetime and an X-axis of coverage – people to business risk. The Venn diagram has been selected over other representations because of its visual simplicity to convey summary information such as the positioning of arguments against boundaries which form the axis.

The second objective is to establish, through interviews with Subject Matter Expert (SME)s, that the literature gap is not just a theoretical anomaly and that there is a real industrial need to address the omission in literature.

> Validate the hypothesis and the business need for this new methodology by interviewing key individuals in the JLR business. A JLR SME questionnaire has

been created to review the current process awareness of potential materials during the early concept phase of an NPD and its usefulness if it existed.

A meeting was arranged through internal JLR networking to ensure that the questionnaire received appropriate SME attention. The results were reflected to the JLR SMEs to ensure that their answers had been correctly documented.

The third objective was to determine a gap closing solution which would make use of existing tools and where possible existing secondary data within the OEM.

The approach taken was to establish what secondary data already existed within JLR as well as a determination of pre-existing 'tools' across industry and the Cost Estimating profession.

An extended literature review was undertaken to review each tool and secondary data source in literature and validate key findings with key SMEs. In particular this led to validating the current status of PCE through interviewing a key individual who is a leading figure in PCE toolsets, a fellow of the ACostE, member of SCAF and ICEAA. He is also a Visiting Professor in Whole Life Cost Engineering and Cost Data Management, University of Bath.

In a similar way to JLR SME validation the tool set validation started with the preparation of a PCE SME questionnaire.

A meeting was arranged through pre-existing networks to allow the SME to examine the critical preliminary findings as far as the PCE method and normalisation of data was concerned. The results were reflected to the PCE SME to ensure that their answers had been correctly documented.

The fourth objective to this research was to establish the current status of both the tools and the secondary data within JLR.

An examination of the existing PCE methodologyJLR as deployed at JLR with a focus on the engineering data construction and the tier 1 material data CER creation.

Access was obtained to the proof of concept and the production PCE system design documents along with the source data. Particular attention was taken to the structuring of data across USC's and feature delivery. Attention was also paid to any normalisation and data clean-up processing that had taken place.

A further examination of sources of data that might be used to identify the uncertainties.

Access was obtained to review both semi-public records for potential data as well as JLR confidential data records relating to tier 1 material costs. Particular attention was paid to the breadth of coverage, were all parts covered in detail or restricted to a few parts. The quality of the available data was additionally reviewed.

The JLR business was reviewed for potential business risks that are co-dependent upon tier 1 material costs.

An additional objective was to define methodology and frameworks to resolve the gap and provide a viable business solution that could solve the aim of the identification of the uncertainties as business risks.

The resulting methodology required two distinct elements. The first element was how to re-combine secondary data to establish the sub-data behind CER data points. The second methodology was the determination of data apportionment and the statistical stressing of any data allocation when the data served more than one feature delivery.

Through these methodologies when applied to the secondary data a new derived data set will be extracted in a manner that allows interrogation of the target business risk areas; High cost material usage, usage of highly economically volatile materials, achievement of NPD recyclability targets, establishment of a circular economy, an appropriate currency distribution, maximised importation commodity code utilisation and achievement of preference market targets.

The resulting methodologies required validation, verification that the resulting new NPD information was both credible and reasonable. It was also felt to be both complementary to proper research, but a declared requirement established by the JLR SMEs during interview discussions. A review of the decisions and allocations was made to identify the variables within the methodology. A Monte-Carlo simulation was applied to show the effect of changing values being applied to the methodology variables. Business variables outside of the methodology were excluded from the Monte-Carlo simulation.

Validation of the methodology has been achieved through reflection back to established methods for the recognition of the materials in an ELV. These though only covered the materials and alignment has therefore been demonstrated between the source metadata of these established methods and alternative metadata sources that provide the non-material metadata, manufacturing processes, currency, import duty and preference markets.

3.3. Research boundaries.

Within the scope of this research is the identification of NPD concept phase uncertainties. These include all aspects of business risk arising from economic volatility of materials, the nature and capacity of the manufacturing process and international trading that manifest in the tier 1 material cost line of Table 6.

Table 6: Typical automotive cost structure (reduced to show the significance of tier 1 material cost relative to all other costs)

Structure	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
	(Pct.)	(Pct.)	(Pct.)	(Pct.)	(Pct.)	(Pct.)	(Pct.)	(Pct.)
Gross Vehicle Revenue	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Tier 1 Material Cost	**(48.3)%**	**(48.9)%**	**(50.4)%**	**(50.8)%**	**(50.6)%**	**(49.7)%**	**(49.1)%**	**(49.2)%**
Manf Labour, Eng Expense ...	(41.8)%	(39.8)%	(41.2)%	(39.7)%	(39.9)%	(38.1)%	(38.4)%	(39.2)%
All other Costs & Profit	9.9%	11.3%	8.4%	9.5%	9.5%	12.2%	12.5%	11.6%

These in-scope tier 1 material costs will include ‘carry-over’, ‘modified’ and ‘new’ technology as required to deliver existing automotive features in a new way as well as new features. The carry-over and modified tier 1 materials being as an output from PCE analysis, the new being sourced from an overlaid analogous SCE source.

As can be seen from Table 6, cost other than tier 1 material cost such as Vendor tooling, in-house manufacturing, in-house tooling and facility cost as well as other in-house costs including NPD investment costs collectively represent less than the impact of tier 1 material costs and increased complexity in sourcing credible data. The reasons for this are however out-of-scope for this research. Tier 1+, in-house tooling and facilities present additional issues to the analysis as they are non-variable costs, fixed costs. In-house manufacturing costs and the NPD investment costs, for the most part, do not include any economically volatile material costs, importation duties, currency, the nature of the uncertainties and business risks that they potentially contain are different to those contained within tier 1 material costs for these reasons they are out-of-scope.

Whilst the scope of this research is clear from an automotive cost verses revenue perspective clarification is required when considering the tools and secondary data that are being applied within the hybrid methodology framework solution.

<u>In scope</u> - alongside the exploration of tier 1 material cost for business risks within the NPD during its concept phase the following are in scope for methods of application:

i. In scope
    a. Tools/Methods.
        i. Monte-Carlo.
        ii. Composition Analysis.
        iii. FAST.
    b. Secondary data sources.
        i. Should Cost Estimates
        ii. Quotation Analysis Forms
        iii. International Material Database System
    c. Output data influences.
        i. Mitigation Causal Loop Diagrams.

<u>Out of scope</u> includes any detailed exploration of pre-existing tools and methods that can be explored through other sources and do not in themselves form new knowledge delivered through this research and thesis.

ii. Out of Scope
    a. Monte-Carlo.
    b. Pareto Analysis.
    c. Should Cost Estimating.
    d. Quotation Analysis Form generation.
    e. International Material Database System.

3.4. Access to supporting data.

The research presented in this thesis is using secondary data drawn from Jaguar Land Rover. Because of the commercially sensitive nature of the data being accessed (it being restricted under competition law), it is usually not available to academic research. Even though the thesis author was for many years a senior manager within JLR with direct access to engineering, financial and purchasing data some data has remained inaccessible. JLR IMDS data has remained restricted.

Chapter 4. Methodology development

4.1. Validation of the hypothesis.

To validate the hypothesis and the need for this research interviews have taken place with industry Subject Matter Experts (SMEs) from Jaguar Land Rover (JLR) and the Parametric Cost Estimating (PCE) support base. Both SME questionnaires are available in Appendix 2 & Appendix 3.

The interview with JLR SMEs, (Fennelly and Robottom, comm., 5th Feb 2018)[7], confirmed that while there is some knowledge of the materials that might be involved in the NPD at production these would only be known in generic terms of; steel; aluminium; platinum; palladium. There would be very little detail and no acknowledgement of the plastics content. No awareness would be available of the recyclability of the concept, and there would be no awareness of the materials associated with the introduction of new technology. The JLR SMEs were also able to confirm that there is no current attempt to use any concept phase data to direct the material substitution towards lower cost; lower economic volatility or towards using more recycled materials.

This lack of knowledge at the concept phase also extends to the requirements of manufacturing processes, currency requirements and implications for importation duty and preference markets. The interview did give rise to a recognised item that is unfortunately out of scope for this research; fuel duty associated with delivery costs. In summary, the JLR SMEs encouraged the research as it addresses a recognised business and academic literature gap. They did express that there would be a need to establish the quality of an answer that results from the application of the research.

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[7] Alan Fennelly is a finance executive director in Jaguar Land Rover Ltd. Alan has held various roles within JLR at executive director level covering financial issues relating to marketing, Engineering including new product developments and cost engineering teams.
Chris Robottom was also a finance executive director in Jaguar Land Rover Ltd. Chris served dealing with issues relating to global procurement, then latterly cost engineering before moving to new product developments. Chris has recently moved onto a new challenge with a different company heading their northern European finance team. Both Alan and Chris are Chartered Accountants.

The interview with PCE SME, (Langridge, comm. 3rd March 2018)[8], confirmed that the PCE method was not generally applied within the automotive industry. There is no known reason why this is the case because as proved already by JLR it can be applied. Professor Langridge confirmed that once underlying data has been normalised, PCE as currently applied across all industries could not re-invent the metadata. Therefore, the current application of PCE methods does build-up uncertainties within the PCE output.

The interview additionally confirmed that the PCE method could be applied at any stage of the NPD timeline, but the input data required to create the CERS would be to be adjusted to become appropriate to expected output being demanded.

4.2. Existing 'Secondary' data

In this section the nature of the secondary data which has been used will be reviewed and if necessary critiqued for quality and sustainability. The intention is to provide insight and background to allow greater understanding of the underlying data being used to develop this research and how it is used within the novel treatment.

4.2.1. Engineering release data

There are many threads of engineering data. This research will focus on a very few; the core codification system for the structure of a vehicle which will be referred to as a Unique System Code (USC). Table 7 shows a small extract of the USC coding system that covers all aspects of a vehicle. As technology changes, the USC will expand to cover the detail requirements. At the time of writing 654+ USC exist. USC's themselves do subdivide into additional meaningful data, but these are not required in the delivery of this research.

[8] Andrew Langridge have worked for several leading cost engineering software companies and worked on several government projects around the world applying parametric cost estimating. He serves as a board member of the Association of Cost Engineers and is a Visiting Professor in Whole Life Cost Engineering and Cost Data Management, University of Bath.

Table 7: Sample USC extract for seating.

USC	Description
011000	Seating Subsystem
011001	Front Seat Trim Set
011002	Front Seat Frames
011003	Second Row Seat Trim Set
011004	Second Row Type Bench or Split Seat Frames
011005	Additional Seat Trim Set
011006	Additional Seat Frames
011009	Power Seat ECU and Software
011016	Switches - Front Seat
011017	Switches - Rear Seat
011013	Seat Comfort Control Module

Vehicles are not made of USC's, for that physical parts are required. Engineering, therefore, releases parts against a vehicle models USC structure. The part itself has a meaningful part number constructed in three key parts; Pre-fix, Base, Suffix. Each part number element can be further subdivided; the characters of the Pre-fix indicate the year of first release of the part and the vehicle model it was released to support. The Suffix divides into the derivative and the release level. The derivative of a part isolates it as delivering to the requirements of features; a single part may be involved in the delivery of one or more features. Table 8 shows an example of USC's from the seating family of a range of Land Rover Discovery's, the feature family description, feature description and feature code. The Vehicle Identification Numbers (VIN) of the specific source examples have also been included.

Table 8: Feature family to USC mapping

Feature Family Description	Feature Description	011001	011002	011003	VIN
Passenger Seat Configuration	Seven Pass Seat Configuration	BYNAL		BYNAL	SALLAAAG6CA632327
Passenger Seat Configuration	5 Pass Seat Configuration	BYNAR		BYNAR	SALLAAAG6CA645001
Jacks	Scissor Jack			AHDAQ	SALLAADG5CA614531
Passenger Seat Configuration	2 Pass Seat Configuration	BYNAW			SALLAADG5CA614531
Dvd Screen	Less Dvd Screen	IBRAA			SALLAADG5CA614531
Dvd Screen	Dvd Screen	IBRAB		IBRAB	SALLAAAG6CA632327
Seat-rear Fold Down	Rr Seat-35/30/35 Split	BWCAN		BWCAN	SALLAAAG6CA645001
Seat-rear Fold Down	Rr Seat-65/35 Split	BWCAP		BWCAP	SALLAAAD4CA618241
Head Impact Crash Criteria	Less Head Impact Crash Criteria	ADTAA			SALLAADG5CA614531
Head Impact Crash Criteria	Head Impact Crash Criteria	ADTAB			SALLAAAD4CA645650
Seat Adjuster Total Vehicle	Elect Frt Seat Adj Drv Memory	A4EAC	A4EAC		SALLAAAG6CA645001
Seat Adjuster Total Vehicle	Manual Frt Seat Adj Drv & Pass	A4EAD	A4EAD		SALLAAA14CA626402
Seat Adjuster Total Vehicle	Elec Frt Seat Adj Non-memory	A4EAE	A4EAE		SALLAADG5CA614531
Lj -m-l -windsor	Lj -m-l -windsor[4BHE6][4BHL3][4BHMZ][4BHN7]	4BH00		4BH00	SALLAAAG6CA645001
Lg -h-c -land Rover Cloth	Lg -h-c -land Rover Cloth[4CAE6][4CAMZ]	4CA00		4CA00	SALLAAA14CA626402
Lg -h-l -land Rover Leather	Lg -h-l -land Rover Leather[4CBE6][4CBL3][4CBMZ][4CBRX]	4CB00		4CB00	SALLAADG5CA614531
Ccr Seats	Ccr Seats	A57AB	A57AB	A57AB	SALLAADG5CA614531
Seat Center Armrest-front	Frt Seat Armrest-fully Adjust.	BVHAR			SALLAADG5CA614531
Seat-rear	Rear Bench Seats 1x2	BWAAW		BWAAW	SALLAAAG6CA632327
Seat Bolster-drv	Less Drv Articulated St Bolstr	KEFAA			
Seat Bolster-drv	Articulated Drv Seat Bolster	KEFAB			
Seat Temp Cntrl- Total Vehicle	Heated Seats - Drv/pass		A4DAB		SALLAADG5CA614531
Seat Temp Cntrl- Total Vehicle	Heated Seats - Frt/rear		A4DAC		SALLAAAG6CA645001

Engineering release the parts to facilitate the delivery of the required complexity which may require several parts to achieve a single feature delivery. Table 9 shows a small sample of parts released against a sample of the seating USCs shown in Table 7 (pg 58).

Table 9: Sample Part mapping to USC's and features

Part Number	Part Description	USC	Minor Feature String
UH12-0069-LCA	Screw	011001	
UH12-0610-LDA	Blt Bdy Mtng	011001	A57AB BVHAR
UH12-0610-LFA	Blt Bdy Mtng	011001	A4EAD A57AB
UH12-0610-LFA	Blt Bdy Mtng	011001	A4EAC A57AB
UH12-0610-LFA	Blt Bdy Mtng	011001	A4EAE A57AB
6H52-3925-CB	Bracket	011002	A4DAB A4EAD A57AB
6H52-3925-CB	Bracket	011002	A4DAC A4EAD A57AB
6H52-3925-JB	Bracket	011002	A4DAB A4EAD A57AB
6H52-3925-JB	Bracket	011002	A4DAC A4EAD A57AB
UH12-F9121-CA	Anti Rattle Pad	011001	A57AB
UH12-F9121-DA	Anti Rattle Pad	011001	A57AB
CH2M-06202-AA	Try Asy Uty(lght Vnr)	011003	
CH2M-06202-BA	Try Asy Uty(drk Vnr)	011003	
CH2M-06202-CA	Try Asy Uty(gry Vnr)	011003	
CHCH2M-06202-AA	Try Asy Uty(rr St Opt)	011003	
UH12-13093-DRA	Riv-eylt Typ	011001	A57AB BWCAN
5H22-17626-AAW	Pnl Frt Vlc	011001	A4EAD A57AB
5H22-17626-BAW	Pnl Frt Vlc	011001	A4EAD A57AB
AH22-60010-AA	Lbl St Clnr Inst	011001	A57AB 4CB00
AH22-60010-AA	Lbl St Clnr Inst	011001	A57AB 4BH00
5H22-60034-BAW	Kit Frt St(plinth	011001	A57AB
5H22-60034-CAW	Kit Frt St(plinth)	011001	A57AB
MAH2M-60034-AA	Kit Frt St(ccr Costs 2 Seat	011001	A57AB BYNAW
MBH22-60034-AA	Kit Frt St(ccr Costs 5 7 Seat	011001	A57AB BYNAR
MBH22-60034-AA	Kit Frt St(ccr Costs 5 7 Seat	011001	A57AB BYNAL
CH32-60035-AAW	Bk & A Rst Asy Rr St	011003	A57AB IBRAB
5H22-60050-AA	Cshn Asy Frt St	011002	A57AB
XH22-60056-AA	Blt Frt St Att	011002	
XH22-60056-AA	Blt Frt St Att	011003	AHDAQ BYNAR
5H22-60536-AAW	Srp Rr St Cshn Flr Bd Pnl Rr Fin	011001	A57AB BWAAW

The features shown in Table 9 are referred to as minor features. There is a group of features known as 'primary features' covering substantive and basic requirements; cab style, wheelbase, engine, transmission, emission, air conditioning, driveline, and front seat. These have not been shown as very few further complicate the release of the seating parts. At the date when this data was sourced (Nov 2012 in support of the PCE

POC) this data source was showing 248 individual part numbers within the USC group 011001, 011002, 011003.

4.2.2. NPD Engineering attribute data.

NPD engineering attribute data does exist and within the industry is a crucial deliverable for any NPD. Within the automotive sector there are typically 17 recognised key attributes; Product efficiency, Safety, Perceived Quality, Accommodation & Usage, Vehicle HMI & audio-visual, Vehicle dynamics, Braking, Performance & driveability, Durability & reliability, Off road & all road capability, Weight, Environment & energy management, Service & ownership, All-weather comfort & vision, TASE (Thermal and Aerodynamic System Engineer), Security. Some automotive OEMs have added an 18th, Cost.

The data shown in Table 10 is taken from a real NPD it critically shows the ranking attributed to each USC/Attribute combination; 3 being the highest priority and 0 showing no prioritisation.

Table 10: USC to engineering attribute mapping.

USC	USC NAME	A0: Product Efficiency	A1: Safety	A2: Perceived Quality	A3: Accommodation & Usage	A4: Vehicle HMI & Audio-Visual Performance	A5: Vehicle Dynamics	A6: Braking	A7: Performance & Driveability	A8: Vehicle NVH & Sound Quality	A9: Durability & Reliability	A10: Off Road & All Road Capability	A11: Weight	A12: Environment & Energy Management	A13: Service & Ownership	A14: All Weather Comfort & Vision	A15: TASE	A16: Security
011001	Front Seat Trim Set	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
011002	Front Seat Frames	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0
011003	Second Row Seat Trim Set	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Engineering sourced data mapping also exists showing the accessed contribution to each attribute from each USC, a sample of this is provided in Table 11. Individual rows of data are a percentage contribution adding up to 100% + 1 for A11: Weight.

Table 11: USC to Attribute contribution.

USC	A0: Product Efficiency	A1: Safety	A2: Perceived Quality	A3: Accommodation & Usage	A4: Vehicle HMI & Audio-Visual Performance	A5: Vehicle Dynamics	A6: Braking	A7: Performance & Driveability	A8: Vehicle NVH & Sound Quality	A9: Durability & Reliability	A10: Off Road & All Road Capability	A11: Weight	A12: Environment & Energy Management	A13: Service & Ownership	A14: All Weather Comfort & Vision	A15: TASE	A16: Security
011201	0	50	0	0	0	0	0	0	0	50	0	1	0	0	0	0	0
011202	0	0	50	45	0	0	0	0	0	5	0	1	0	0	0	0	0
011203	0	0	100	0	0	0	0	0	0	0	0	1	0	0	0	0	0
011001	0	0	25	75	0	0	0	0	0	0	0	1	0	0	0	0	0
011002	0	0	0	80	0	0	0	0	0	20	0	1	0	0	0	0	0
011003	0	0	25	75	0	0	0	0	0	0	0	1	0	0	0	0	0
011004	0	0	0	50	0	0	0	0	0	50	0	1	0	0	0	0	0
011005	0	0	0	100	0	0	0	0	0	0	0	1	0	0	0	0	0
011006	0	0	0	100	0	0	0	0	0	0	0	1	0	0	0	0	0
000203	0	75	0	0	0	0	0	0	0	0	0	1	0	0	0	0	25
010501	0	0	60	10	0	0	0	0	30	0	0	1	0	0	0	0	0
010502	0	0	0	0	5	0	0	0	95	0	0	1	0	0	0	0	0
010503	0	0	85	0	5	0	0	0	5	0	0	1	0	0	0	5	0

Table 11 shows the USC to 17 key attribute mapping; everything attracts the 18th attribute, cost. Each of the 17 key attributes sub-divides creating 70 + attributes in total, a sample of these are shown in Table 12. Once established the NPD engineering attribute data is used to rank the performance required from each USC-f combination: the x-axis of the PCE CERs.

In Table 13 the data is again from a real NPD, it shows the NPDs target ranking against each attribute and the NPD target competitor.

Table 12: Sample Sub-attribute to Key attribute mapping.

Key attribute	**Sub-attribute**
A0: Product Efficiency	Derivative level Fuel Economy / CO_2
	Fleet level Fuel Economy / CO_2
	Real World Fuel Economy - RWFE
A1: Safety	'Consumer' Safety Test Performance
	Safety Feature Fit
A2: Perceived Quality	Crafted Quality
	Materials
	Design
	Ambient Lighting
A3: Accommodation & Usage	Driving Position & Passenger Accommodation
	Visibility
	Seat Comfort
	Premium Passenger
	Daily Life Usage

Table 13: NPD attribute targets

Vehicle	A0: Product Efficiency	A1: Safety	A2: Perceived Quality	A3: Accommodation & Usage	A4: Vehicle HMI & Audio-Visual Performance	A5: Vehicle Dynamics	A6: Braking	A7: Performance & Driveability	A8: Vehicle NVH & Sound Quality	A9: Durability & Reliability	A10: Off Road & All Road Capability	A11: Weight	A12: Environment & Energy Management	A13: Service & Ownership	A14: All Weather Comfort & Vision	A15: TASE	A16: Security
NPD	7.0	8.0	8.0	8.5	8.5	7.8	7.0	7.3	7.5	8.0	8.5	7.0	7.0	7.3	7.5	7.0	7.5
Competitor	7.5	8.0	7.8	7.8	8.3	6.5	7.5	6.8	6.8	7.5	6.8	7.0	7.0	7.5	7.5	7.0	7.5

(The measure used in ranking the attributes in Table 13 is out of 9.0 but, any relative ranking can be used.)

4.2.3. Parametric Cost Estimating (PCE).

Because there is no established usage of PCE within JLR or any other automotive OEM, no pre-existing secondary data is available.

4.2.4. Historically detailed source metadata

Detailed source metadata consists of a grouping built from 'real' world rather than statistical origin data. Within the group are; 'bottom-up estimates' also known as Should Cost Estimates (SCE); Quotation Analysis Forms (QAF); International Material Database (IMDS); Metals Stamping DataBase (MSDB); raw material claims and for the purposes of this research; composition analysis and Price Volatility Index (PVI). The following looks at each in more detail.

Should cost estimate (SCE).

JLR in common with many other OEMs uses several SCE software tools. JLR prioritise on a bespoke tool called CAPPe[9], other tools in everyday use include ProCalc[10]. Other commercial tools exist including; Seer-DFM[11]; FACTON EPC[12]; LeanCost[13]; aPriori[14].

CAPPe's JLR Cost module was defined by JLR to deliver its cost report in the structured form of a QAF but with the addition of additional information that had proved useful during years of negotiation experience between OEM and tier 1 supply base.

Fig 22 shows a sample of the output document from JLR's CAPPe SCE system.

Fig 23 shows an example of a QAF. That the layout of the two documents is extremely similar wasn't an accident, it aids the primary use of the SCE, tier 1 negotiation.

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9 Core CAPPe is owned by T-Systems do Brazil Ltda and distributed in Europe by PRICE® Systems International, Ltd, JLR Cost module owned by Jaguar Land Rover Ltd, all rights are acknowledged.

10 ProCalc is owned by Siemens Industry Automation Division, all rights are acknowledged.

11 Seer-DFM also known as Seer-Manufacturing is owned by Galorath Inc. http://galorath.com/products/manufacturing/SEER-software-estimation-manufacturing-projects, all rights acknowledged.

12 FACTON EPC is owned by FACTON GmbH, www.facton.com all rights acknowledged.

13 LeanCost is a product from hyperlean, www.hyperlean.eu all rights acknowledged.

14 aPriori, is owned by aPriori, www.apriori.com/about-us/ all rights acknowledged.

Cost Engineering PD Finance

Cost Engineering
Should Cost Analysis Report

JAGUAR | LAND-ROVER

Should Cost No.	11111AAA	**Part Number**	XW83-55055-AB	**Desc.**	Under bonnet support stamping Assembly
Process Plan No.	12345	**Model Code**	[redacted]	**Volume**	[redacted]
				Programme Life	8
Estimate Date	09-02-12	**Supplier**			

1. Bought Out Parts

Part number	Description	Unit Cost	Country of Origin	Exchange Rate	Local Unit Cost	UOM	Qty per Assembly	Cost per Assembly	Scrap (%)	GBP Item Cost	Usage in Assembly	Assoc. Scrap	GBP Total Cost
1101553	M5 x 30mm bolt	0.035	GBP	1.000	0.035	Ea.	4.00	0.140	1.00%	0.141	1.000	0.000	0.141
2105668	M5 Nut	0.025	GBP	1.000	0.025	Ea.	4.00	0.100	1.00%	0.101	2.000	0.002	0.204
INS001	Insulation	2.33	EUR	1.200	1.942	Ea.	2.00	3.883	2.00%	3.961	4.000	0.134	15.978

Bought Out Parts Continuation Sheet..? No | BOP Scrap Value = 0.080 | Sub Total (1) 16.323

2. Raw Material

Part number	Description	Country of Origin	Exchange Rate	Gross Weight	Net Weight	UOM	Scrap (%)	Gross Usage	Cost per UOM	Reclaim Usage	Reclaim Cost per UOM	GBP Item Cost	Usage in Assembly	Assoc. Scrap	GBP Total Cost
8006005021	Coil - HRP14 115W - 115 x 250 x 2mm	UK	1.000	3.000	2.000	KG	5.00%	3.150	0.855	1.150	0.150	2.521	1.000	0.000	2.521
6058845	Paint - Base coat (Wet)	EUR	1.200	0.500	0.350	Ltr	15.00%	0.575	0.850			0.489	1.000	0.000	0.489

Raw Material Continuation Sheet..? No | Material Scrap Value = 0.173 | Sub Total (2) 3.010

3. Process Costs

Part Number	Op	Operation	Manning	Actual Qty per hour (No./Hr.)	Direct Labour (Rte./Hr.)	Social Labour Fringe (Rte./Hr.)	Indirect Labour (Rte./Hr.)	Total Labour Cost	Machine Rate (Rte./Hr.)	Total Machine Cost	In Process Scrap (%)	Set-up Cost	Operation Cost	Usage in Assembly	Assoc. Scrap	GBP Total Cost
XW83-55055-AB	10	Pierce, Notch, Blank	1.00	400.00	10.31	4.95	8.39	0.06	45.50	0.114	1%	0.015	0.190	1.000	0.000	0.190
XW83-55055-AB	20	Raise	1.00	350.00	10.31	4.95	8.39	0.07	15.60	0.045	1%	0.150	0.263	1.000	0.000	0.263
XW83-55055-AB	30	Inspect	2.00	1750.00	10.31	4.95	8.39	0.03	155.00	0.089	2%	0.035	0.153	1.000	0.000	0.153
XW83-55055-AB	40	Pack	1.00	45.00	10.31	4.95	8.39	0.53	9.50	0.211	1%	0.010	0.754	1.000	0.000	0.754
W83-55055-AB - Sub	10	Blank	1.00	200.00	10.31	4.95	8.39	0.12	155.00	0.775	2%	0.035	0.928	3.000	0.224	3.009
W83-55055-AB - Sub	20	Raise	1.00	200.00	10.31	4.95	8.39	0.12	155.00	0.775	2%	0.035	0.928	3.000	0.017	2.802

Process Costs Continuation Sheet..? No | Operation Scrap Value = 0.013 | Sub Total (3) 7.170

Should Cost Assumptions

Country	Great Britain
Local Currency	GBP
Period	01-01-12
Shift Pattern	Double 16hrs
Working Days / Year	235
Hours per year	3572
Set-up	Included

4. Other Costs

Description	Category	Handling	SG&A	Profit	Item Cost	Usage in Assembly	Assoc. Scrap	GBP Total Cost
Delivery Charge	Transport	N	N	N	0.550	1.000	0.000	0.550
Sequencing of assembly to line	Sequencing	N	Y	Y	1.250	3.000	0.055	3.805

Sub Total (4) 4.355

Total Value Added activities (2) + (3) + (4 if applicable) = 13.985

TOTAL MANUFACTURING COST (1) + (2) + (3) + (4) — **30.858**

Top Level Mark-up Assumptions

Complexity	Low
Organisation Size	Medium
Design Responsibility	Joint
Handling	5.0%
SG&A	6.5%
Profit	4.4%

5. Mark-ups

		Total Cost
BOP Handling:	On Bought Out Parts	0.816
General Overheads:	On Value Added Activities (raw materials and process)	0.699
Profit:	On Value Added Activities (inc general overheads)	1.389

Sub Total (4) 2.904

Estimator	DABHI, PARESH
Creation Date	09-02-12

FINAL ESTIMATE TOTAL (1) + (2) + (3) + (4) + (5) — **33.762 GBP**

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Fig 22: Sample SCE output taken from the specification document of CAPPe.

Quotation Analysis form (QAF).

An example QAF is shown as Fig 23. The QAF has been redacted to comply with the requirements of European Competition Law. It shows a non-current production part. Although not explicitly shown on this extracted worksheet the summary page shows the cost to be in Euros and the source to be in Italy.

As with many available data sources, the example QAF is incomplete as it fails to specify the Unit of Measure (UoM) although the form does provide a column for UoM. Most QAFs can provide quality data covering all aspects of the subject parts incurred costs for; Purchased Parts, Raw Material, Process / Assembly, Non-Manufacturing costs and logistics costs. Production tooling costs can also be extracted, but these are out of scope for this research.

JLR Quotation Cost Detail Sheet

Supplier Name:	[redacted]					**Supplier Code:**	[redacted]		
Date:	00-Jan-00	Sheet:	2	Eng. or Drawing Level (Previous):	0		New Eng. or Drawing Level (New)	0	
Ref. No.:	0	Sheets:	6	Part Number (Previous)	0	0	0	Part Number (New):	[redacted]

1. Purchased Parts (Non-Value Added)

Directed Source Y/N?	OEM Engineering Part Number	Supplier Part Number	Description	Tier 2, 3, or 4?	Country of Origin	Exchange Rate	Actual Purchased Parts Cost (Each)		Part Quantity Per End Item	Inbound Trans Cost (Per Unit)	Tax and Duty (Per Unit)	Price (New) Per Unit	Price (Previous) Per Unit
							From	To					
												0.000	
												0.000	0.000
												0.000	
			Purchase Parts Continuation Sheet..?	No	< Yes or No..?						Sub total (1)	0.000	0.000

2. Raw Material (Value Added)

Auto Materials Y/N?	Raw Material Part Number (MATS)	Desc./Type/Grade	Country of Origin	Unit of Measure	Price per UOM	Economics - Material	Exchange Rate	Gross Usage		Net Usage	Re-claim Revenue (Per Unit)	Tax and Duty (Per Unit)	Price (New) Per Unit	Price (Previous) Per Unit
								From	To					
N		PRIMARY ALUMINIUM	Various		1.986	Q3-2012			24.871	15.100	16.184		33.210	
N		ADDITIVE	Various		2.600	Q3-2012			0.150				0.390	
N		PAINT			1.860				1.000				1.860	
			Raw Material Continuation Sheet..?		No	< Yes or No..?						Sub total (2)	35.461	0.000

3. Process / Assembly (Value Added)

Op. #.	Operation Description	Heads (Direct Labour)	Actual Realized (No./Hr.)		Dir._Labour Fully Fringed (rate/hour)	Ind._Labour Fully Fringed (rate/hour)	Dir._Labour Fully Fringed	Ind._Labour Fully Fringed	Fixed Mfg. O/H (rate/hour)	Variable Mfg. O/H (rate/hour)	Tot._Mfg. O/H Cost	Price (New) Per Unit	Price (Previous) Per Unit
			From	To									
1	MELTING	1.00		46	39.758	11.267	0.861	0.244	21.671	71.689	2.023	3.128	
2	CASTING	0.50		8	38.033	4.969	2.444	0.319	9.462	19.598	3.734	6.497	
3	X-RAY	1.00		207	37.358	4.462	0.181	0.022	8.134	7.314	0.075	0.277	
Process Costs Continuation Sheet..?		Yes	< Yes or No			Totals	11.45	2.22		Sub total (3)	12.55	26.221	20.698
TOTAL MANUFACTURING COST (Value Add) = (2) + (3)												61.681	20.698

4. Non-Manufacturing Costs	Enter Calculations...	Price (New)	Price (Previous)
End Item Scrap (Value Added)	Subcontract cost (stripping)	0.180	
Corporate Overhead/SG&A (Value Added)		1.850	
Profit (Value Added)		4.653	
Purchased Part Mark-up (Non-Value Added)			
Research & Development			
Engineering, Design & Testing		0.217	
	Sub total (4)	6.900	
TOTAL PART COST (excluding logistics costs): (1) + (2) + (3) + (4)		68.581	20.698

5. Production Tooling

Line Number	Description	Country of	Tool Life (in # of	Country of Origin & Currency	Lead Time Weeks	Parts Per Tool Cycle	Exchange Rate	Cycle Time	Ave. Capacity/ Week	Max. Capacity/ Week	Design Cost	Mfg. Cost	Material Cost	Total Cost
		Production Tooling Continuation Sheet..?			No	< Yes or No..?							Total Tooling Amount (5)=	

6. Logistics Costs	Enter Calculations...	Price (New)	Price (Previous)
Total Packaging Costs		1.080	
Freight			
Sequencing			
Supplier Warehousing (Pre-shipping/transport)		0.250	
Other			
Logistics Sheet..?	No < Yes or No..? Sub total (6)	1.330	
Signed Supplier: Date:	**TOTAL OFFER PRICE (Ex-Works) (1) + (2) + (3) + (4) + (6)**	69.911	

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JLR Purchasing Business Office, July 2008

Fig 23: Example, redacted, tier 1 QAF.

Note: The example QAF shown in Fig 23 includes 'end item scrap'. The identified end item scrap is in fact 'in process material waste' rather than 'scrap'. The item is showing the recycling of aluminium trimmings back into the smelt at the source.

Metal Stampings Database (MSDB).

Metal Stampings Database (MSDB) is an SCE, QAF equivalent (Materials and process consumption only, no costs) for the internal stampings or press shops. The summary forms contain data relating to; raw materials; gross weight; Nett weight; stamping process requirements.

Analysis has shown that the MSDB coverage by tier 1 material cost is between 2.3 and 3.9% by model, as shown in Fig 24. Model 4 is an outlying data set; internal stamping shops are loaded to optimise their capacity at a point in time and stamping for body sides are switched from internal to external tier 1 suppliers as required. Model 4 is low volume and at the point in time of the data sample mainly outsourced to create in-house capacity for higher volume models. Data associated with Model 4 will show as QAFs, tier 1 supplied.

Two forms of material are included in the tier 1 material costs feeding into the internal stamping facilities; pre-cut blanks (Flat form) and coil.

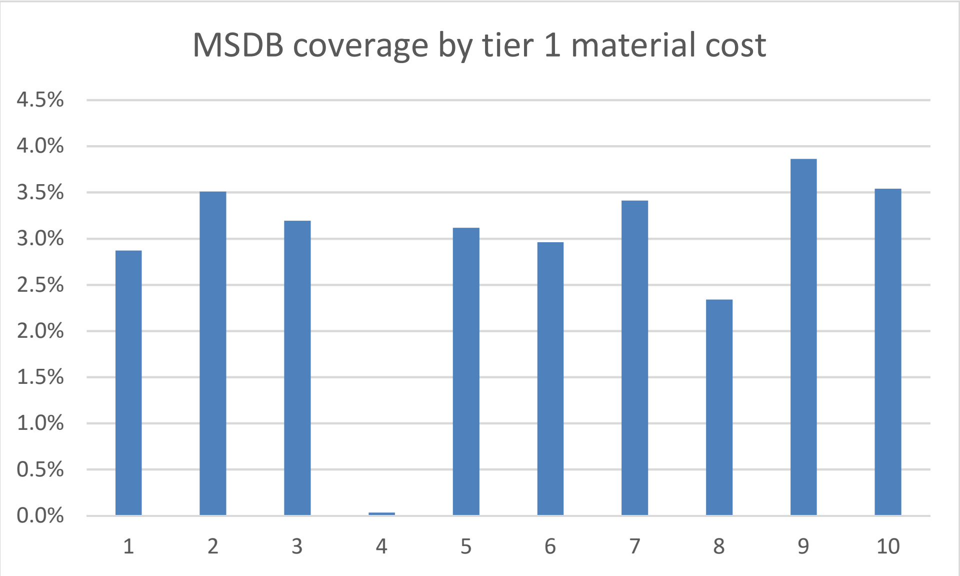


Fig 24: MSDB coverage by tier 1 material cost.

International Material Data System (IMDS).

The IMDS material data for a single part, as shown in Table 14 and its continuation Table 15 is for a fuel tank assembly. Interestingly this data provides evidence of virgin and recycled Polyethene (PE) (see Table 15) being used in a single part. One of the objectives of this research is to provide the evidence at the NPD concept stage that increased levels of recycled material should be specified.

Table 14: Complex IMDS data sample for a single part number HK93-9K007-DD (Fuel tank Assembly)

IMDS Material	Total Material Mass (g)	Material Category
11SMn30	4.5	1.1.1 - unalloyed. low alloyed
AB1262 (Feuerverzinkung)	0.3	3.3 - Zinc alloys
Acrylic Adhesive	0.0	6.2 - Adhesives. sealants
Acrylic resin for labels	0.4	6.2 - Adhesives. sealants
Austenitic Cr-Ni Stainless Steel (301)	0.1	1.1.2 - highly alloyed
AverydennisonFT202	0.6	6.2 - Adhesives. sealants
C10C	12.2	1.1.1 - unalloyed. low alloyed
Co49Fe2V	0.2	4.2 - Other special metals
Coating film inorg./org. PAK (Sealant inorganic/organic with content of polyacrylat)	0.0	6.1 - Lacquers
Copper Nickel	3.8	3.2 - Copper alloys
Cu-ETP1	71.9	3.1 - Copper (e.g. copper amounts in cable harnesses)
CuSn4	4.4	3.2 - Copper alloys
CuSn6	5.9	3.2 - Copper alloys
CuZn30	4.3	3.2 - Copper alloys
DC01 (Synonym: . Fe P01. St 12. CR4. C. 1142. AP00)	0.1	1.1.1 - unalloyed. low alloyed
DX53D	435.0	1.1.1 - unalloyed. low alloyed
E195	14.9	1.1.1 - unalloyed. low alloyed
E-COAT	2.4	6.1 - Lacquers
EPDM 40	5.5	5.3 - Elastomers / elastomeric compounds
Ep-Fe/ZnNi(12-15) (electrodeposited Zinc-Nickel Coatings)	0.1	3.3 - Zinc alloys
e-plate Ag (electrodeposited Silver Coatings)	0.3	4.2 - Other special metals
e-plate Au (Hardgold) (electrodeposited Hardgold Coatings)	0.0	4.2 - Other special metals
e-plate Ni (bright) (electrodeposited Nickel bright)	0.0	3.4 - Nickel alloys
e-plate Ni (Watts) (electrodeposited Watts-Nickel)	0.0	3.4 - Nickel alloys
e-plate Sn (electrodeposited Tin Coatings. bright and matt)	3.0	4.2 - Other special metals
e-plate Zn (electrodeposited Zinc Coatings)	0.4	3.3 - Zinc alloys
e-plate ZnNi(12-15) (electrodeposited Zinc-Nickel Coatings)	0.1	3.3 - Zinc alloys

Table 15: Table 14 continuation.

IMDS Material	Total Material Mass (g)	Material Category
ETFE	4.0	5.1.b - unfilled Thermoplastics
EVOH	178.1	5.1.b - unfilled Thermoplastics
FKM	26.5	5.3 - Elastomers / elastomeric compounds
FVMQ	1.6	5.3 - Elastomers / elastomeric compounds
HDPE	5.7	5.1.b - unfilled Thermoplastics
HNBR	0.2	5.3 - Elastomers / elastomeric compounds
Hybrid-ceramic-LTCC(1%-Pb)	1.5	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-ceramic-LTCC(5%-Pb)	1.5	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-glas-LTCC(1%-Pb)	0.0	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-glas-LTCC(5%-Pb)	0.0	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-inorganic-LTCC	0.3	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-metal-LTCC	0.5	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-organic-LTCC	0.0	8.1 - Electronics (e.g. pc boards. displays)
Hybrid-polymer-LTCC	0.1	8.1 - Electronics (e.g. pc boards. displays)
ISOPARAFFINE	5.3	9.1 - Fuels
KTL schwarz/ E- Coat black	0.5	6.1 - Lacquers
M530-65A	137.7	1.1.1 - unalloyed. low alloyed
Monarch Elastomer Closed Cell Rubber-5932	29.4	5.3 - Elastomers / elastomeric compounds
NBR	10.0	5.3 - Elastomers / elastomeric compounds
NdFeB 43/80p	24.9	7.3 - Other compounds (e.g. friction linings)
Ni42	8.3	3.4 - Nickel alloys
PA 6.6	0.5	5.1.b - unfilled Thermoplastics
PA11	22.0	5.1.b - unfilled Thermoplastics
PA11-P	8.1	5.1.b - unfilled Thermoplastics
PA12	6.7	5.1.b - unfilled Thermoplastics
PA12-GF30	25.4	5.1.a - filled Thermoplastics
PA12-P	44.6	5.1.b - unfilled Thermoplastics
PA66	10.4	5.1.b - unfilled Thermoplastics
PA66-GB30	0.2	5.1.a - filled Thermoplastics
PA66-GF30	13.8	5.1.a - filled Thermoplastics
PAI	0.1	5.1.b - unfilled Thermoplastics
Paper for labels	1.6	7.1 - Modified organic natural materials (e.g. leather. wood. cardboard. cotton fleece)
Passivation thick layer Zn/ZnFe/ZnNi	0.0	7.3 - Other compounds (e.g. friction linings)
PE	4490.9	5.1.b - unfilled Thermoplastics
PE (Regenerat)	4264.5	5.1.b - unfilled Thermoplastics
PE-HD	94.9	5.1.b - unfilled Thermoplastics
PESTI	0.5	5.4 - Duromers
PET	0.0	5.1.b - unfilled Thermoplastics
PET-foil for labels	0.1	5.1.b - unfilled Thermoplastics
PF	39.9	5.4 - Duromers
Polyacetal Copolymer	65.9	5.1.b - unfilled Thermoplastics
POM	680.2	5.1.b - unfilled Thermoplastics
POM-GF26	23.4	5.1.a - filled Thermoplastics

Table 16: Last continuation table of Table 14.

IMDS Material	Total Material Mass (g)	Material Category
PPA CF15	6.7	5.1.a - filled Thermoplastics
PPS (GFMD)65	0.5	5.1.a - filled Thermoplastics
PPS-GF40	6.3	5.1.a - filled Thermoplastics
RSt 34-2; S205G2T	15.9	1.1 - Steels / cast steel / sintered steel
screen-/pad-/letterpress-/flexo printing ink	0.0	6.1 - Lacquers
Sint-D39	22.6	1.1 - Steels / cast steel / sintered steel
SmCo 1/5	0.2	4.2 - Other special metals
Sn 99.99	0.0	4.2 - Other special metals
Sn96.5Ag3Cu0.5 (Soft solder A30C5)	0.2	4.2 - Other special metals
S-Sn96Ag4(Sn96.3Ag3.7)	1.0	4.2 - Other special metals
S-Sn96Ag4(Sn96.5Ag3.5)	1.0	4.2 - Other special metals
X10CrNi18-8	38.0	1.1.2 - highly alloyed
X2CrNiMo17-12-2 (Synonym: . X 2 CrNiMo 17 13 2. X 2 CrNiMo 18 10. Z 3 CND 17-12-02. Z 3 CND 18-12-03. Z 3 CND 18-12-02)	0.2	1.1.2 - highly alloyed
X46Cr13 (Synonym: . Z 44 C 14)	9.2	1.1.2 - highly alloyed
X47Cr14	0.8	1.1.2 - highly alloyed
Yellow 11000	1.8	5.5.1 - Plastics (in polymeric compounds)
Z100 (hot-dip zinc coating)	0.3	3.3 - Zinc alloys
ZA130 (hot-dip zinc-aluminium coated)	0.5	3.3 - Zinc alloys
Zinc phosphate coating	0.5	9.8 - Other fuels and auxiliary means

Raw Material Claim data.

While raw material claims exist, they do not occur in a standardised format. In whatever format they do exist they relate to part numbers supplied by a tier 1 supplier, the quantity of a material consumed, the current contract rate and the rate that has been experienced over the claim period. All useful information. They can be used as a good indicator that a material might be economically volatile. By making a claim, the tier 1 supplier is indicating a profit erosion due to variation from the contracted material pricing.

Composition Analysis.

Composition analysis is not widely used across JLR and is not known to be used in any other automotive OEM. Any use that was to be made of this analysis tool would, therefore, need to be from first principles, either as validation of other sources such as IMDS or as a means of isolating business risk. Greater detail including an example is shown in Table 31 in section 5.2.2 (pg 141).

Historical metadata alignment.

At the core of all of the cited metadata proposed to be used in the delivery of this hybrid PCE/SCE methodology is the part number. The part number delivery into the feature; the part number delivery into the engineering bill of materials structure; the materials stated to be used in the part; the materials and processes used in the part; the transaction currencies and the country of origins of the parts in Table 17 and Fig 25 samples of IMDS and detailed source, QAF data are compared to show the alignment below the part number. Establishing this data key is essential as it supports the potential that data from these different sources can be used together and in substitution of each other.

Table 17: IMDS data for HK83-20518-AA

Material	Material Mass (g)	Country of Origin	Material Category
EPDM F029	63.1	Poland	5.3 - Elastomers / elastomeric compounds
EPDM F017	59.4	Poland	5.3 - Elastomers / elastomeric compounds
EPDM F057	27.0	Poland	5.3 - Elastomers / elastomeric compounds
Clip polyamide	3.0	Poland	5.1.b - unfilled Thermoplastics
VMQ	1.2	Poland	5.3 - Elastomers / elastomeric compounds
Total reported mass (g)	**153.7**		

Between Table 17 and Fig 25 the material names are an imperfect alignment but knowing that the material mass shown in the IMDS must be less than the gross weight shown in the QAF it is possible to draw conclusions as shown in Table 18.

Table 18: IMDS, QAF alignment

IMDS Material	Material Mass (g)	QAF gross weight (g)	QAF Material
EPDM F029	63.1	174.0	Dense EPDM compound + Inj
EPDM F017	59.4		
EPDM F057	27.0		
Clip Polyamide	3.0	Purchased parts	Clip
VMQ	1.2		
Total reported mass (g)	**153.7**		

JLR Quotation Cost Detail Sheet JAGUAR LAND ROVER

Supplier Name:	[redacted]			Supplier Code:	[redacted]		
Date:		Sheet:		Eng. or Drawing Level (Previous):		New Eng. or Drawing Level (New):	
Ref. No.:		Sheets:		Part Number (Previous):		Part Number (New):	HK83 / 20518/19 / AA

1. Purchased Parts (Non-Value Added)

Directed Source Y/N?	OEM Engineering Part Number	Supplier Part Number	Description	Tier 2, 3, or 4?	Country of Origin	Exchange Rate	Actual Purchased Parts Cost (Each) From	Actual Purchased Parts Cost (Each) To	Part Quantity Per End Item	Inbound Trans Cost (Per Unit)	Tax and Duty (Per Unit)	Price (New) Per Unit	Price (Previous) Per Unit
N		P9 Profile	Flock PA					8.228	0			0.011	
N			Glue					7.740	0			0.011	
N		Mould F/G	Clip					0.014	2			0.028	
		Post coating	Freeze release					38.040	0			0.030	
			Purchase Parts Continuation Sheet..?	No	< Yes or No..?						Sub total (1)	0.080	

2. Raw Material (Value Added)

Auto Materials Y/N?	Raw Material Part Number (MATS)	Desc./Type/Grade	Country of Origin	Unit of Measure	Price per UOM	Economics - Material	Exchange Rate	Gross Usage From	Gross Usage To	Net Usage	Re-claim Revenue (Per Unit)	Tax and Duty (Per Unit)	Price (New) Per Unit	Price (Previous) Per Unit
	P9 Profile	Dense EPDM compound			2.405				0.064				0.153	
		Dense EPDM compound			2.772				0.076				0.210	
	Mould F/G	Inj			2.986				0.034				0.102	
				Raw Material Continuation Sheet..?	No	< Yes or No..?						Sub total (2)	0.465	

3. Process / Assembly (Value Added)

Op. #.	Operation Description	Heads (Direct Labour)	Actual Realized (No./Hr.) From	Actual Realized (No./Hr.) To	Dir._Labour Fully Fringed (rate/hour)	Ind._Labour Fully Fringed (rate/hour)	Dir._ Labour Fully Fringed	Ind._Labour Fully Fringed	Fixed Mfg. O/H (rate/hour)	Variable Mfg. O/H (rate/hour)	Tot._Mfg. O/H Cost	Price (New) Per Unit	Price (Previous) Per Unit
1	Extrusion P9 Profile	2.00		665	7.900	1.975	0.024	0.006	231.300		0.348	0.378	
2	Cutting P9	1.00		168	7.900	1.975	0.047	0.012	10.000		0.060	0.119	
3	Moulding F/G	1.00		39	7.900	1.975	0.203	0.051	25.000		0.641	0.895	
4	Post coating	1.00		280	7.900	1.975	0.028	0.007	35.000		0.125	0.160	
5	Control	1.00		2700	7.900	1.975	0.003	0.001	1.200		0.000	0.004	
6	Packaging	1.00		800	7.900	1.975	0.010	0.002	1.200		0.002	0.014	
	Process Costs Continuation Sheet..?	No	<Yes or No?			Totals	0.32	0.08		Sub total (3)	1.18	1.569	

Fig 25: QAF extract for HK83-20518-AA

IMDS weight of the material is, as expected, slightly less than that shown on the QAF; total EPDM included in the IMDS is just 149.5 g vs 174.0 g shown in the QAF, a 16% material loss.

As demonstrated in Table 18 it is possible to align IMDS and QAF data. It is therefore considered reasonable to assert that detailed source data from sources other than IMDS can be used to establish the materials within an NPD, including those within the vehicle at EOL. The case is also made that the additional data held within alternative sources such as manufacturing process, quantities of the process, countries of origin, the currency of transaction can be incorporated into analytical models for the NPD.

4.3. Hybrid methodology development.

The literature review indicates that while academic literature exists for individual cost estimating techniques and the application of cost estimating techniques through the timeline of an NPD, there is very little that investigates the combination of PCE and detailed sources such as SCE. Moreover, the business challenge exists to gain an early understanding of the uncertainty that exists within the PCE NPD evaluation.

Understanding the existing secondary data is considered critical to success. Fig 26 in combination with equations (4), (5) & (6) show the high-level engineering data relationships. The relationships defined by equations, (4) & (5), as noted are defined, defined within the engineering data. Equation (6) however is allocated, that is there is an amount of discretion about the sub-total costs attributed to the delivery of a feature and or an attribute. In a few cases though a USC for all of its defined parts delivers only one feature or contributes to the delivery of only one attribute. In these specific situations, all of the costs can be attributed to the feature and or attribute as there is no ambiguity.

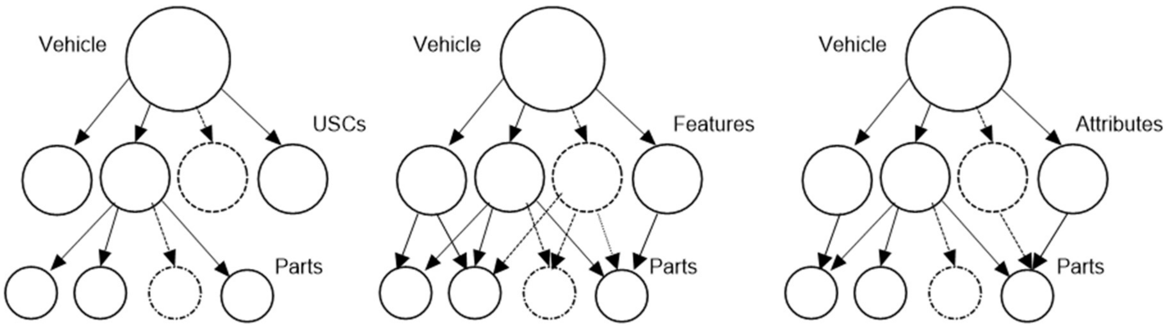


Fig 26: JLR key data relationships.

$$Vehicle = \sum_1^n USC = \sum_1^m Features = \sum_1^l Attributes - \text{\{Defined relationships\}} \quad (4)$$

$$\sum_1^n USC\ parts \neq \sum_1^m Feature\ parts \neq \sum_1^l Attribute\ parts - \text{\{Defined relationships\}} \quad (5)$$

$$\sum_1^n USC\ parts\ cost\ types \neq \sum_1^m Feature\ parts\ cost\ types \neq \sum_1^l Attribute\ parts\ cost\ types - \text{\{Allocated relationship\}} \quad (6)$$

Legend	Description
n	Max quantity of USC's
m	Max quantity of features
l	Max quantity of attributes

Because of this need to allocate cost, the hybrid methodology developed within this research needs to provide a validation of the results. This validation is provided by stressing the allocation of costs within a USC-f using a Monte-Carlo simulation.

An NPD can be a combination of existing and modified vehicle line USC's plus added new technology. It is therefore reasonable that a representative bill of materials (BOM) of the respective data will only be modified in detail rather than showing total change. It is therefore also true that any pre-existing academic studies based on a metadata source will also only be modified by detail content rather than discarded entirely. IMDS is a case in point were academic studies have already been undertaken to show the composition of the materials remaining during EOL. Two fundamental principles need to be established; the substitution of metadata from multiple detailed sources, SCE, QAF where existing academic literature was based upon IMDS; the mechanics required to extrapolate between given sets of data and the required NPD performance.

To address the extrapolation mechanics, Fig 27 shows the next nearest below (NNB), next nearest above (NNA) and required data points associated with a USC-f CER. The proposed method will take the NNB and NNA USC-f Part BoMs and establish an allocation ratio by the contribution of the individual parts contribution to the USC-f using the individual part details sourced from detailed source data; SCE, QAF or IMDS. The result will be a quantification of the probable raw materials that will be involved in the NPD to deliver the USC-f requirements. The analytical approach will also deliver the detail of the raw material.

The resulting new NPD data will then use a composition analysis in combination with commodity volatility index and NPD volume data to establish a Pareto analysis of the volatile commodities to identify high impact commodity content that should be reviewed for mitigation activity.

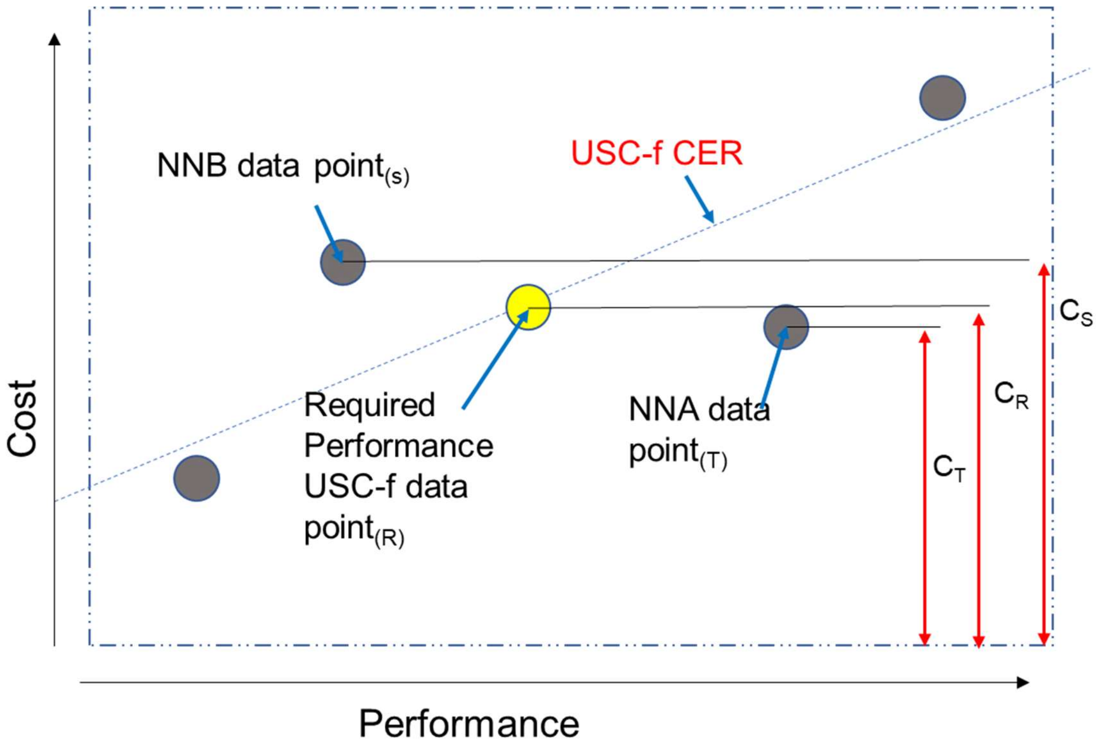


Fig 27: Apportionment of cost from near USC-f source data points.

The 'lower' NNB USC-f source data point is referenced as 'S', the 'higher' NNA is referenced as 'T', the required data point given by the required performance against the CER is referenced 'R'. Lower and higher is referring to the required performance relative to the required data point. Using Fig 27, the required ratios to be applied as a factor to data drawn from the lower source data point S relative to the required is:

$$C_R/C_S \quad (7)$$

When applied to the higher source data point T the required ratio is given by:

$$C_R/C_T \quad (8)$$

Equations (7) and (8) established the potential scaling from both known data points to model the required data point. It is also necessary to establish the influence that should be attributed to each data point; this is also possible using simple ratios. Fig 28 shows a simple method of proportioning the influence of each CER data point on the required performance point.

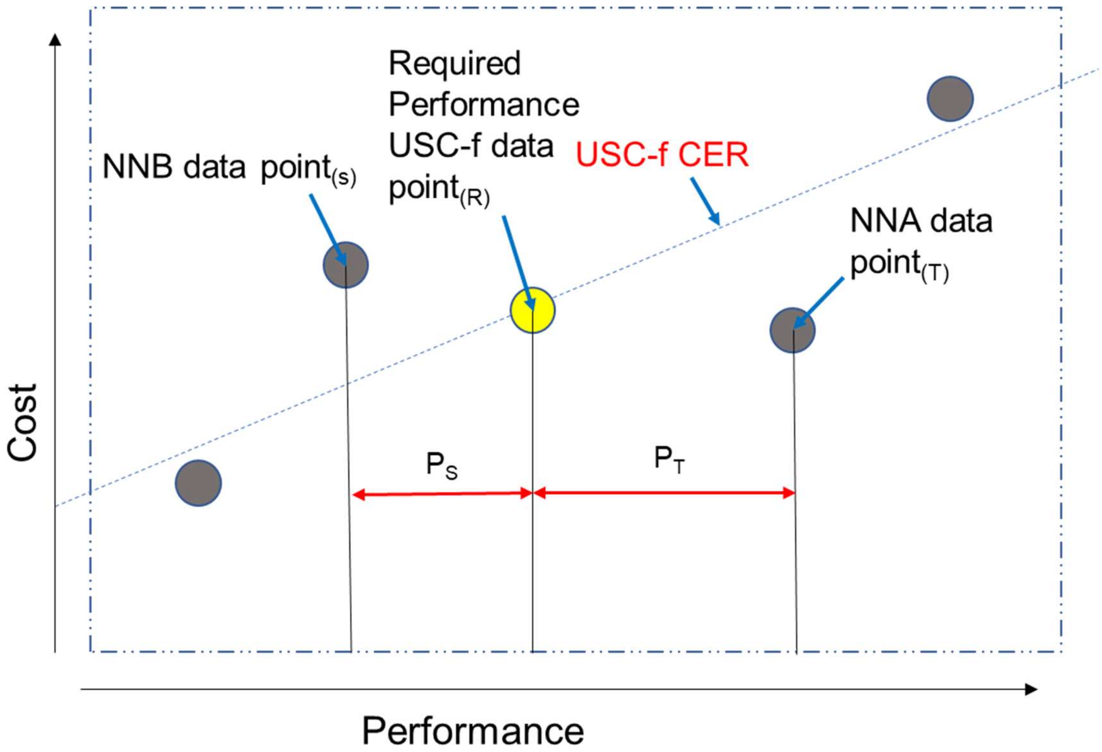


Fig 28: Proportionate influence by CER data points.

$$P_T/(P_S+P_T) \quad (9)$$

$$P_S/(P_S+P_T) \quad (10)$$

Unusually the influence applied by data point$_{(S)}$ is given by equation (9) while the influence applied by data point$_{(T)}$ is provided by equation (10). The equations correspond to the principle that the closer given data point used to create the CER should have a more significant influence. Table 19 is showing the influence of the relative position of known data points on the outcome of the required data point using equations ((9) and (10).

Table 19: Influence of known data points upon required point simulations

Relative position		Influence		Observation
P_S	P_T	P_S	P_T	
1	1	50%	50%	
2	1	33%	67%	Required is between P_S and P_T.
3	1	25%	75%	Required is outside of P_T
1	3	75%	25%	Required is outside of P_S

.

The research method stresses the validity of the findings by applying Monte Carlo analysis to the variables derived through the allocation of cost to a feature delivery, FAST.

Carry-over and modified technology can be assessed using the outlined Hybrid methodology but where new technology is required a should cost estimate from first principles is required to supply the various cost type detail such as materials and processes. The starting position for an SCE is to gain an understanding to the question, “if I wanted a quantity of these what will I need to do and with what.”? Very few things are genuinely new, sources of suitable technology delivery can be found either in; Other cross-over industry technology transfer; or Patent Analysis. Research presented in this thesis is centred around providing clarity to uncertainty through the identification of business risk the inclusion of an SCE supporting new technology introduction has to give rise to a new class of business risk - delivery readiness. Known as Technology Readiness Levels (TRL) and Manufacturing Readiness Levels (MRL) these risks assess the readiness of the new technology to deliver volume product at the point of NPD volume production.

The substitution of metadata from multiple detailed sources, SCE QAF where existing academic literature was based upon IMDS is answered thus. The reasonableness of metadata substitution is that a physical part included in a BoM can only be that physical part irrespective of it being recorded within an IMDS database or a QAF source, SCE source. Each source may bring something extra to the knowledge about the part and as a combined total will provide an enhanced view of the part. Physical data comparison is offered to validate this claim in Table 18 (pg 71).

The following section will detail each step and technique to allow the hybrid methodology to be replicated.

4.3.1. Proposed hybrid methodology in detail.

The research method that has been undertaken has been driven by the available data or secondary data that has been introduced in section 4.2.4. Principally these sources were identified by looking across the JLR business for data sources that would bridge between PCE as a starting point and a detailed vehicle bill of materials of a vehicle coming off the production line or going into the end of life. Data keys were determined using common data such as part numbers.

To understand the application of the proposed hybrid method a level of understanding of PCE and the application within JLR needs to be considered, the method itself could be applied to any known cost driver relationship. In JLR's case, the cost driver relationship is the USC-f delivery through the contribution of the sum of parts.

Each feature can be represented as a series of historical cost data providing varying performance within a total vehicle cost and within a substructure of USC's. Each data source point that results can be used to create and define the regression line. Each data source point is itself the sum of parts, known parts with a known accumulated raw material and processing cost definition.

Within the automotive sector, there is only one known application of PCE, and that is within Jaguar Land Rover as a proof of concept. It was noted that the data being used as input to the PCE CER development were mini-bills of materials (mBoM), accumulations of data from more granular data sources. The lowest level of the data source was SCE level data that had been partially normalised but also allocated to individual features that the tier 1 parts supported. The allocations of cost to an individual feature were then accumulated within a single Unique System Code (USC) to create a USC-f data point and CER within the PCE application. These observations of the existing data gathering and application within JLRs PCE show a retained clear linkage between PCE and detailed source data such as SCE.

Fig 29 shows a 'V' diagram of the critical data relationships. Vehicle features can be mapped to engineering systems and parts. Parts can be cross-mapped to detailed source data and that within detailed source data is a sub-structure of 5 cost types within a tier 1 part; Bought parts (tier 2 and below); Material; Manufacturing Process; General Overheads; Other plus Manufacturing Origin and Currency.

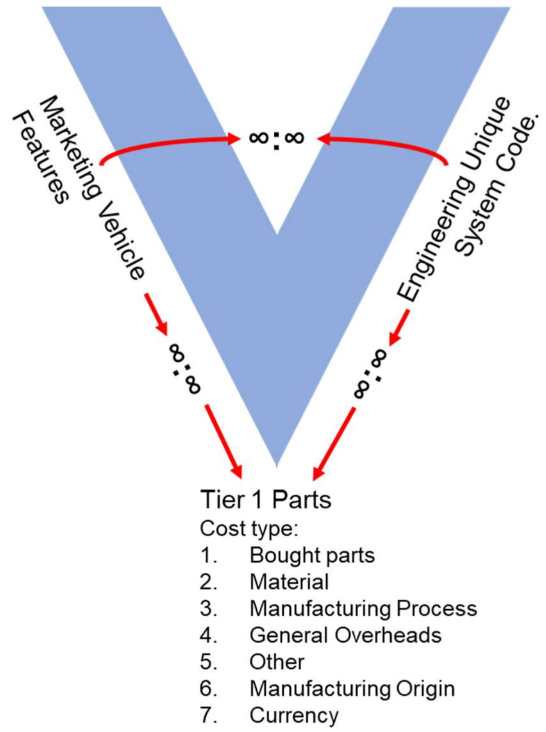


Fig 29: High-level illustration of existing data relationships.

4.3.2. Applying PCE.

The basic model applied to PCE is a simple regression analysis historically using weight as the independent cost driver.

In the automotive application of PCE, the independent cost driver has been determined to be a feature and its impact upon corporate product USC structures cost. In physical terms, this will translate to the terms in which the Marketing teams talk about a product offering and the structural impact as seen by Engineering and the Business.

Because an individual feature can involve many USC's and implicate several parts and sub-attributes of an individual part a method is required to analyse the way in which the cost can be allocated between features. The method proposed to analyse the breakdown of cost and attributed to each feature through the sum of parts within each USC is through the application of the underlying method of cost allocation, FAST, used within VA and introduced in section 2.4 (pg 25).

$$Total\ USC\ Cost = \sum_{1}^{n} USC\ PartCost \tag{11}$$

Equation (11) makes a simple mathematical statement that the total cost of a USC must be the equal of the cost sum of its parts.

$$Total\ USC\ Cost = \sum_{1}^{m} Delivered\ Feature\ Cost \qquad (12)$$

Equation (12) makes a simple mathematical statement that the total cost of a USC must be the equal of the sum of the allocated cost of its feature. This is not the same as the sum of the cost of its feature some aspects of which might be delivered by parts within other USCs.

The FAST based method is used to complete the allocation of cost to feature, and its results are achieved through considered assessment, this will typically involve a review of the cost structure of each part against the delivered features of the USC. The cost structure can be extracted through analysis of the SCE and or QAF. The allocation is typically taken in the order of feature contribution to a low trim variant vehicle, shown as basic in Fig 30, progressing to a high order feature deliverable, shown as +5 in Fig 30. For example, in the case of a seat assembly cost might first be allocated to the delivery of a basic seat without electrics then progressively the finish (fabric or leather), followed by the electrics.

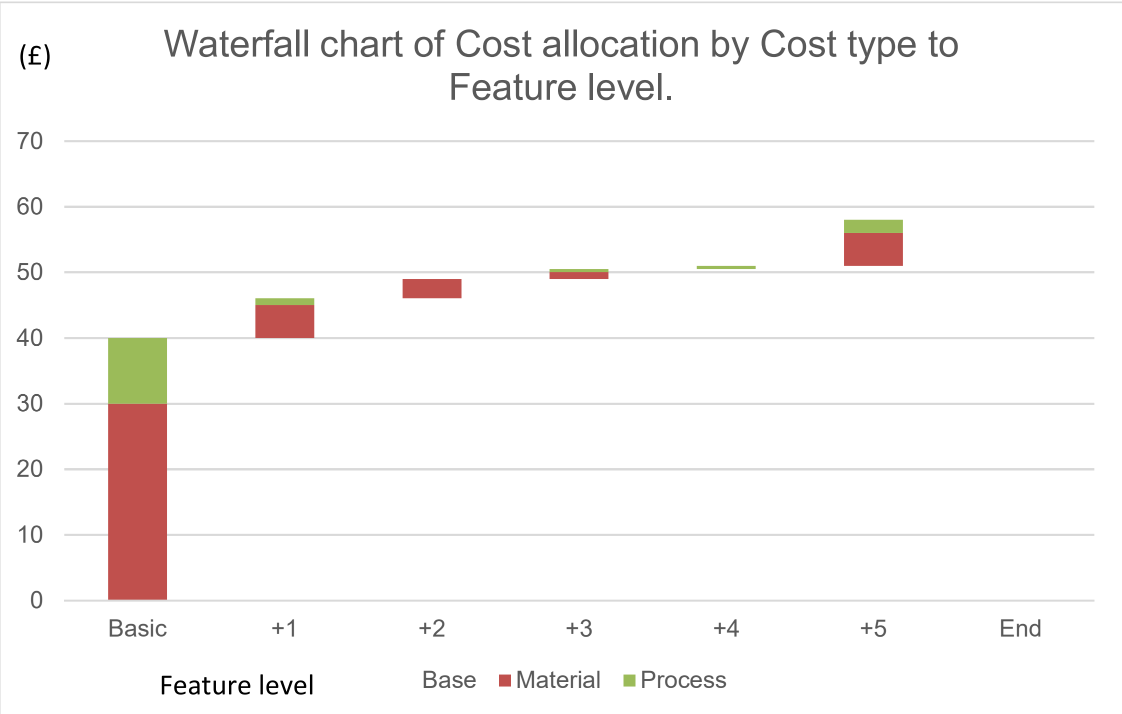


Fig 30: Chart showing USC Part cost summation and subsequent apportionment to Feature level.

As shown in the classical waterfall chart, Fig 30 is showing only the incremental change in cost between the USC-f performance or feature levels. While this is good for seeing the change and nature of the change the total cost by feature level will be required to establish the CERs.

The left-hand side of Fig 31 shows the original PCE data flow that was being used to deliver the JLR POC for PCE. The right-hand side of Fig 31 shows how this was revised to incorporate the cost type data requirements as described in the research method.

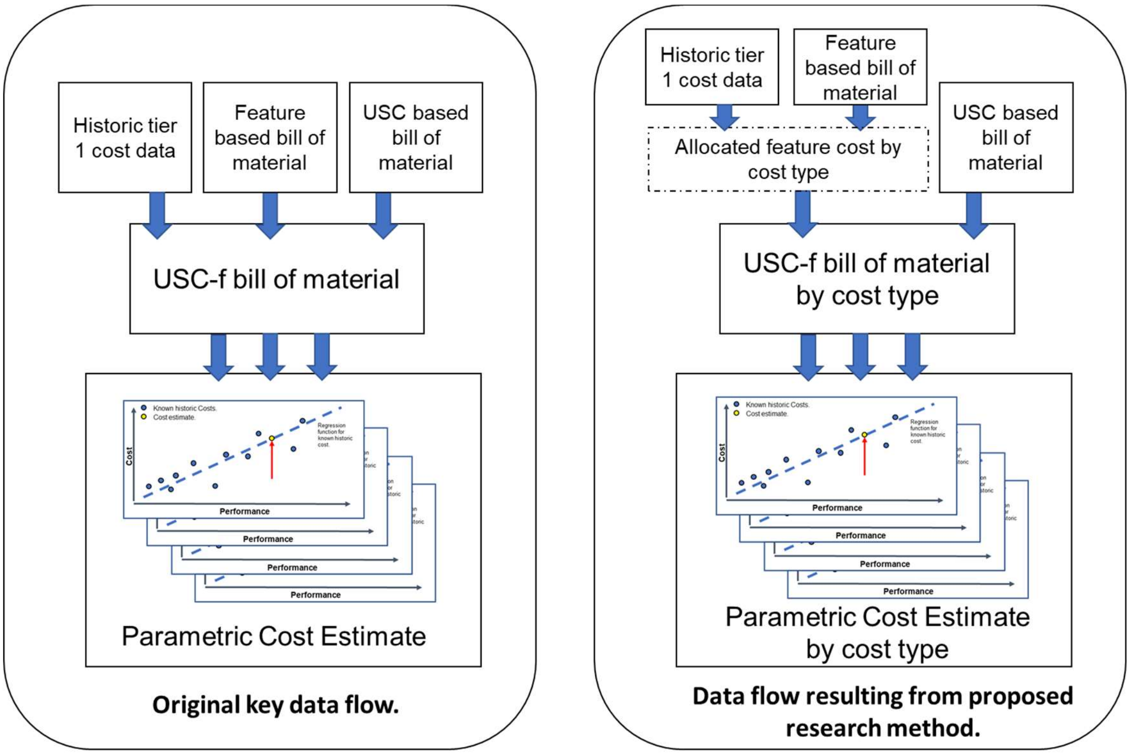


Fig 31: Visualisation of data flows discussed and resulting from the research method.

The research has established that there can be two ways of applying the hybrid methodology; an application to simple structures; an application to more complex structures. It is the application to complex structures that are most appropriate to an automotive application. Both will be described.

In applying the hybrid methodology applied to a simple structure an imaginary part or assembly is envisaged. A CER derived from each material cost type and each process cost type. Fig 32 shows the same data as shown in Fig 30 now broken down into three material cost types, two process cost types and the total cost equivalent that would be used in classic PCE.

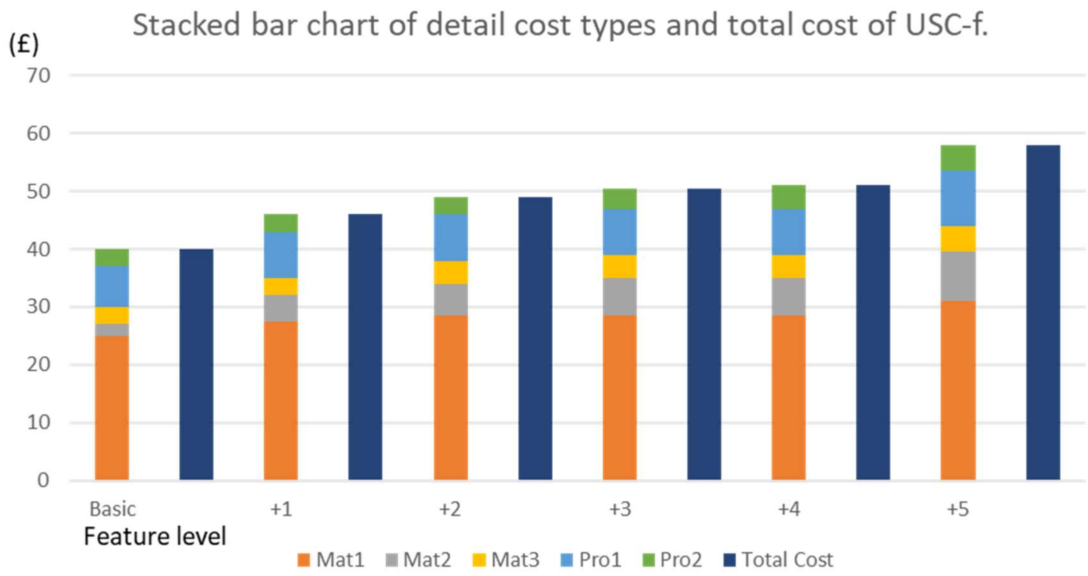


Fig 32: Bar chart detailing cost types and total cost of USC-f.

Fig 33 shows the data used to create the bar chart diagram shown in Fig 32 plotted as a scattergram with linear trendlines known as CERs in PCE. Presented in this way the difference between the use of material and process types can be seen. In this illustration, simple linear CERs have been used other forms and equation forms may be more appropriate in individual applications; exponential, linear, logarithmic, polynomial, power, and moving average can be automatically provided by software such as Microsoft Excel. The most appropriate to be used can be determined by considering the resulting value of R^2 (correlation.). R^2 can range -1 to 1; the closer R^2 is to 1 the better the CER fit to the source data.

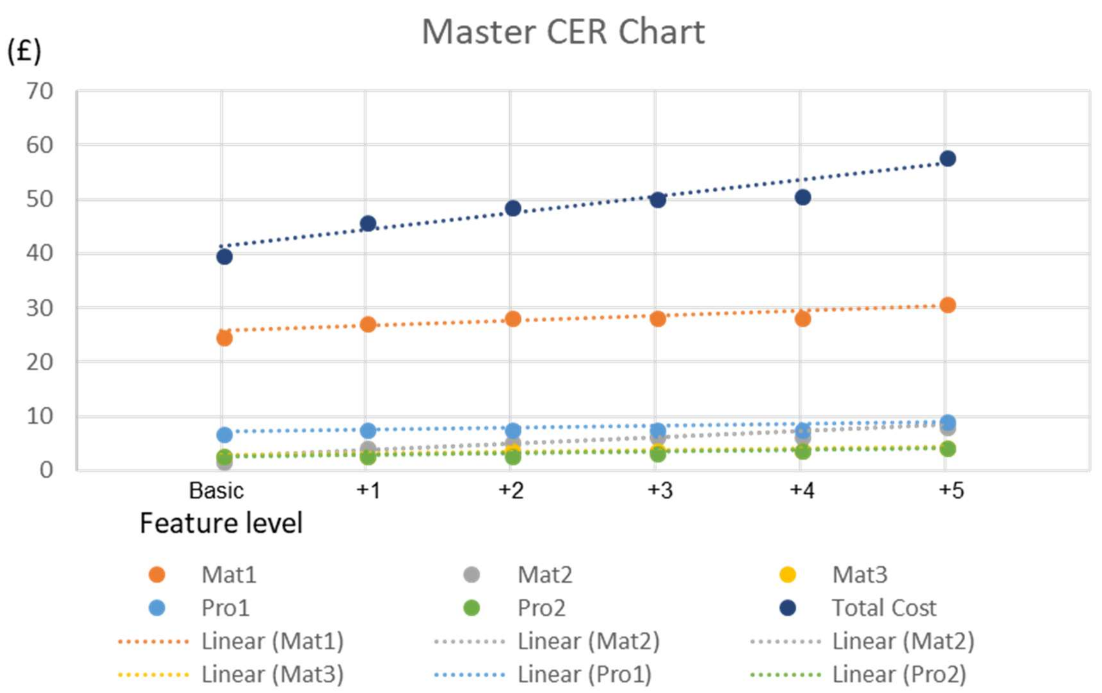


Fig 33: Master CER Chart showing the difference between cost types.

Table 20 shows the CERs and R^2 values associated with Fig 33.

Table 20: CERs and R^2 associated with Fig 32.

CER	***Equation***	***R^2***	
Mat_1	*y =0.9429x + 24.867*	*0.826*	*(13)*
Mat_2	*y = 101286x + 1.6333*	*0.9207*	*(14)*
Mat_3	*y = 0.3x + 2.7*	*0.84*	*(15)*
Pro_1	*y = 0.3571x + 6.8333*	*0.6957*	*(16)*
Pro_2	*y =0.3143x + 2.4*	*0.8643*	*(17)*
Total Cost	*y = 3.0429x + 38.4433*	*0.9144*	*(18)*

With a CER for each material and each process, the requirements to satisfy the required USC-f is given by the CER trendline equation itself, and there is no need to apply apportionment to the NNB and NNA data points. The only potential known error in the result will be derived from the allocation of cost types to the delivery of the feature itself which is stressed by the application of Monte-Carlo simulation.

The possibility, however, to complete a CER for each material and each process can only apply to small and simple parts and assembles, hardly the generic description of an automobile. To evaluate a complicated part, assembly or a group of parts within an engineering structure such as a USC-f the hybrid methodology is applied to using CERs that represent the whole of the material and the whole of the other cost types.

Fig 34 provides a bar chart view of the cost type data by cost type. A key point is that the sum of the cost types for each performance data set must sum to the total cost.

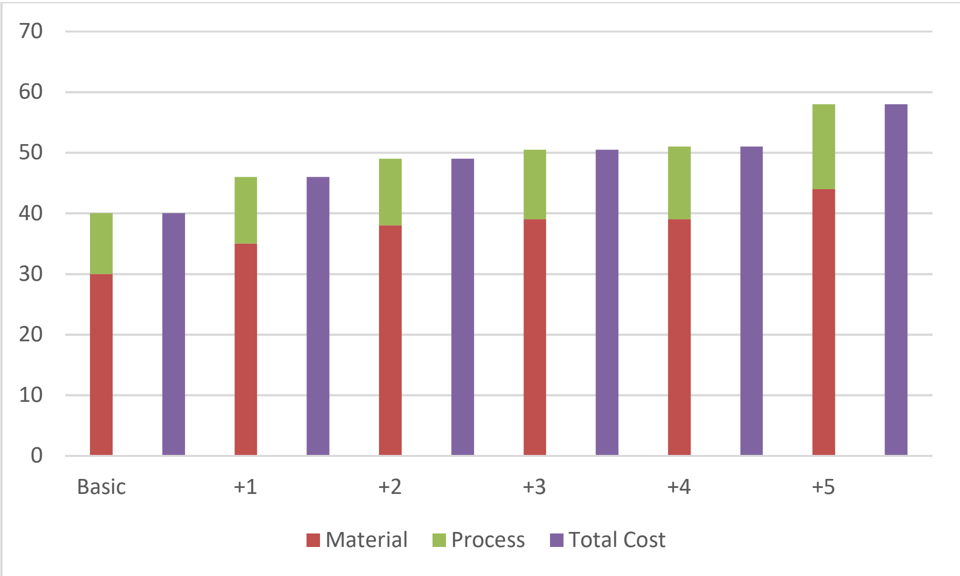


Fig 34: Bar chart detailing cost types and total cost of a complex USC-f

Fig 35 shows the Master CER Chart it depicts the difference between cost types applied to a complex USC-f.

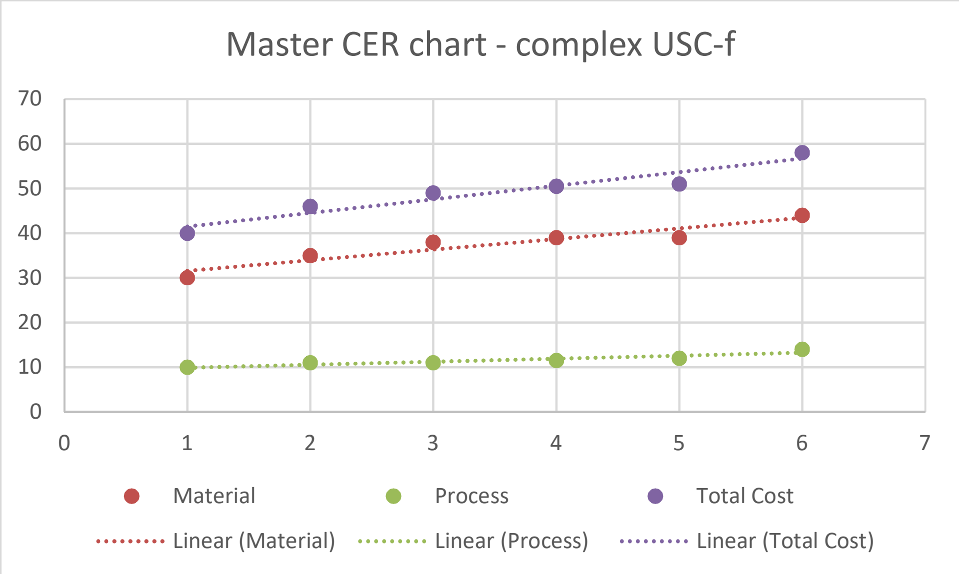


Fig 35: Master CER Chart showing the difference between cost types applied to a complex USC-f

Table 21 records the CER equation for each cost type associated with Fig 35 together with the R^2.

Table 21: CERs and R^2 associated with Fig 35, complex USC-f

CER	***Equation***	***R^2***	
Material	*y =2.3714x + 29.2*	*0.8988*	*(19)*
Process	*y = 0.6714x + 9.2333*	*0.8568*	*(20)*
Total Cost	*y =3.0429x + 38.433*	*0.9144*	*(21)*

Having utilised a cost types CER the detail data behind the NNB and NNA data points are apportioned. Simple apportioning methods are given in equations (7), (8), (9) & (10).

With PCE and detailed source data re-associated together to provide the input data into the proposed method for 'carry-over' and 'modified' technology, a method was still required to establish the materials, manufacturing process details and other interesting data associated with the delivery of new technology. It was observed that within JLR there is a parallel process to the delivery of an NPD. This parallel process delivers research on new technology through to a readiness state for mainstream NPDs to incorporate. Typically, these new technology research projects culminate with a financial evaluation which includes a materials and process cost estimate. If the data contained is sufficiently detailed and of adequate quality, it should form the input data into the proposed method resulting from this research.

> There can be situations where the planned introduction of new technology is because of a reaction to market forces rather than a planned progression. Under these circumstances, it is still possible to establish the new technologies possible materials and manufacturing process structure using the Patent analysis; TRL & MRL techniques that were reviewed in section 2.4.

The research progressed to establish how the tier 1 detail data that might support the successful validation of the hypothesis can be tracked through the allocation to feature methodology and ultimately out through the PCE CER itself.

Fig 36 shows the high-level data flow for the proposed method being presented within this thesis. The start point, at parametric cost estimate, is the output stage of the

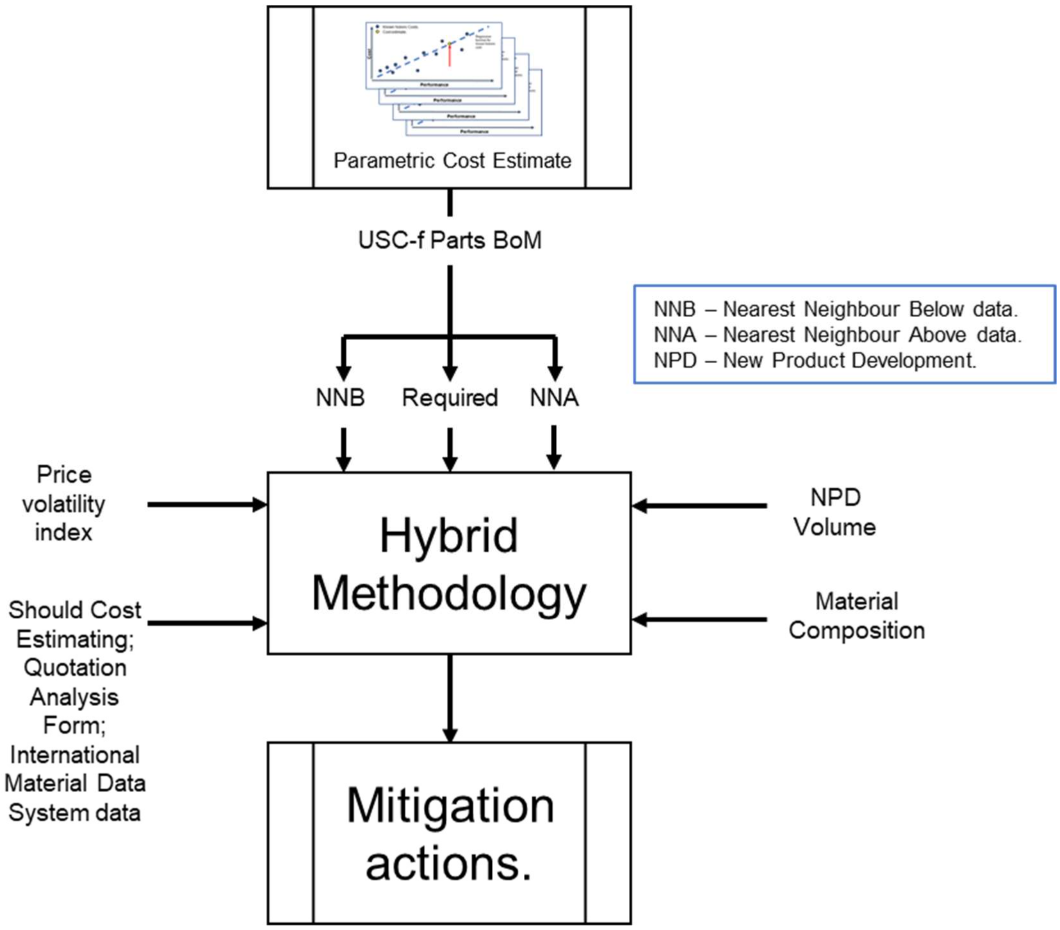


Fig 36: Data flows of the proposed method.

modified process shown in Fig 31 (pg 81). Key to this method is that the cost driver data is correctly captured within the PCE CER data points and an appropriate volatility index is adopted for the cost driver. SCE and or QAF data sources to provide the detail along with NPD volume data should remain constant across all cost drivers' analysis. The potential mitigation actions are considered in more detail in section 4.4 (pg 89).

The following section will explore the proposed method and required data flow to allow the uncertainty of volatile raw materials and other metadata feeds to be better understood and mitigation actions established to reduce the business exposure.

The USC-f parts BoM is the assigned parts within the PCE CER data points. The 'required' represents the virtual BoM of the performance outcome as indicated by the required performance against the CER. The 'nearest neighbour below Data' (NNB) and 'nearest neighbour above Data' (NNA) represent the source data BoMs of the CER data points either side of the 'required' data point against the performance axis.

Considering Fig 27 (pg 75), the USC-f CER for each cost type is known. The point on the CER that corresponds to the required performance is also known and determines the source data point for the NNB and NNA. If, as is the case for the central working premise, the technology delivering the adjusted or carry-over feature performance is itself carry-over then the amount of material, process, currency, can be apportioned according to a simple apportionment as described by equations (7), (8), (9) & (10). In the case of new technology being introduced to deliver the required feature performance, a provisional SCE with an existing definition of materials and processes will exist or can be constructed to provide the required metadata. Once the Adjusted metadata for the NPD has been identified covering all feature requirements, it can be accumulated and feed into the mitigating actions, as described in section 4.4 (pg 89), for appropriate treatment during the design phase of the NPD.

4.3.3. Why introduce composition analysis on top of tier 1 material analysis?

At this stage of the methodology development, it was observed that within the NPD material aspect of the hypothesis alone there was potentially more 'bits' of data that might be useful in establishing a practical answer. The resulting data that represented the near performance data points of the CER is still too high to understand the material at the commodity exposure. The data contained in the SCE & QAF sources did not in themselves deconstruct the materials into the recognised traded commodities where the economic volatility could be examined. A method would need to be established that allowed the SCE or QAF declared materials to be analysed at the commodity level. Although not heavily exploited within JLR there had been some use of an internally devised method called ‘composition analysis’. The application of this method would allow the normalisation of the required NPD material data to be accumulated into annual budgeted quantities of planned usage.

4.3.4. The result required stress testing.

The JLR SMEs highlighted that there would be a need to establish that the output from this method was of appropriate quality to ensure confidence in the redirection of resources toward mitigations at this early concept phase. The variables within the data were identified and stressed using Monte-Carlo analysis. A small, resulting deviation is indicating that the output is of sufficiently high quality to allow progression to the application of migration resources.

Assumptions have been made in the delivery of the hybrid methodology; technology; sourcing remains a constant. However, even if these assumptions are not meet the delivery is still catered for because the delivery mechanism moves from trended using a PCE based delivery to delivery based on SCE as described for new technology. Most of the hybrid mythology is based on factual evidence, being trended from known facts. Other aspects are judgemental such as the allocation of cost and cost type to the delivery of a specific feature. A Monte-Carlo analysis was applied to the allocations to confirm the reasonableness of the results obtained. What reasonableness might look like is very subjective and is very much dependent upon the way in which the specific business risk is impacted. The reasonableness is assessed post the composition analysis and pareto analysis having assessed the implication post the allocation of planned usage. Even a 50% variation of something that is itself a very low business risk is still a very low business risk.

Having a greater understanding of the planned usage allows the business risk to be better understood. Both cost and the rate of change of cost were sourced and cross-matched to the usage. A simple Pareto analysis was then applied to establish the business risk commodities that should receive attention due to real economic pressures.

The hypothesis challenge remains to enable an assessment at the concept phase of an NPD of the degree to which the NPD is likely to meet the requirements of recyclability at the end-of-life. With the NPD volume production materials identified the end-of-life comparison to legislation became possible.

4.4. Business risk causal loops (Mitigation actions)

To build the hybrid methodology a high-level view of the metadata that is required. This high-level overview establishes the data required at the output and how the output data might be employed to achieve NPD mitigation.

NPDs are typically evaluated under ‘frozen’ economic conditions; that is that the economic business risks have been levelled out by using a data substitution while the business case is established. The act of substitution, freezing the economic conditions is reasonable, but the business risks still exist and should not be ignored during the early NPD to become a surprise during the final delivery stages of the NPD.

The following causal loop diagrams for; Material Price; Material Volatility; Manufacturing Processes; Preference Markets; Importation Duty; Recyclability and Currency show how the early identification of concept phase uncertainty through the associated metadata can turn uncertainty into business risks with dimensions allowing them to be balanced within any NPD optimisation and mitigated as required.

4.4.1. Absolute Material Price impacts.

The included use of high price material will always damage the final value for money and profitability of an NPD. The objective of treating them as a business risk during the NPD concept phase will allow them to be recognised and avoided by better design. The methodology proposed by this research is designed to bring the identification of the proposed material usage both by type and by quantity earlier in the NPD life cycle; at the concept phase.

Fig 37 shows a high-level causal loop diagram (CLD) showing the relationships between high price materials and their mitigation actions.

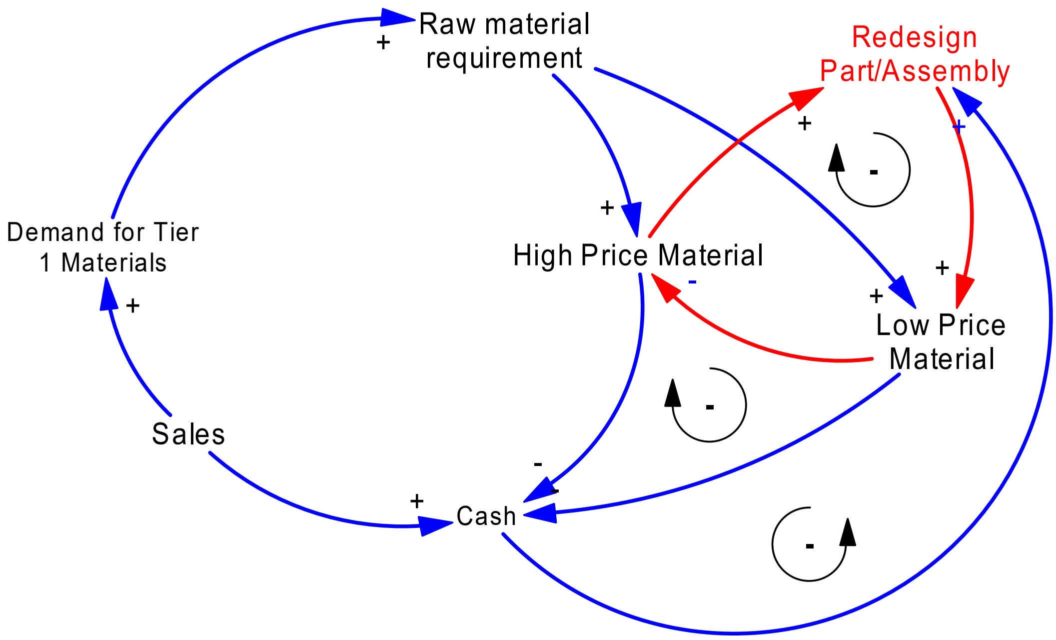


Fig 37: Causal Loop Diagram: Material price impact

For this description, there will be a focus upon the potential concept phase mitigation activity. That sales drive demand for tier 1 materials, and hence raw materials are taken as a given and not subjected to research within this thesis.

Mitigation loop 1.

> Loop #1 of length 2; Redesign Part/Assembly, Low Price Material, & High Price Material.

The NPD Concept derived metadata allows for high priced materials to be identified, scheduled for redesign of the part/assembly with an objective of retaining the feature delivery using low price material.

Mitigation loop 2.

> Loop #2 of length 2; Redesign Part/Assembly, Low Price Material, Cash.

Loop 2 is an enabling loop. The mitigating activity to deliver greater adoption of low-priced materials requires funding, and this is delivered from cash. As cash becomes available, it is possible to undertake redesign activity.

Mitigation loop 3.

> Loop #3 of length 3; Redesign Part/Assembly, Low Price Material, High Price Material' & Cash

Loop 3 is an extension of mitigation loop 1, in loop 3 instead of the loop being closed with reducing link between low price materials and high price materials the loop joins high and low price materials through cash. Both high and low-price materials will have a negative effect upon cash but adopting low price materials will reduce the rate of a cash drain.

High material prices can be tolerated and priced for, too much high price material will overburden the NPDs ability to recover costs when the marketplace is restricting the retail price that can be achieved. Just because within the design and material make-up of the NPD there is gold, a relatively high-cost material, consideration needs to be given to the total usage of gold. The cost of the material needs to be weighted by the total usage and reviewed within a ranking structure such as a Pareto analysis to target the materials that are delivering the highest business risk.

With the business risk level due to material prices established high-risk materials need to be traced back to their USC-f as targets for the potential redesign to design out the high price material for suitable lower cost alternatives.

A stock and flow diagram is shown in Fig 38 for the material price migration. The 'High Price Materials' having been identified are reviewed for redesign actions, the objective being to convert them as far as possible to 'Low Price Materials'.

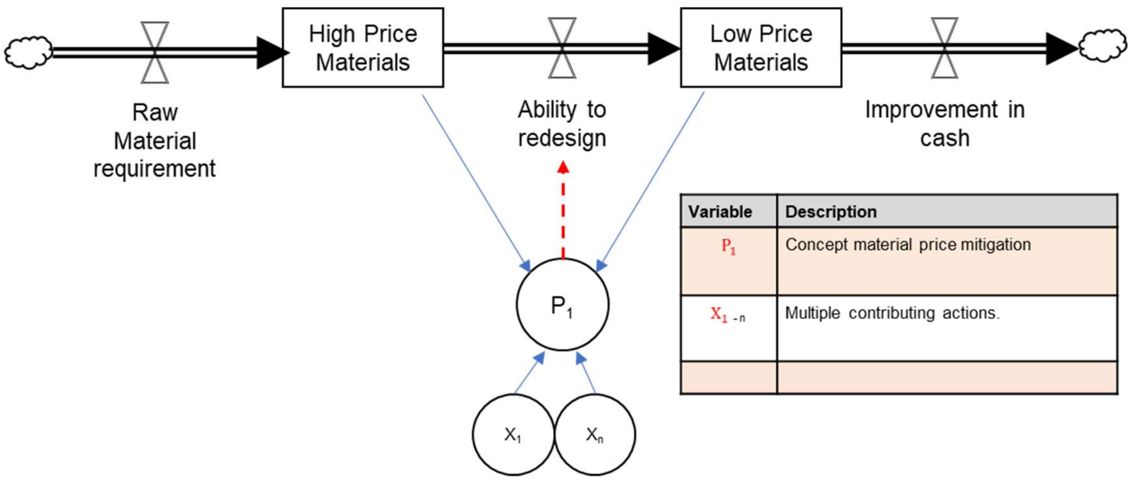


Fig 38: Stock and flow diagram: Material price impact.

4.4.2. Material Price Volatility.

Business risks exist wherever there is an instability; something that cannot be reliably predicted. When material costs form a significant part of the overall costs within a business, volatility within them becomes a business risk. Economic volatility is price movement over a period of time, for discussion purposes, this might be ±5% during a single year and not exceeding ±10% during the same year or versus an established NPD baseline for the material. As with the material prices discussed in section 4.4.1, the overall contribution of business risk needs to be established using a suitable weighting tool such as a Pareto analysis.

The high-level CLD for material price volatility is presented as Fig 39.

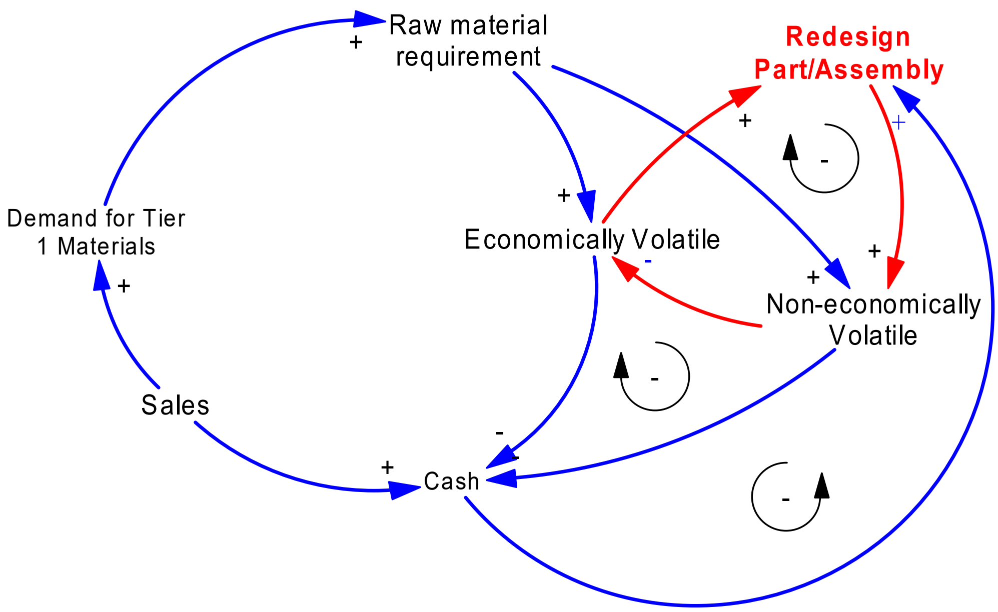


Fig 39: Causal Loop diagram: Material price volatility.

Again, and as with Material Prices, 4.4.1, the description will focus upon the mitigating action.

Mitigation loop 4.

> Loop #4 of length 2; Redesign Part/Assembly, Non-economically Volatile, Economically Volatile.

The NPD Concept derived metadata allows for economically volatile materials to be identified, scheduled for redesign of the part/assembly with an objective of retaining the feature delivery using the non-economically volatile material.

Mitigation loop 5.

> Loop # 5 of length 2; Redesign Part/Assembly, Non-economically Volatile, & Cash.

As with loop 2 in 4.4.1 loop 5 is an enabling loop. The mitigating activity to deliver greater adoption of non-economically volatile materials requires funding, and this is delivered from cash. As cash becomes available, it is possible to undertake redesign activity.

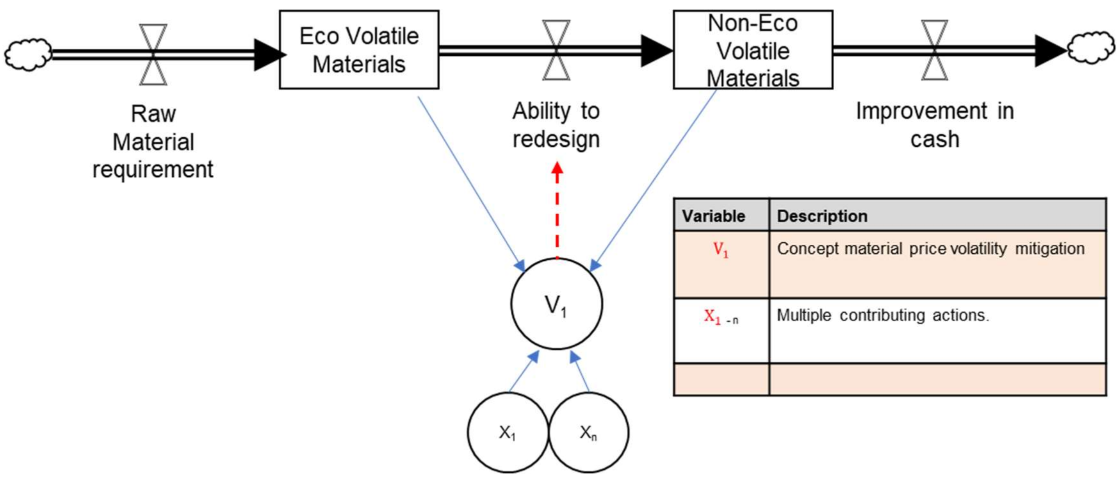
Mitigation loop 6.

> Loop #6 of length 3; Redesign Part/Assembly, Non-economically Volatile, Economically Volatile, & Cash.

Loop 6 describes the achievement of greater cash stability enabled through a redesign to use non-volatile or reduced economically volatility materials within the NPD to be delivered.

Once the materials that are likely to derive volatility to the business risk have been established and traced back to their usage within the USC-f structure they can be mitigated through redesign or if necessary mitigated using financial tools such as hedging.

The stock and flow diagram shown in Fig 40 shows the material price volatility migration.



Variable	Description
V_1	Concept material price volatility mitigation
X_{1-n}	Multiple contributing actions.

Fig 40: Stock and flow diagram: Material price volatility.

The ‘Eco Volatile Materials’ having been identified are reviewed for redesign actions, the objective being to convert them as far as possible to ‘Non-Eco Volatile Materials’.

4.4.3. Manufacturing Process.

The demand for manufacturing processes as driven by an NPD may appear to be trivial, but within JLR the creation of single sources due to the limited global capacity or capability has been internally identified. Examples: Fuel tanks designed as a single piece saddle-tank requiring large capacity injection moulding capability; beams that required hydraulic bending capacity only available in Canada; total press shop capacity that exceeded global availability when combined with the concurrent requirements of other OEMs. The creation of an understanding of the potential manufacturing process demand as defined by the sum of metadata during the NPD concept phase will allow early recognition and the opportunity to redesign or resource.

Fig 41 presents the CLD for manufacturing process.

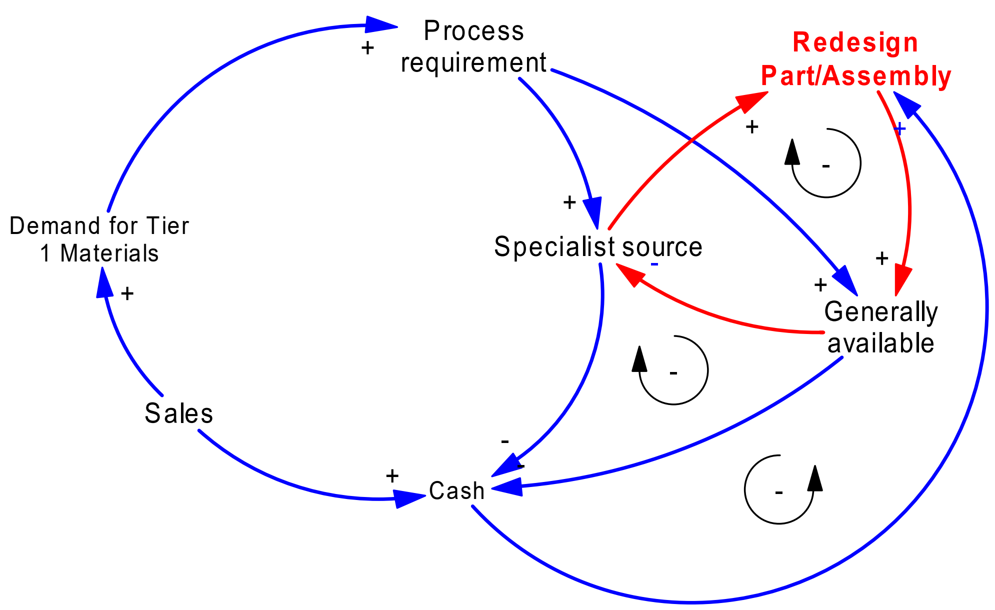


Fig 41: Causal Loop diagram: Manufacturing process

Mitigation loop 7.

Loop #7 of length 2; Redesign Part/Assembly, Generally available, & Specialist source.

The objective with loop 7 is to move processes from single sources to generally available sources, increasing the tier 1 competition and reducing the cost.

Mitigation loop 8.

> Loop #8 of length 2; Redesign Part/Assembly, Generally available, & Cash.

In common with loops 2 & 5 associated with another causal loop diagrams (CLDs) loop 8 is an enabling loop. Cash is required to fund the redesign that will enable the utilisation of generally available sources.

Mitigation loop 9.

> Loop #9 of length 3; Redesign Part/Assembly, Generally available Specialist source, & Cash.

Loop 9 shows the effect upon cash through the adoption of actions driven by loop 7. As the dependency on specialist sources gives way to the use of generally available sources the rate at which cash will be spent reduces.

Where does the manufacturing process data originate from? Reflecting the analytical method already applied during the material analysis during the allocation of cost to a feature delivered within a USC the manufacturing process cost was also allocated to the delivery of the feature. This additional dataset was applied using an additional set of PCE CERs that established the amount of manufacturing process that would be required to deliver the required feature performance. Using the original detailed source data which included the definition of the processing and the capacity of the specific machine tool facility it was found to be possible to access the NPD volume production requirements.

Fig 42 shows the simple stock and flow diagram associated with manufacturing processes. Where a 'specialist source' is identified a redesign action is required, that will move the design to a lower level 'generally available' source.

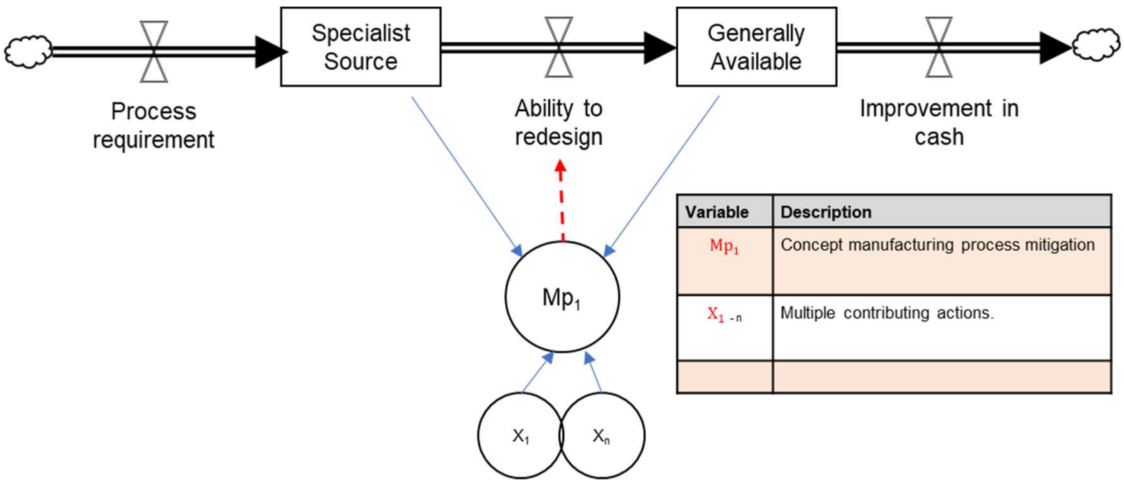


Fig 42: Stock and flow diagram: Manufacturing process.

4.4.4. Preference Markets.

Preference markets and their impact are rarely considered during the classical evaluation of an NPD and may not be widely known across an OEMs operation; this is undoubtedly the experience within an OEM such as JLR. Subject to the volumes of product planned to be sold in a specific market ignoring them when making design and sourcing decisions could force the abandonment of a specific market if preference conditions are not achieved.

> A preference market is one where the NPD sales market will provide a reduced importation duty on the product under specific conditions. The conditions will typically be met if the incurred cost of the NPD production originates from specific international origins and is more than 60% of the invoiceable value of the NPD.

The preference market to mitigations can also be represented as a CLD and is presented in Fig 43. Within this CLD there are possibilities to affect the outcome through more than one mitigation route, hence it appears to be more complex than is actually the case. If appropriate the solution might take on actions from all mitigation routes.

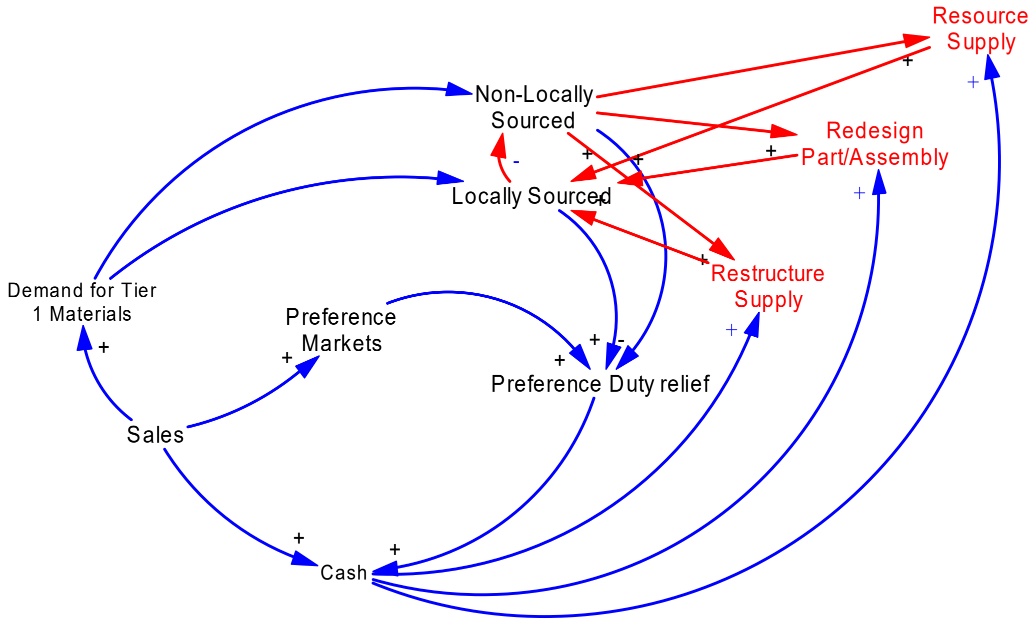


Fig 43: Causal Loop diagram: Preference markets.

Mitigation loop 10.

> Loop #10 of length 2; Resource Supply, Locally Sourced, & Non-Locally Sourced.

The demand for tier 1 materials has created two material demand sub-sets; Non-locally sourced; Locally sourced. Achieving preference market conditions requires a minimum level of locally sourced materials and other costs incurred pre-landing the product at the port of entry to the preference market. Mitigation loop 10 seeks to reduce the non-locally sourced material sub-set and increase the locally sourced through resourcing actions.

Mitigation loop 11.

> Loop #11 of length 3; Resource Supply, Locally Sourced, Preference Duty relief, & Cash.

Within mitigation loop 11 is a reality statement, rebalance might be achieved through a resourcing action to locally sourced achieving preference relief and a cash credit, but there is a need for cash in the first place to be able to fund the resourcing action.

Mitigation loop 12.

> Loop #12 of length 4; Resource Supply, Locally Sourced, Non-Locally Sourced, Preference Duty relief, & Cash.

Mitigation loop 12 is a reflection that as the rebalancing takes place the increasing locally sourced value will be matched in part terms if not in monetary terms by a reduction in the non-locally sourced. Effectively 'doubling' the effect.

Mitigation loop 13.

> Loop #13 of length 2; Redesign Part/Assembly, Locally Sourced, & Non-Locally Sourced.

Mitigation loop 13 follows loop 10 but uses a redesign mitigation to adjust the relative balance of the non-locally sourced and local sourced sub-sets of material demand.

Mitigation loop 14.

> Loop #14 of length 3; Redesign Part/Assembly, Locally Sourced, Preference Duty relief, & Cash.

Mitigation loop 14 reflects loop 11 with redesign as the mitigation rather than resourcing.

Mitigation loop 15.

> Loop #15 of length 4; Redesign Part/Assembly, Locally Sourced, Non-Locally Sourced, Preference Duty relief, & Cash.

Mitigation loop 15 reflects loop 12 with redesign as the mitigation rather than resourcing.

Mitigation loop 16.

> Loop #16 of length 2; Restructure Supply, Locally Sourced, & Non-Locally Sourced.

Mitigation loop 16 follows loop 10 and 13 but uses supply restructuring as the mitigation to adjust the relative balance of the non-locally sourced and local sourced sub-sets of material demand.

Mitigation loop 17.

> Loop #17 of length 3; Restructure Supply, Locally Sourced, Preference Duty relief, & Cash.

Mitigation loop 17 reflects loop 11 with restructure as the mitigation rather than resourcing.

Mitigation loop 18.

> Loop #18 of length 4; Restructure Supply, Locally Sourced, Non-Locally Sourced, Preference Duty relief, & Cash.

Mitigation loop 18 reflects loop 12 with restructure as the mitigation rather than resourcing.

If preference conditions can be met, then the NPD product could be sold at a lower price to the customer or sold at a higher market price where the competition has not been able to achieve preference conditions and is forced to sell at a higher price. The worst case is where the NPD has not achieved preference conditions and as a result is at a sales price disadvantage.

> Example: South Africa is an automotive preference market. Import duty usually is 26% but if preference conditions can be met the import duty reduces to 19%. If the landed value of the vehicle were the equivalent of £35,000, the preference effect would be worth £2,450 either to the OEM profit of the customer price tag. To achieve South African preference 60%+ of the cost must be incurred from 'Local' sourcing which can include both OEM manufacturing costs and tier 1+ materials.
>
> Equally important and dependent upon knowledge of the country of origin of a part or its parts down through the tier 1 + sourcing structure is the legislation undertaken by some countries to ban the import of products that have materials sourced from other restricted countries. Inappropriate material sourcing can cost the potential sales of a complete market.

Table 22 shows known preference markets and JLRs wholesale volumes for each of those markets. As shown at the bottom of the table preference markets in 2016 represented just under 5% of the total wholesales, but this is the average across all models. The detail data shows a range for preference market dependency by model from a high of 11% down to 1%. The table itself was created using data sourced from (correspondence Cusack, 2016), original source data from (HM Revenue & Customs, 2016b) and (JLR wholesale volumes data 2016.).

Table 22: Known automotive preference markets for UK JLR exports 2016.

Preference Market	**15/16 FY WSales (Quanity of vehicles).**
Chile	704
Dominican Republic	171
Egypt	249
Ghana	75
Iceland	321
Israel	577
Jordan	365
Lebanon	642
Macedonia	116
Mexico	1,428
Moldova	173
Morocco	1,766
Norway	1,249
South Africa	6,880
Switzerland	5,186
Tunisia	204
Turkey	2,798
Ukraine	762
Zambia	41
Zimbabwe	97
Sub-total preference markets	**23,804**
Total wholesales - all markets	**509,339**
Preference markets as a percentage	4.67%

In extreme cases to achieve an optimally balanced impact upon the NPD profit, split sourcing can be considered; splitting the tier 1 supply currency to achieve an improved currency balance. In theory, this is possible but, split sourcing introduces additional business risk during the NPD manufacture. The additional risk is associated with traceability of the part sourcing for customs declaration, import duty recovery against non-locally sold product and which supplier should be paid for the supply of the parts when the parts are on ‘pay on production’ contracts. Tracing which supplier supplied the part that incurred the warranty claim and therefore whom to claim against.

Fig 44 shows a more complicated stock and flow diagram involving three potential mitigations. The complexity here is provided by needing to maintain a tier 1 sourcing that allows preference market conditions to be met in all target markets for the NPD. Having identified a failure to meet Preference Market requirements the ‘Non-locally Sourced’ tier 1 material is resourced to ‘locally sourced’ until the conditions are met.

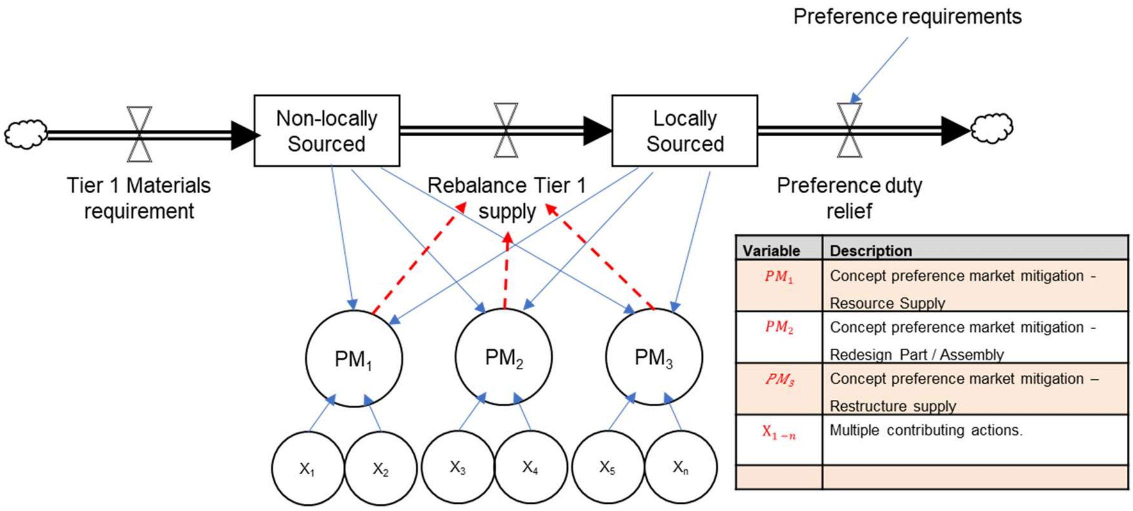


Fig 44: Stock and flow diagram: Preference markets.

Importation duty.

Import duty analysis is itself complex. The importation duty[15] applied to an imported product is dependent upon several factors; Origin; Material; the state of the material; the state of the WIP, in combination these factors create a 'commodity code' which is internationally common. The applied duty can be 'engineered' by modification of any of these factors. Changing the assembly point across an international trading border may significantly change the total incurred duty. The applied import duty itself can be pre-empted as these are laid down in available databases. HM Revenue & Customs, (2016a).

Within the proposed research method, the existing baseline of the importation duty can be established as it is predefined as a part of the detailed source metadata assuming that the materials, manufacturing technology and sourcing remain as per the original and existing component data.

Fig 45 shows the CLD relating to importation duty. There is more than one route that can be taken to achieve mitigation, but mitigation actions only need to be taken in cases

[15] Incurred importation duty is applied to the 'landed value' of the importation. It may be necessary to add transportation charges to the tier 1 costs subject to the source data contractual terms.

of non-locally sourced, local sales. The importation duty incurred by non-locally sourced, non-local sales being recoverable on NPD exportation.

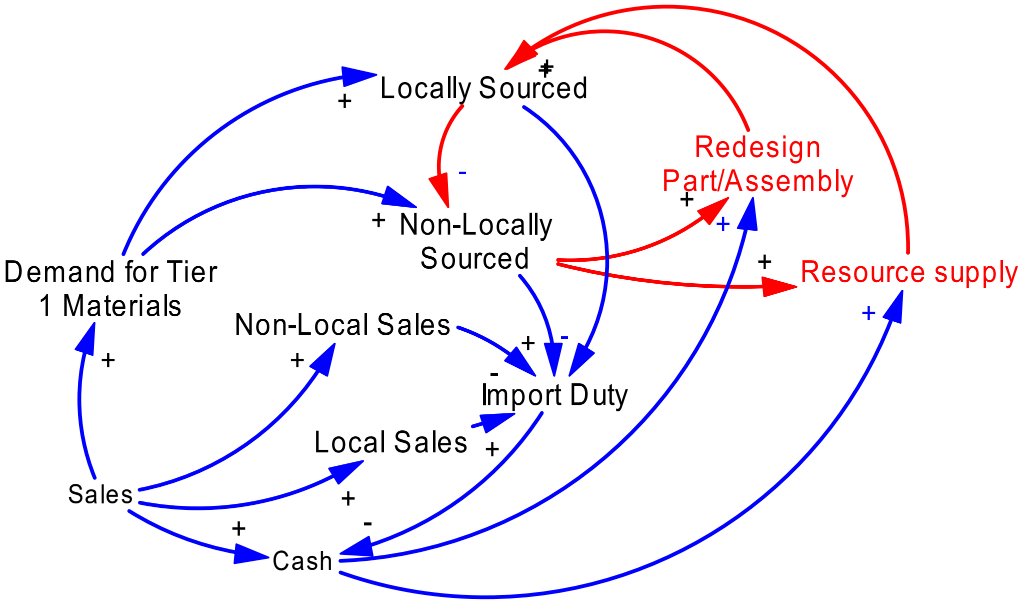


Fig 45: Causal loop diagram: Importation duty.

Mitigation loop 19.

> Loop #19 of length 2; Redesign Part/Assembly, Locally Sourced, & Non-Locally Sourced.

As with previous loops, loop 19 illustrates seeking to redesign a part to rebalance between locally sourced and non-locally sourced material demand.

Mitigation loop 20.

> Loop #20 of length 3; Redesign Part/Assembly, Locally Sourced, Import Duty, & Cash.

The issue is highlighted by loop 20 is that to enable the redesign of the parts to address the need to reduce incurred import duty to increase the cash generated by the NPD the cash is also required to enable the redesign action in the first place.

Mitigation loop 21.

> Loop #21 of length 4; Redesign Part/Assembly, Locally Sourced, Non-Locally Sourced, Import Duty, & Cash.

Mitigation loop 21 is addressing the double impact effect that as locally sourced value is increased moving the material out of importation duty the non-locally sources value attracting importation duty will decrease.

Mitigation loop 22.

> Loop #22 of length 2; Resource Supply, Locally Sourced, & Non-Locally Sourced.

Mitigation loop 22 reflects loop 19 with resourcing as the mitigation rather than redesign.

Mitigation loop 23.

> Loop #23 of length 3; Resource Supply, Locally Sourced, Import Duty, & Cash.

Mitigation loop 23 reflects loop 20 with resourcing as the mitigation rather than redesign.

Mitigation loop 24.

> Loop #24 of length 4; Resource Supply, Locally Sourced, Non-Locally Sourced, Import Duty, & Cash.

Mitigation loop 24 reflects loop 21 with resourcing as the mitigation rather than redesign.

In this importation CLD, importation duty is to be avoided as it reduces available cash.

The parts requirement in combination with the global tier 1 supplier spend locates the part source either with a 'local' source where the incurred importation duty is zero or into sourcing that will make it subject to importation duty. The rate at which importation duty will be incurred is subject to several aspects of the source and supplied condition; type of materials; type of manufacturing processes involved; class of technology; country of origin.

Because there are several aspects to the establishment of import duty classification, it is possible to engineer the importation duty that will be incurred although the engineering will need to be optimised along with other measures of success to achieve the optimised impact upon the NPD as the business risk is managed.

- The most straightforward action is to work with the selected supplier to relocate the source to a location within the 'locally' sourced area or find a suitable supplier already within the 'locally' sourced boundary.

- A breaking up of an assembly can achieve importation duty only being levied upon a lower value with critical parts being sourced at tier 2+ as required but the final assembly being undertaken 'locally'. Importation duty is levied on the 'landed value' of the part or in this case the sub-parts from the tier 2+ suppliers. Each subpart will be treated as a unique part with its own landed value and customs commodity code evaluation.
- Redesign the part/assembly to avoid high importation duty.

Full details of the importation duty classifications and the level of duty they attract can be found @ https://www.trade-tariff.service.gov.uk/trade-tariff/sections. The classification is international but the level of duty they attract is set by each tariff setting body, and it can change over time

> Note: The import duty incurred on non-locally sourced parts subsequently exported within a non-local product sale are refunded upon application and verification of the export. According to JLR 2016 Wholesale data 52% of sales were into non-local markets where the importation duty incurred during manufacture was recoverable.
>
> Also, a software tool has just been released that might provide early insight into the importation duty. A press release from FACTON (12th November 2018) has announced that FACTON EPC v10 has a module to calculate the importation tariff of tier 1+ materials automatically. The inclusion of such a tool could form the basis of a redesign/resourcing support tool.

As with Preference Markets, in extreme cases to achieve an optimally balanced impact upon the NPD profit, split sourcing can be considered; splitting the tier 1 supply currency to achieve an improved currency balance. In theory, this is possible but, split sourcing introduces additional business risk during the NPD manufacture. The additional risk is associated with traceability of the part sourcing for customs declaration, import duty recovery against non-locally sold product and which supplier should be paid for the supply of the parts when the parts are on 'pay on production' contracts. Tracing which supplier supplied the part that incurred the warranty claim and therefore whom to claim against.

The stock and flow diagram shown in Fig 46 shows a mechanism attempting to deal with a set of conditioning only actually required to be achieved on a subset of the total

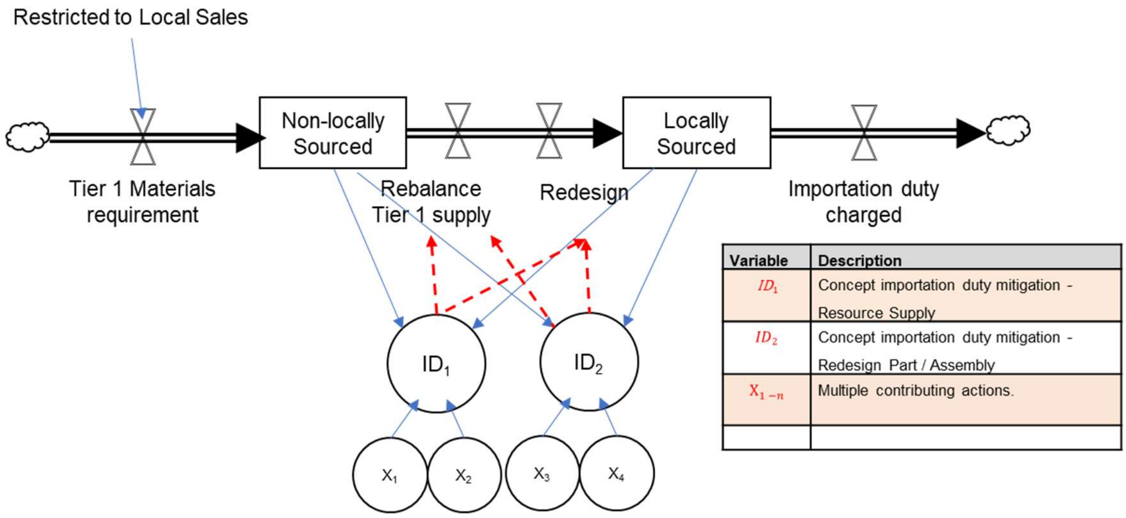


Fig 46: Stock and flow diagram: Importation duty.

tier 1 material requirement: that material bought to fit into local sales. The 'Non-locally Sourced' material having been identified two mitigations can be applied: 'Redesign' and or 'Resource'. Redesign will have the effect of reducing the incurred importation duty while a resource might remove it.

4.4.5. Recyclability.

The need to provide early consideration to recyclability during the End of Life (EOL) either of a part replaced during the lifetime of the NPD in use or at the EOL of the vehicle is covered by legislation. A target percentage of the vehicle materials must be recyclable. The ability to achieve the targets is most typically left to a post design phase evaluation that must result in an iterative design activity which may additionally demand a resourcing action to achieve the redesigned part or parts. The early identification of the materials included in the NPD product through the metadata makes the preliminary identification of legislative target achievement an action that can be covered during the concept phase ahead of the design phase reducing the need for an iterative design phase.

The early identification of the materials in the recyclability loop additionally make it possible to create additional recycled material demand by increasing the specified recycled to virgin material ratio within the specification of the OEM tier 1 supplied part. The increase in recycled material demand, with the provision of a sustainable recycling industry, will have the effect of both stabilising the material price volatility and reducing the absolute price of the material. Li et al., (2016) apply their cost-reducing effect of recycled materials to carbon fibre reinforced polymers waste. They assess that there is a high cost to the dismantling. Already highlighted in section 2.6, access is required to clean waste to start the specific recycling and that due consideration needs to be given to achieving this during the early product design phases.

Fig 47 shows a CLD depicting migration action in respect of recyclability.

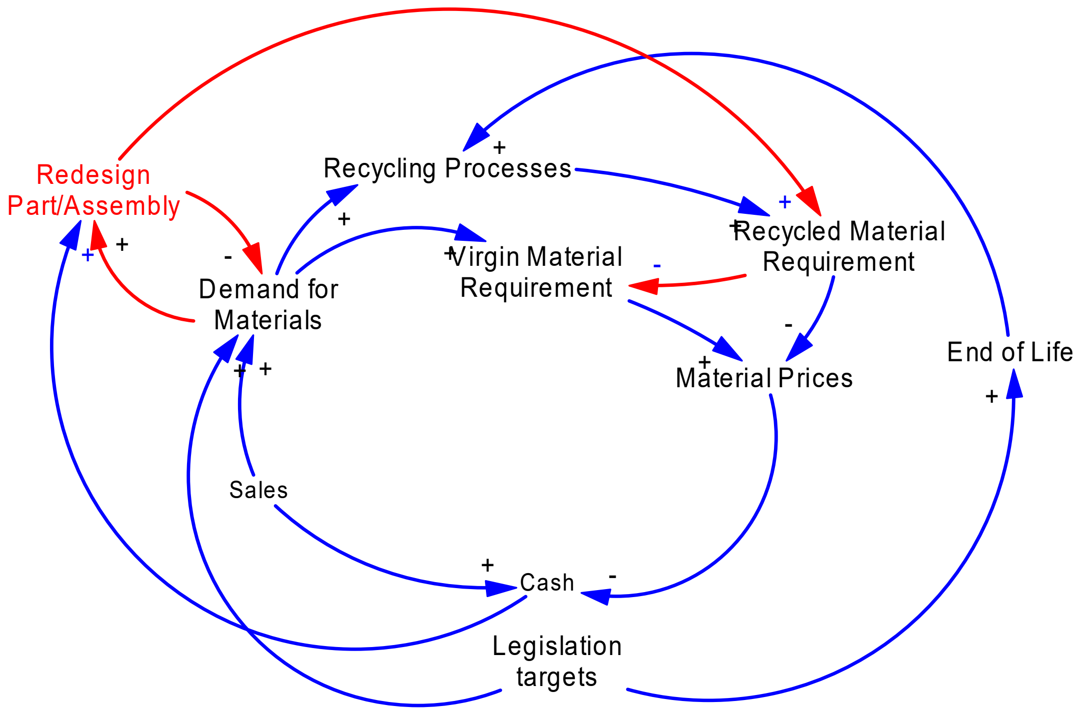


Fig 47: Causal loop diagram: Recyclability.

Mitigation loop 25.

Loop #25 of length 1; Redesign Part/Assembly, & Demand for Materials.

In many respects mitigation loop 25 is making a fundamental statement; because there is a demand for the material, there is a need to redesign.

Mitigation loop 26.

Loop #26 of length 3; Redesign Part/Assembly, Recycled Material Requirement, Material Prices, & Cash.

Mitigation loop 26, however, is more exciting and gives purpose to loop 25. In loop 26 the redesign is shown to seek the objective authorising the inclusion of recycled materials, reducing material costs as a result and thereby achieving an increase in cash. The same cash that is required to initiate the redesign activity in the first place.

Mitigation loop 27.

> Loop #27 of length 4; Redesign Part/Assembly, Demand for Materials, Virgin Material Requirement, Material Prices, & Cash.

Loop 27 reflects loop 26. As increased or maintained demand is made of virgin material, material prices will increase placing a drain on cash.

Mitigation loop 28.

> Loop #28 of length 4; Redesign Part/Assembly, Recycled Material Requirement, Virgin Material Requirement, Material Prices, & Cash.

Mitigation loop 28 further reflects loop 27 and loop 28. As the virgin material is reduced, recycled material usage is increased.

Mitigation loop 29.

> Loop #29 of length 5; Redesign Part/Assembly, Demand for Materials, Recycling Processes, Recycled Material Requirement, Material Prices, & Cash.

Loop 29 shows that as the inclusion of recycled materials increases it creates a demand for recycling processes to satisfy the requirement further driving recycled material prices down and increasing cash.

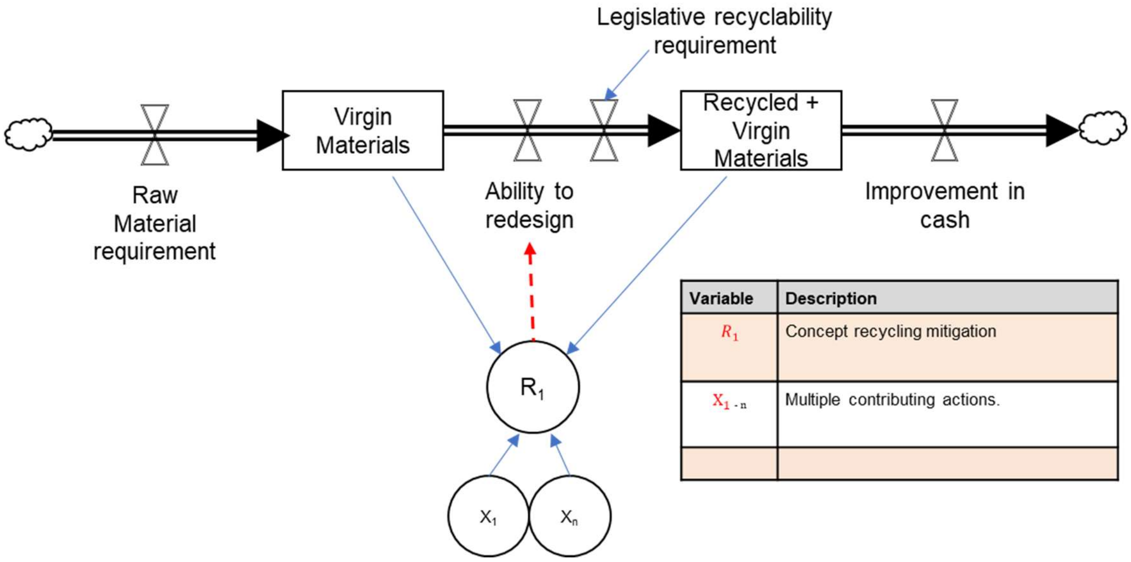
Mitigation loop 30.

> Loop #30 of length 6; Redesign Part/Assembly, Demand for Materials, Recycling Processes, Recycled Material Requirement, Virgin Material Requirement, Material Prices, & Cash.

Loop 30 reflects loop 29 introducing the balancing between the virgin and recycled materials driving the virgin material demand down.

The stock and flow diagram in Fig 48 shows a mechanism designed to isolate 'Virgin Materials within the 'Raw Material requirement' redesign the required parts to either or a material that can be recycled; create a recycling route through its identified need;

reduce the virgin raw material to allow the recycled material to be used. The external 'Legislative recyclability requirement' is used as a minimum threshold to be achieved.



Variable	Description
R_1	Concept recycling mitigation
X_{1-n}	Multiple contributing actions.

Fig 48: Stock and flow diagram: Recyclability.

Much is made of recycling at the ELV, with legislation having been introduced to provide thresholds. However, the metadata available provides insight into 'in-process waste' that should drive an additional recyclability action. Its inclusion as a study item in addition to ELV might drive an absolute reduction in gross material and therefore cost, but also it might identify alternative design and manufacturing processing options.

4.4.6. Currency.

Within currency, two high-level tools become available to the NPD once the metadata is known. The first is the traditional finance toolset. Within this traditional toolset, the objective is to optimise any imbalance between the available currency achieved through sales currency and the currency required to pay tier 1 suppliers. When there is insufficient sales currency to fund tier 1 suppliers currency requirements, sales currency needs to be exchanged into the required currency. Exchanging currency costs money and therefore generates a negative profit performance which is to be avoided. The challenge that can be undertaken once the potential currency imbalance has been identified is to either; stimulate sales in the currency where there is a currency shortfall; resource a tier 1 supply to a more plentiful currency. The optimisation can be achieved by moving as much currency risk either through exchange rates or contract fees into naturally balanced exchange mechanisms where the exchange rate is 1, and there are no fees.

Due to the creation of new knowledge, a second mitigation toolset becomes available at the concept phase, resourcing of some tier 1 material can take place to reduce the demand on a specific currency. Active resourcing is not as radical as it first sounds as many tier 1 suppliers have a global presence and can switch between supplying facilities. At the early concept phase, there is a more significant potential to cost reduce the design and hence the demand for a specific currency. Alternatively, this can also be achieved by redesigning the supply chain, splitting the sub-parts and assembly between supplier facilities under differing currency payment.

Fig 49 presents the design and sourcing based mitigations in the case of currency imbalance. The classical financial mitigations are represented but are not focused upon for this research other than to know that they exist.

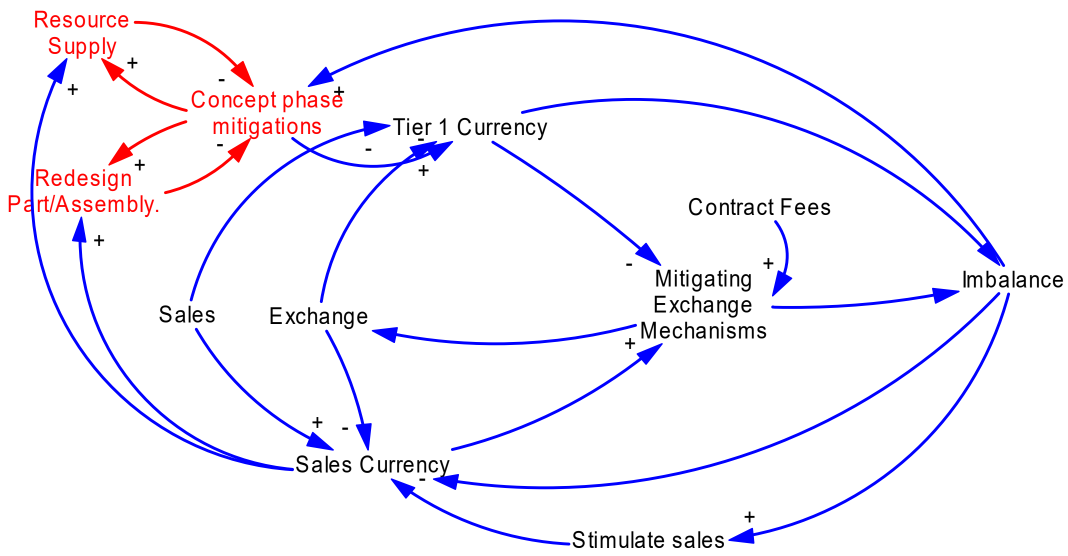


Fig 49: Causal loop diagram: Currency.

Table 23 provides a summary of classical exchange rate mitigations through hedging mechanisms, their respective contract fee implications and the associated business risks.

Table 23: Mitigating exchange mechanism pre-existing options.

	Mitigating Exchange	Imbalance	Exchange	Contract Fees	Business Risk
F1	Natural	Self-covering	1	None	Minimised
F2	Spot Rates	Short-term emergency	Completely variable	Low	Currency market variability
F3	Fixed hedge	Forward planned	Fixed	Medium	Reduced but guarantees missing better than expected market performance
F4	Option hedge	Forward Planned	Fixed ceiling	High	Reduced but allows better than expected market performance to be realised.

Mitigation loop 31.

Loop #31 of length 1; Redesign Part/Assembly, & Concept phase mitigations.

As with the earlier loops with other mitigations mitigation loop 31 is making a fundamental statement; currency base mitigation demands can be achieved through a redesign.

Mitigation loop 32.

Loop #32 of length 4; Redesign Part/Assembly, Concept phase mitigations, Tier 1 Currency, Imbalance, & Sales Currency.

Mitigation loop 32 is providing purpose to loop 31 in that the need to redesign is due to an imbalance between tier 1 currency and sales currency.

Mitigation loop 33.

Loop #33 of length 5; Redesign Part/Assembly, Concept phase mitigations, Tier 1 Currency, Imbalance, Stimulate sales, & Sales Currency.

In loop 33 there is alternative mitigation being offered to address currency imbalance; increase sales to generate a required currency to balance the demand for tier 1 currency.

Mitigation loop 34.

Loop #34 of length 5; Redesign Part/Assembly, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Imbalance, & Sales Currency.

In mitigation loop 34 the option to fall back on classical exchange mitigations is confirmed as still available to the NPD. Note that this route is likely to come with additional contract fees.

Mitigation loop 35.

> Loop #35 of length 5; Redesign Part/Assembly, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Exchange, & Sales Currency.

Mitigation loop 35 while still valid, is an alternative statement to mitigation loop 34.

Mitigation loop 36.

> Loop #36 of length 6; Redesign Part/Assembly, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Imbalance, Stimulate sales, & Sales Currency.

Mitigation loop 36 is attempting to highlight that all mitigations can be undertaken concurrently.

Mitigation loop 37.

> Loop #37 of length 1; Resource Supply, & Concept phase mitigations.

Mitigation loop 38.

> Loop #38 of length 4; Resource Supply, Concept phase mitigations, Tier 1 Currency, Imbalance, & Sales Currency.

Mitigation loop 39.

> Loop #39 of length 5; Resource Supply, Concept phase mitigations, Tier 1 Currency, Imbalance, Stimulate sales, & Sales Currency.

Mitigation loop 40.

> Loop # 40 of length 5; Resource Supply, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Imbalance, & Sales Currency.

Mitigation loop 41.

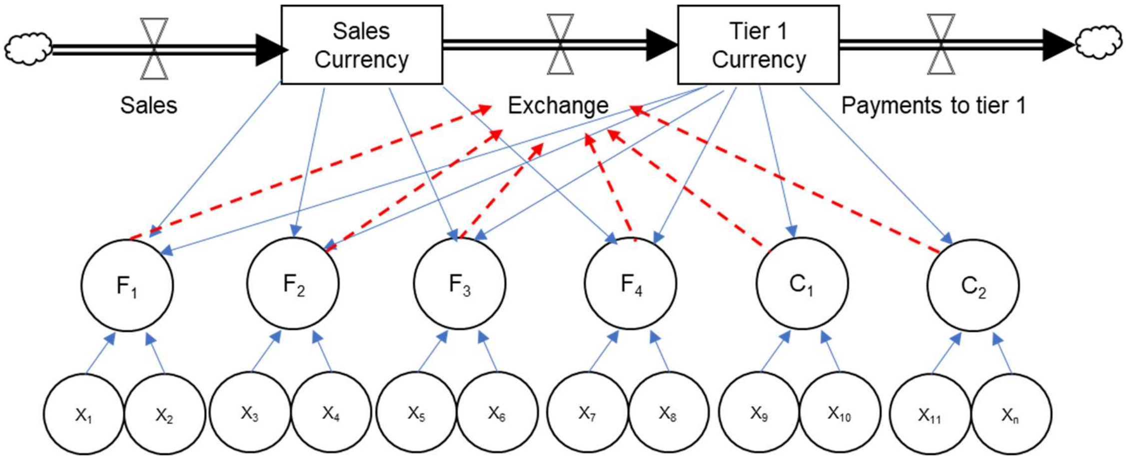
Loop #41 of length 5; Resource Supply, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Exchange, & Sales Currency.

Mitigation loop 42.

Loop #42 of length 6; Resource Supply, Concept phase mitigations, Tier 1 Currency, Mitigating Exchange Mechanisms, Imbalance, Stimulate sales, & Sales Currency.

Mitigation loops 37 to 42 follow 31 to 36 with a resourcing mitigation replacing redesign.

Fig 50 is showing the stock and flow diagram associated with currency mitigation. As shown, there are two migrations processes both of which act upon the exchange to achieve the desired balance between 'Sales Currency' and 'Tier 1 Currency'. Represented by the variable F are mitigations that are typically applied at or about the time of volume production such as hedging. Represented by the variable 'C' are Concept Mitigations. Concept mitigations include the ability to redesign or resource to avoid the identified currency imbalance.



Variable	Description
F_1	Classical financial currency exchange mitigation - Natural
F_2	Classical financial currency exchange mitigation - Spot Rates
F_3	Classical financial currency exchange mitigation - Fixed hedge
F_4	Classical financial currency exchange mitigation - Option hedge
C_1	Concept currency exchange mitigation – Resource Supply
C_2	Concept currency exchange mitigation – Redesign Part / Assembly
X_{1-n}	Multiple contributing actions.

Fig 50: Stock and flow diagram: Currency.

The ultimate objective of any currency restructure is to achieve a ‘natural’ balance between the currency obtained from the NPD sales revenue and the currency profile of the tier 1 purchases. Economic volatility exists in both the material and currency pricing. Revenue cannot be considered fixed as market forces, including competition will drive revenue fluctuations. Over the life cycle of the NPD, a marketing device known as variable marketing will be used to stimulate flagging sales volumes which will reduce the planned revenue. Another sale stimulating action is bundling accessories, this will add cost that will not be covered by revenue potentially increasing currency exposure. Undertaking an early review of the NPDs currency balance is therefore essential to ensure that sourcing adjusts away from volatile and poorly balanced currencies as far as is possible and takes advantage of any earned currency where practical. (If the sourcing of tier 1 parts and assembles is in the same currency as earned currency and exchange rate movement is naturally offset.).

This research and the proposed method of bringing through detailed source metadata at the early concept phase has allowed the early identification of tier 1 purchases currency profile. The currency data contained within the detailed source metadata flows through the PCE rather than being normalised out of the PCE. The absolute value of the currency was achieved through the sum of the five cost types within a tier 1 part; Bought parts (tier 2 and below); Material; Manufacturing Process; General Overheads and Other.

In this currency model, there are two aspects in play; the demand for various currencies to be available and the quantity of any given currency to be available. Cash may be available, but it may not be in the required currency. In the ideally balanced model, the currencies and quantity of any currency to buy parts from the global tier 1 suppliers would be provided by the sum of the customers through the global markets in the required currencies. However, where the model is out of balance cash is required to be spent by going to the exchange markets to obtain cash in the required currencies.

For this research and achieving a higher level of understanding of the currency-based metadata at the concept phase of the NPD, it may be possible to direct the global sourcing through the tier 1 suppliers to improve the currency balance between the potential supply and demand for currency avoiding exchange markets and hedging contracts.

There is an additional complexity within a currency causal loop which in the interest of simplicity has been omitted from the Currency CLD. There are countries, markets, where while it is possible to withdraw revenue from goods sold it is made very difficult. Historically China and Russia have been good examples. The difficulty is generated by national government balance of trade policy to ensure that the countries trade balance remains stable. If there are significant vehicle sales expected in countries with these policies, it may be worth considering ensuring that there is an equivalent part spend in the country to avoid any difficulties in recovering the nett revenue from vehicles sold in the country.

As with Preference Markets and Importation Duty, in extreme cases to achieve an optimally balanced impact upon the NPD profit, split sourcing can be considered; splitting the tier 1 supply currency to achieve an improved currency balance. In theory, this is possible but, split sourcing introduces additional business risk during the NPD manufacture. The additional risk is associated with traceability of the part sourcing for customs declaration, import duty recovery against non-locally sold product and which supplier should be paid for the supply of the parts when the parts are on 'pay on production' contracts. Tracing which supplier supplied the part that incurred the warranty claim and therefore whom to claim against.

Common basic mitigation mathematics.

Table 24 provides a legend to the variables used.

$$Cash\ t_1 = \int (material\ price + material\ volitility + processes + preference + import + recycle + exchange) \tag{22}$$

$$Classic\ Financial\ actions\ (CFa) = (F_1 + F_2 + F_3 + F_4) \tag{23}$$

$$Concept\ Stage\ actions\ (CSa) = (C_1 + C_2) \tag{24}$$

$$exchange\Delta = CFa + CSa \tag{25}$$

$$\text{Total concept mitigation} = t_1 = f(P_1) + f(V_1) + f(Mp_1) + f(PM_1, PM_2, PM_3) + f(ID_1, ID_2) + f(R_1) + f(C_1, C_2) \tag{26}$$

Table 24: Legend of mitigation variables

Variable	Description
t_1	Total Cash generated by NPD concept mitigations
CSa	Total Concept financial currency exchange mitigation
CFa	Total Classical financial currency exchange mitigation
F_1	Classical financial currency exchange mitigation - Natural
F_2	Classical financial currency exchange mitigation - Spot Rates
F_3	Classical financial currency exchange mitigation - Fixed hedge
F_4	Classical financial currency exchange mitigation - Option hedge
C_1	Concept currency exchange mitigation – Resource Supply
C_2	Concept currency exchange mitigation – Redesign Part / Assembly
P_1	Concept material price mitigation
V_1	Concept material price volatility mitigation
Mp_1	Concept manufacturing process mitigation
PM_1	Concept preference market mitigation - Resource Supply
PM_2	Concept preference market mitigation - Redesign Part / Assembly
PM_3	Concept preference market mitigation – Restructure supply
ID_1	Concept importation duty mitigation - Resource Supply
ID_2	Concept importation duty mitigation - Redesign Part / Assembly
R_1	Concept recycling mitigation

4.4.7. Business risk summary.

Thoughts of optimisation, determination of which mitigation should be prioritised first, second, third, based on the most significant cash opportunity realised might be considered appropriate. It needs to be remembered that the not all NPD variables and boundary conditions are included here; there is no engineering for instance, and therefore optimisation cannot be realised in isolation.

In section 4.4 a review has been completed using 'causal loop' and 'stock and flow' diagrams. Also, the basis of the associated mathematics has been developed and provided. Fig 51 & Fig 52 bring the identified mitigation activity loops together clearly showing that once established the NPD modified metadata can provide insight into areas where early intervention through redesign, resourcing or restructuring of the tier 1 parts, assemblies and their costs can reduce the resulting business risk.

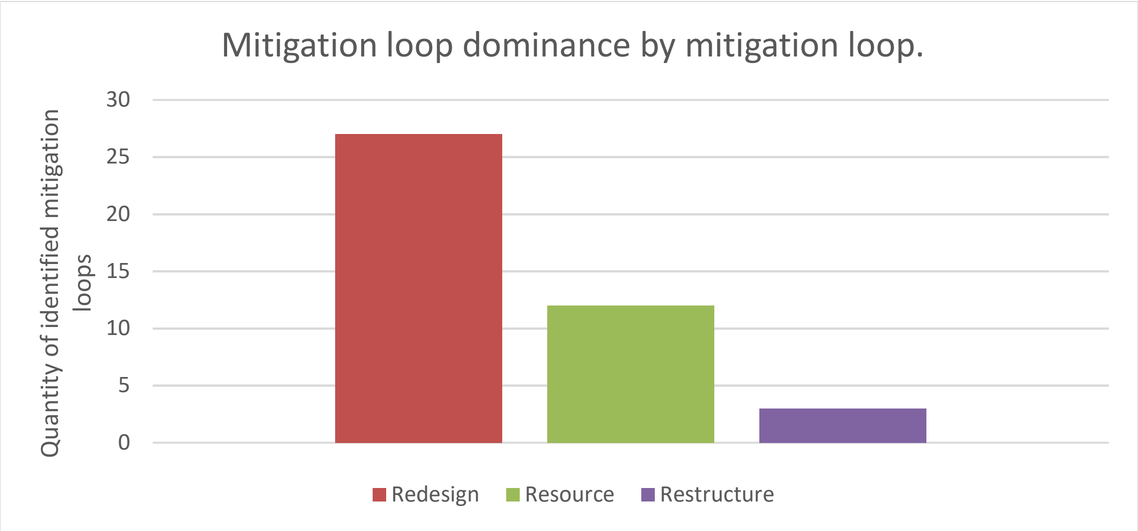


Fig 51: Mitigation loop dominance by mitigation loop.

Fig 51 shows the mitigation loop dominance by mitigation; it clearly shows that with a total 42 potential mitigations across just seven aspects of business risks there is a need for both prioritisation and optimisation as which mitigations to utilise when seeking optimal NPD performance. Feature delivery should also be considered within the optimisation. Development of the optimisation is out of scope for this research. However, while this analysis might be useful, it can also be misleading. The amount of inclusion of a mitigation action against a single business risk can be influenced by the CLDs creation and as already noted within the CLD loop descriptions.

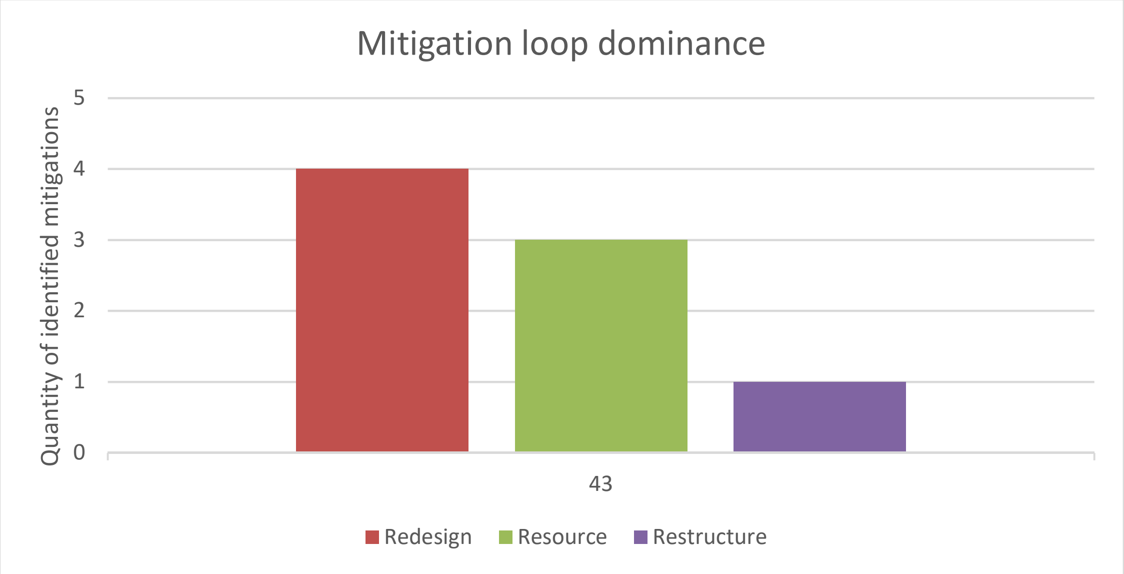


Fig 52: Mitigation loop dominance.

A more realistic review of the mitigation dominance is achieved by reviewing the occurrence of a mitigation type occurring within the cited business risks. This analysis is shown in Fig 52. The indication to be drawn from the occurrence analysis is that most of the cited NPD business risks can be influenced through redesign of the NPD product. Optimisation of the resulting mitigations in conjunction with the required feature delivery is still required.

4.5. Method development summary

In Chapter 4 the hybrid methodology has been developed.

- The basic hypothesis was validated through SME interviews. Achieving an understanding of commercial uncertainty early in the NPD is a real business concern that required addressing.
- An exploration of the metadata inter-relationships has been presented. The identification has provided structure to the hybrid methodology.
- Pre-existing metadata has been identified to allow the construction of structured analysis. Having an output requires a means to apply the resulting analysis. Understanding the output requirements to drive mitigation enables the identification of the required metadata. This somewhat complicated 'chicken and egg' has been solved through a structured assessment of the possible impacts or mitigations that are available using the identified metadata.

Fig 53 shows a summary view of what has been achieved in Chapter 4. Starting with the basic premise of applying Parametric Cost Estimating (PCE) methods in the top left-hand. Flowing through the available metadata and concluding with a structured method to complete the analysis, shown in the top right hand. The insert shown across the bottom of Fig 53 shows the ratio-based assessment that establishes the likelihood of and the quantification of materials, processes, currencies occurring in the NPD given their inclusion in the existing data sources used to establish the Cost Estimating Relationships (CER)'s created and used to define the PCE.

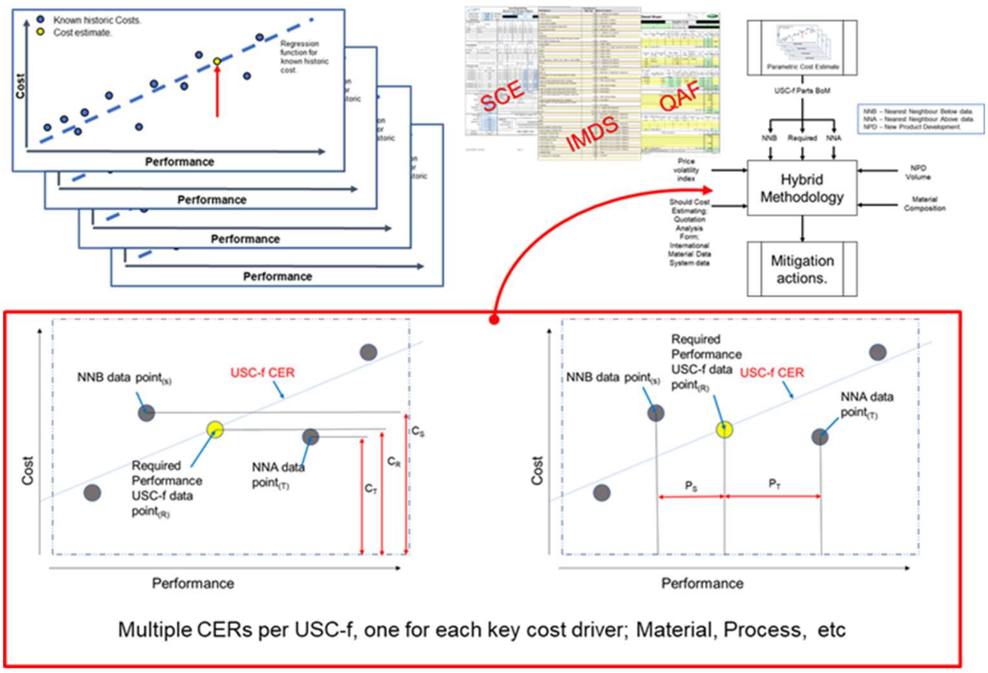


Fig 53: Research in summary

Fig 53 contains some abbreviations that will be more fully explained within the thesis but are described in Table 25.

Table 25: Legend to Fig 53

Abv.	Description
PCE	Parametric cost estimating
CER	Cost estimating relationship
SCE	Should cost estimating
IMDS	International material data system
QAF	Quotation analysis form
USC-f	Unique system code - feature
NNB	Next nearest data point below
NNA	Next nearest data point above

4.6. Hybrid Methodology Framework

The hybrid methodology framework has been developed to deliver the new concept phase data requirement that allows uncertainties to be identified as business risks. The types of data and how they inform the business risks have been outlined in section 4.4 (pg 89 to 116).

Through the research undertaken four 'cases' of change encountered during the NPD concept phase have been identified and each is addressed within the hybrid methodology framework. The 'cases' are:

a. Carryover of an existing feature and parts.
b. Modified feature and parts, where the parts are unique to the delivery of a single feature.
c. Modified feature and parts, where the parts contribute to the delivery of multiple features.
d. New feature and part/s or an existing feature delivered through new technology.

In the 'framework' that is presented both existing tools and data already identified in section 4.2 (pg 57 to 72) have been brought together to form a cohesive flow.

In the series of four framework case flow diagram, Fig 54 (pg 120), Fig 55 (pg 121), Fig 56 (pg 123 and Fig 57 (pg 125), the secondary data is shown on the left-hand side and the tools/methods are shown on the righthand side. Each case diagram shows all elements of data and tools/methods so that specific case inclusion and exclusion is clearly defined. Table 26 shows a common legend to all framework case diagrams.

All framework cases are developed assuming that the cost type being examined is 'Materials' but the same principals apply to 'Manufacturing Processes', 'Currency', 'Importation Duty' and 'Preference Markets'.

Table 26: Legend to framework case diagrams Fig 54, Fig 55, Fig 56 and Fig 57

Abv.	Description
PCE	Parametric cost estimating
BOM	Bill of Materials (Parts list)
SCE	Should cost estimating
IMDS	International material data system
QAF	Quotation analysis form
USC-f	Unique system code - feature
NPD	New Product Development

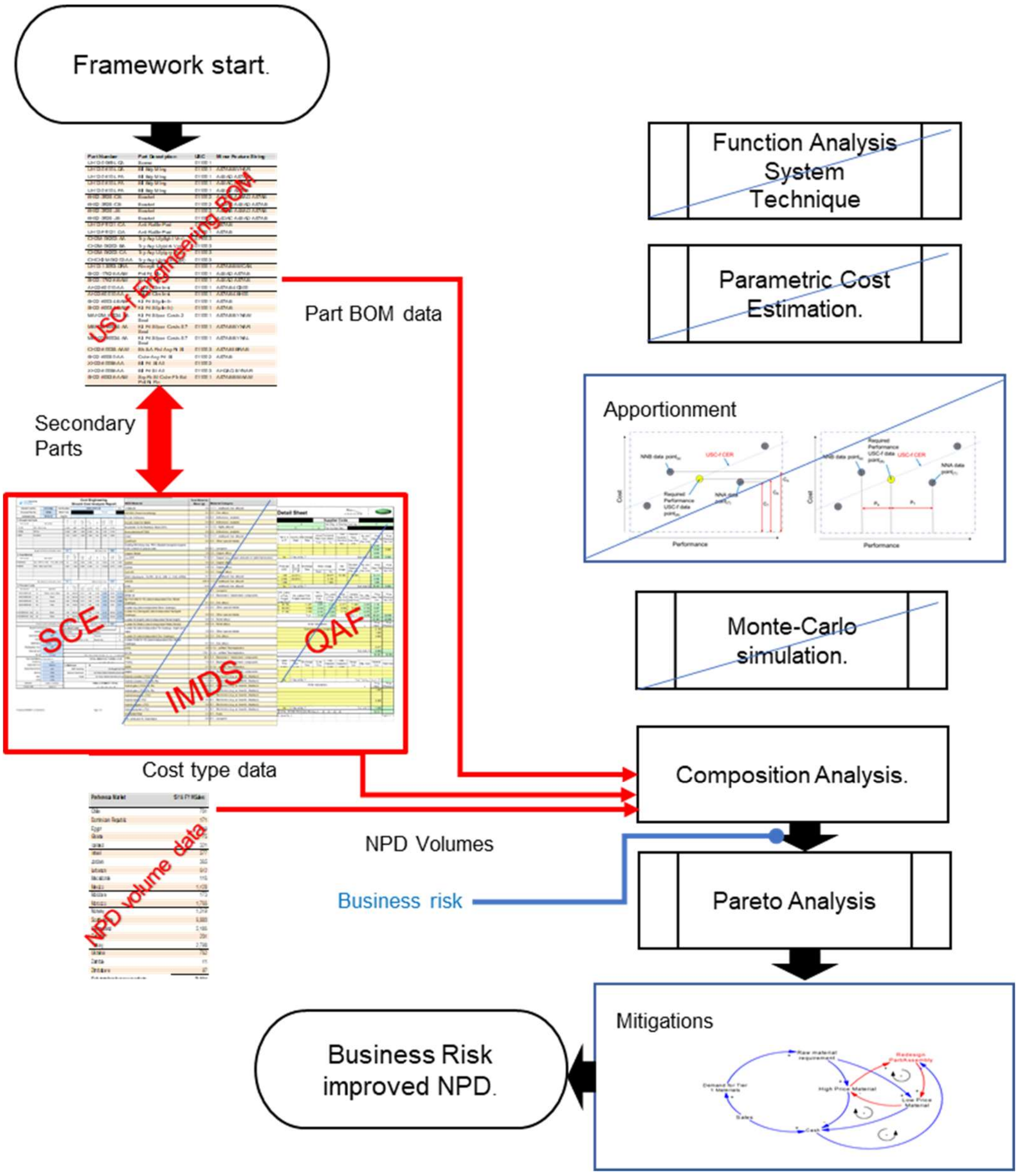


Fig 54: Framework case - Carryover of an existing feature and parts.

The case of 'Carryover of an existing feature and parts' is the simplest of the four cases, in effect it is a 'do nothing' other than check that the current engineering and sourcing compliment the new NPD. Within this case there is no requirement to employ FAST, PCE, Apportionment or Monte-Carlo simulation.

An understanding of composition analysis is required by all framework cases. Composition analysis is not difficult being dependent upon the identification of the grades of materials and their consumed weights. The chemical composition of the grades is typically available from internet sources. The composition by percentage is extrapolated by the consumed weight and the result further extended by the NPD volumes. The output is the composition that forms the business risk. The application of composition analysis is detailed in Table 31 (pg 141).

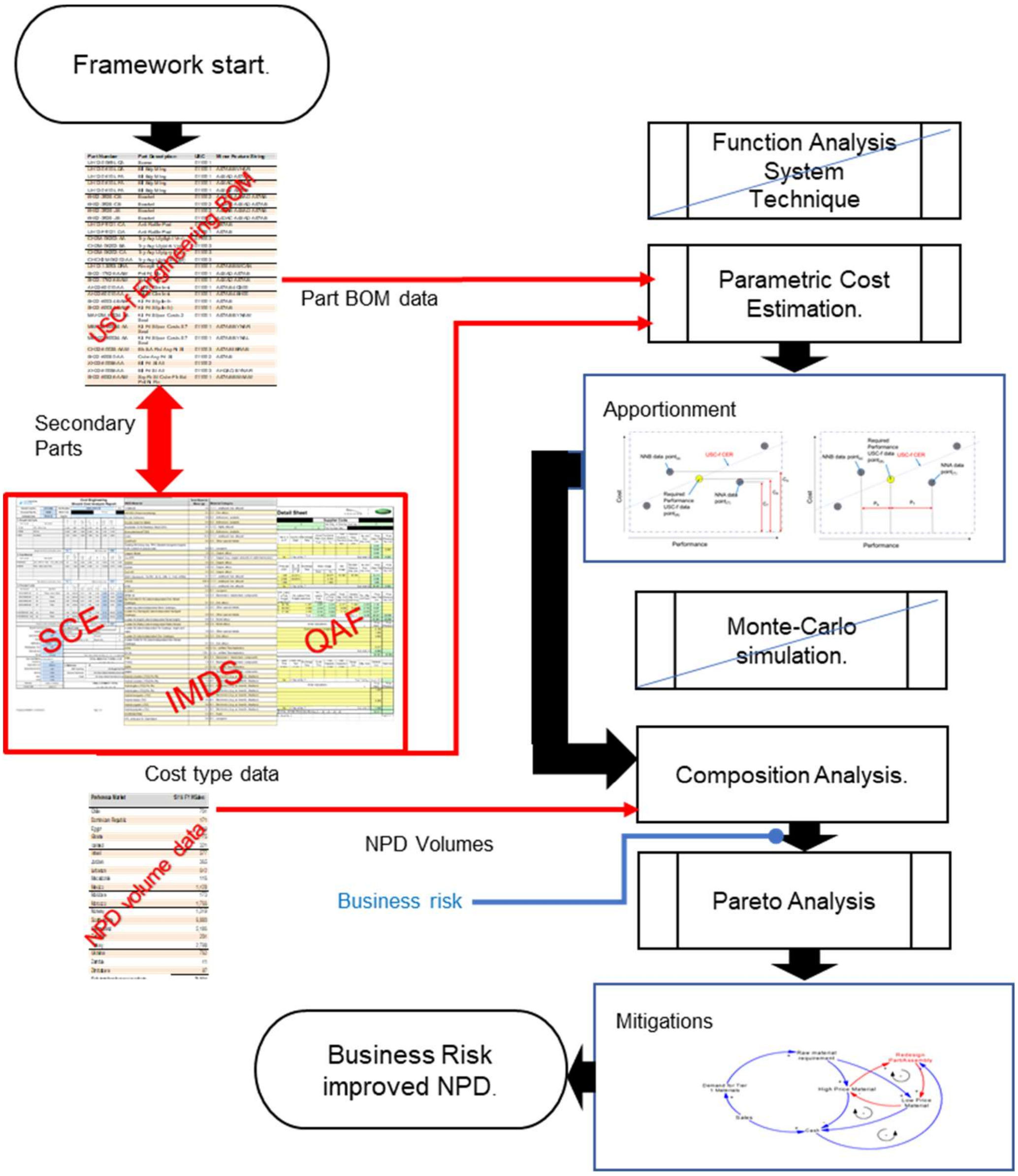


Fig 55: Framework case - Modified feature and parts, where the parts are unique to the delivery of a single feature.

Because the performance required from the feature is being modified to meet the NPD this case requires a means to scale the impact of the new performance requirement. This is achieved through the application of PCE being applied to the cost type and an apportionment being introduced. Monte-Carlo simulation is not required because the cost types within the parts being analysed that deliver the USC-f deliver against a single feature, requiring no allocation of cost data through FAST or similar of cost data to feature.

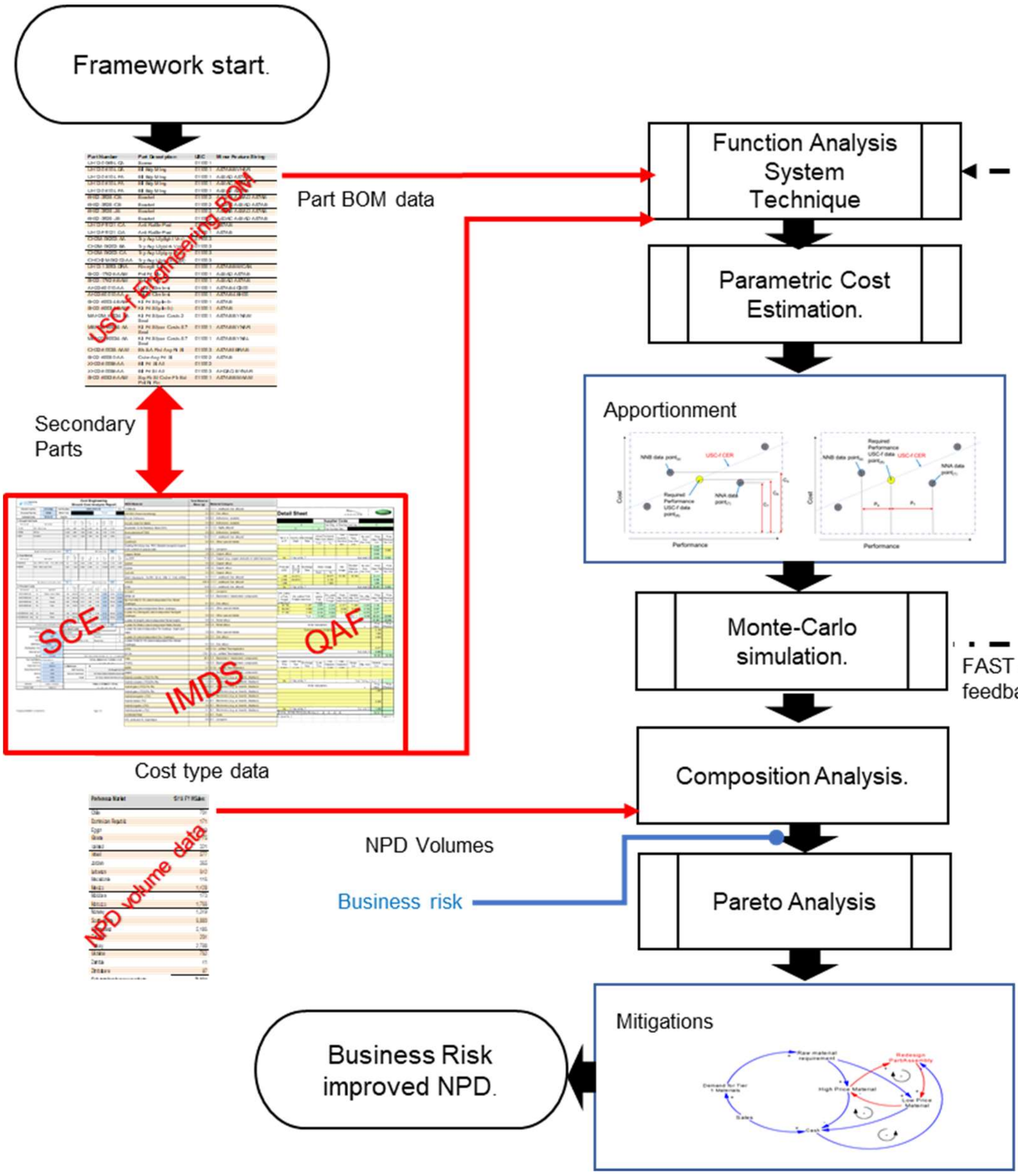


Fig 56: Framework case - Modified feature and parts, where the parts contribute to the delivery of multiple features.

The ‘Modified feature and parts, where the parts contribute to the delivery of multiple features’ is the most complex of the four framework cases and the only situation where both FAST and Monte-Carlo Simulation are employed.

The need to employ Monte-Carlo simulation is because of the ‘allocation’ of cost type impact within the USC-f. In applying the Monte-Carlo simulation the allocation of the cost type data within the FAST application is ‘flexed’ to establish if the allocation itself has a significant impact on the target cost type analysis of business risk.

FAST therefore requires some understanding as the application of the framework where modified feature and where the parts contribute to multiply feature are involved is highly dependent upon it. Table 27 shows an application of FAST to a hypothetical USC BOM against a set of features that the USC and its parts support.

Table 27: Part cost allocation against USC-f

USC (nnnnnn)							
		Features					
PartCost	(£)	(a)	(b)	(c)	(d)	(n)	Total
(a)	22.03	19.80	2.23				**22.03**
(b)	1.29		1.29				**1.29**
(c)	0.78				0.78		**0.78**
(n)	3.37		2.98			0.39	**3.37**
Total	**27.47**	**19.80**	**6.50**	**0.0**	**0.78**	**0.39**	**27.47**

The output USC-f data will be used as a source data in the USC-f CER. It is essential that each row and column accumulate to the original value of the row or column, ensuring that all USC cost has been allocated. It is also vital for subsequent analysis that the nature of the accessed cost allocations is recorded. For example, Part(a) cost allocated to Feature(a) (£19.80), might be the raw material and some processing cost, while the remainder of the cost for Part(a), (£2.23), allocated to feature(b) is processing cost only.

When FAST has been employed to allocate cost data across features there is a requirement to stress the results that are obtained from the composition analysis using devises such as Monte-Carlo simulation. The application of Monte-Carlo simulation flexes the allocation of cost to each feature within the limits of the total cost available to be allocated. The results obtained confirm if the identified business risks are significantly influenced by the allocation of cost rather than the design itself.

Monte-Carlo method.

At its most basic the application of a Monte-Carlo simulation seeks to apply statistical methods to determine the outcome for an event. The event in the case of the hybrid methodology is the allocation of part cost type to each feature provided by the part. Table 27 shows discrete values of cost being assigned against each feature. The table also shows that the sum of the allocation must add up to the whole part cost type, but it also shows that some features supplied by the USC are not dependent upon a specific part within the USC BOM. It may also be that upon inspection a specific feature does not attract a part cost type – the feature maybe indifferent to a manufacturing process for instance. The precise boundary conditions will need to be applied by inspection to each situation. To function the Monte-Carlo simulation needs a randomly generated series of data points, typically 1,000 data points are the minimum. In the case of PartCost (a) in Table 27 this would result in the minimum of 1,000 combinations of feature cost (a) and (b), duplicate data points are permitted. Once generated the statistical means for feature cost (a) and (b) are calculated together with the standard deviation for the result. The statistical means are fed into the feedback loop as shown in Fig 56. The feedback loop should be exercised a prescribed number of times, typically 100 and the variation in NPD composition analysis and Pareto Analysis monitored for stability in the business risks identified.

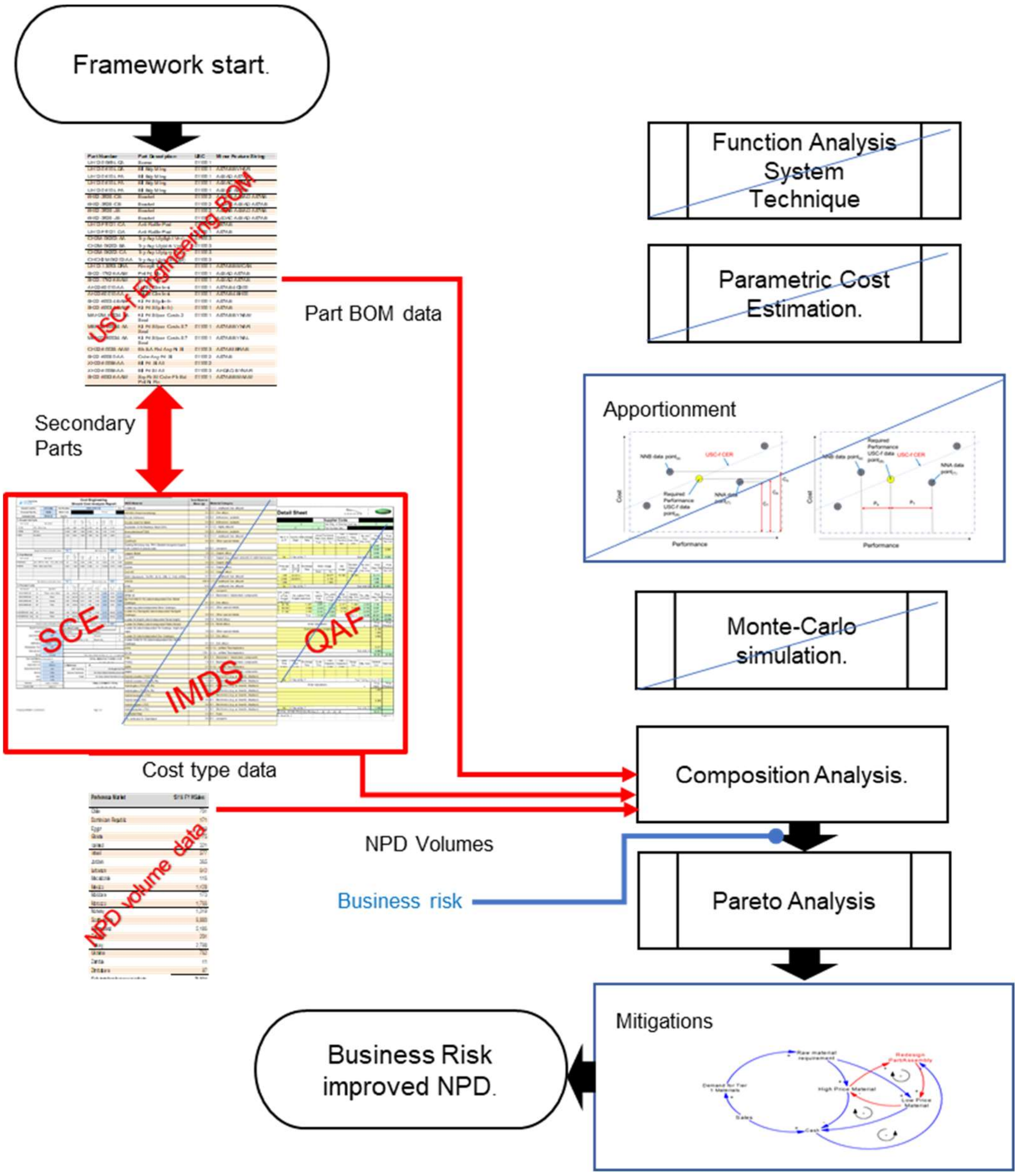


Fig 57: Framework case - New feature and part/s or an existing feature delivered through new technology.

The analysis of 'New feature and part/s or an existing feature delivered through new technology' is the same, as far as the framework flow diagram is concerned as the 'Carryover of an existing feature and parts'. In both cases the source data is already specific to the USC-f and the planned parts that will be required to deliver the required feature content.

In the case of the new feature as shown in Fig 57 the source of cost type data will be constricted to SCE based on the proof of concept research/development. This cost data constraint being due to no historical data available other than through competitor data or complimentary industry application of the feature and or technology. The cost estimating of new technology, as proposed in the literature review, (pg 26) can evolve from many sources of data; pure research; cross industry studies and even competitor analysis or patent analysis. Ultimately it will result in a generalised design which can be turned into an SCE. In situations where the new technology is being developed within a tier 1 supplier relationship the supplier may provide QAF support.

In Chapter 5 - Methodology illustration. the hybrid methodology framework will be physically illustrated with real world examples.

Chapter 5. Methodology illustration.

There is a need to illustrate the proposed method. With the acknowledgement that the real data from an automotive system and its parts may itself be involved and as a result not lead to clarity an illustration of the developed method that results from this research will be presented based on a takeaway cup. Consider the common 8oz to 12oz to 16oz takeaway coffee cup and lid.

5.1. Takeaway cup illustration of the methodology.

Takeaway cups come in several sizes; 8oz, 12oz, & 16oz are most typical. 4oz and 10oz also exist. In this example, physical material and internet sourced data will be used to establish the source data required to create a PCE CER. 8oz, 12oz & 16oz will be used to simulate the existing product that would provide the data to create the CER. Once created a new cup size, 10oz, will be established simulating the intended NPD. The discussion will also be given to the establishment of an NPD outside of the existing data boundaries, 4oz and 24oz.

> The expectation is that NPD quantities of material and process can be established, uncertainties identified and considered for mitigation as potential business risks.

The illustration will be broken down to stages:

> Establishment of the required metadata data. These will be specifically developed using Should Cost methodology.
>
> Establishment of cost type CERs.
>
> Establish the NPD results from CER application.
>
> Review the extraction of business risk data.
>
> Using 4oz, 10oz, 24oz review issues relating to the potential accuracy of the method.

The illustration will not explore the allocation methodology, the apportionment between two known points or the application of Monte-Carlo simulation, the illustration is too simple to need these stages.

5.1.1. Establish required metadata for takeaway cup SCE.

In creating an illustration of the hybrid methodology, it is felt that the complexity of automotive systems may not allow the application of the methodology to be seen against the complexity of the automotive system. In the following illustration, the hybrid methodology is applied to take away paper cups of the type found in coffee shops.

The first stage of the application is to establish the standard metadata that might be involved, and this is undertaken with an internet search.

Fig 58 & Fig 59 show takeaway cup overall size data sourced via the internet. For the interests of this illustration, the data relating to 8ozU, 12oz and 16oz will be used alongside the Universal hot sipper lid.

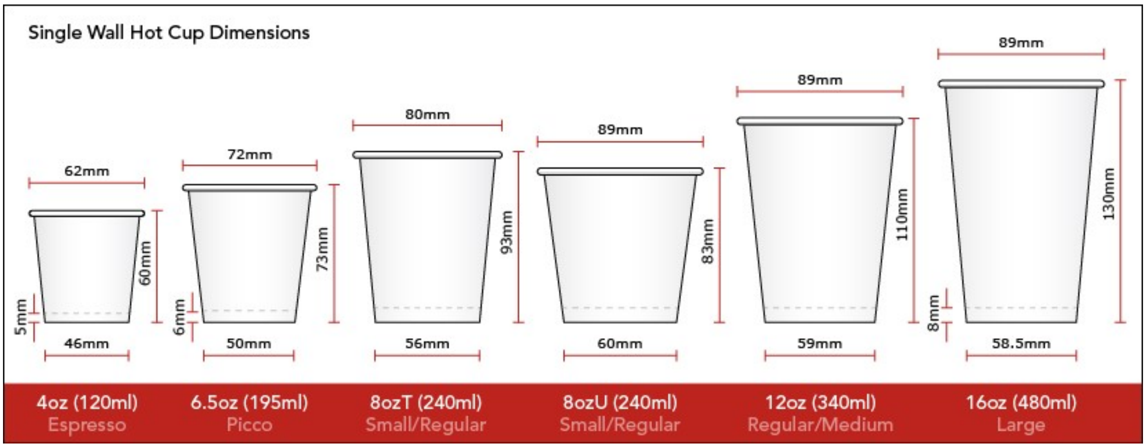


Fig 58: Generic takeaway cup sizes.

(Data source: http://www.thepapercupcompany.com/html/single_wall_hot_drink_cup.html.)

8-12-16oz Universal Hot Sipper Lid (White/Black)	
Product Codes	JL_HL_8~16_W/B
Top Rim Diameter	89mm
Material	PS (Good Poly Biodegradable)
Quantity per Carton	1,000 (10 Sleeves x 100 Lids)
Carton Weight	3.5kg
Carton Dimensions	460mm (L) x 190mm (W) x 480mm (H)
Max. Cartons per Pallet	56 Cartons (=56,000 Lids)

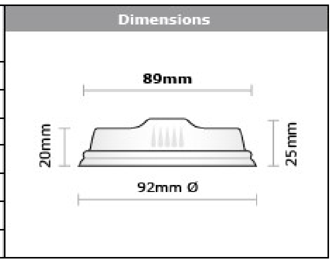


Fig 59: Generic takeaway cup lid.

(Data source: http://www.thepapercupcompany.com/html/single_wall_hot_drink_cup.html.)

Because the lid is common the material and process CERs are already known to be flat lines across the takeaway cup feature levels. As the target NPD takeaway cup is 10oz and within the range of the existing source data, it is reasonable to assume that it will also use this common size of the lid.

Fig 60 shows a 12oz cups dimensional detail. Although from a different internet source the dimensions are similar enough to those shown in Fig 58 to be useful for SCE. Table 28, from a third internet source, shows similar, not perfectly aligned data to either Fig 58 or Fig 60 but is still useful as it provides increased detail of the cup body and bottom material. Most internet sources quote the cup material as P.E. coated paper, single side coating, Table 28 provides the composition detail, how much PE to wood pulp.

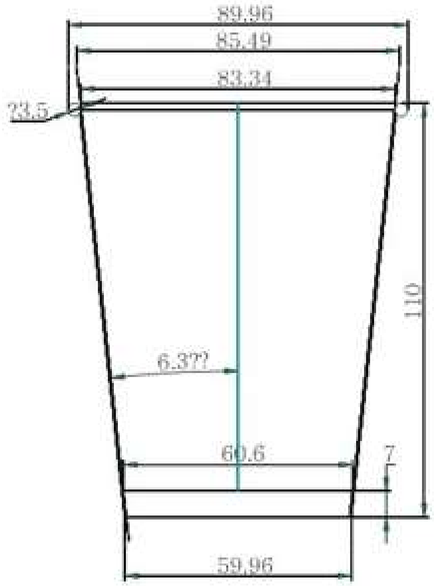


Fig 60: 12oz cup detail. Dimensions in mm.

(Data source: http://www.printed-cups.com/specifications/)

Table 28: Further takeaway cup details - weight of material.

(Data source: https://www.alibaba.com/product-detail/double-wall-paper-coffee-cups-triple_60694977147.html)

Paper Cup for Single Wall

Volume	Paper weight	handle	Package(set)	packing(ctn)	Specification		
					Top(mm)	Bottom(mm)	Height(mm)
	150gsm+15gsm PE		50pcs	2000pcs	48	35	51
2.5oz	170gsm+15gsm PE		50pcs	2000pcs	48	35	51
	150gsm+15gsm PE		50pcs	1000pcs	56	40	56
3oz	180gsm+15gsm PE		50pcs	1000pcs	56	40	56
	190gsm+15gsm PE		50pcs	1000pcs	62	45	60
	210gsm+15gsm PE		50pcs	1000pcs	62	45	60
4oz	230gsm+18gsm PE		50pcs	1000pcs	62	45	60
	180gsm+15gsm PE		50pcs	1000pcs	68	50	71
	190gsm+15gsm PE		50pcs	1000pcs	68	50	71
6oz	210gsm+15gsm PE		50pcs	1000pcs	68	50	71
	200gsm+15gsm PE	with handle	50pcs	1000pcs	73	53	80
	210gsm+15gsm PE	with handle	50pcs	1000pcs	73	53	80
7oz	230gsm+20gsm PE		50pcs	1000pcs	73	53	80
	210gsm+15gsm PE		50pcs	1000pcs	71	45	94
	230gsm+20gsm PE		50pcs	1000pcs	71	45	94
7.5oz	260gsm+20gsm PE		50pcs	1000pcs	71	45	94
	260gsm+20gsm PE		50pcs	1000pcs	80	57	91
	280gsm+20gsm PE		50pcs	1000pcs	80	57	91
8oz	300gsm+20gsm PE		50pcs	1000pcs	80	57	91
	260gsm+20gsm PE		50pcs	1000pcs	78	53	95
	280gsm+20gsm PE		50pcs	1000pcs	78	53	95
9oz	300gsm+20gsm PE		50pcs	1000pcs	78	53	95
9oz	210gsm+15gsm PE	with handle	50pcs	1000pcs	78	53	95
	300gsm+20gsm PE		50pcs	1000pcs	90	60	95
10oz	320gsm+20gsm PE		50pcs	1000pcs	90	60	95
	320gsm+20gsm PE		50pcs	1000pcs	90	60	112
12oz	350gsm+20gsm PE		50pcs	1000pcs	90	60	112
	320gsm+20gsm PE		50pcs	1000pcs	90	60	135
16oz	350gsm+20gsm PE		50pcs	1000pcs	90	60	135

The amount of cup body material can be derived from the feature level size and consideration of the flat fan form blank that the cup body would be formed from. The bottom of the cup like the lid is common to all sizes within the required range, and its contribution would be as a carryover part or system within the NPD.

The flat form characteristics are shown in Fig 61 and dimensioned in Table 29.

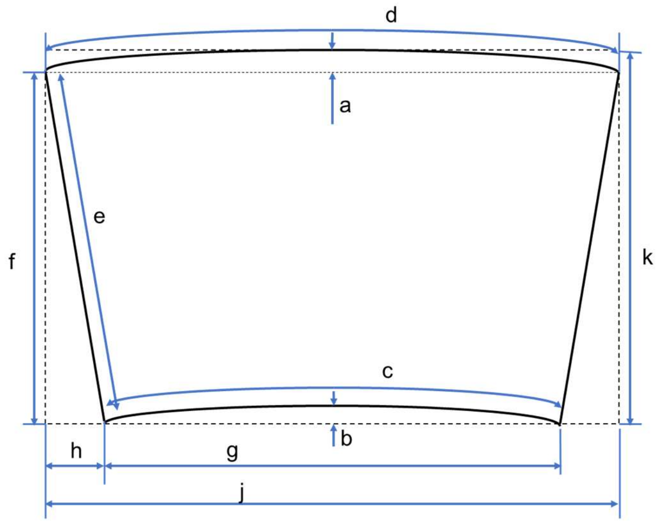


Fig 61: Flatform material size development.

Table 29: Cup data keyed to Fig 61

Cup size		**8oz**	**12oz**	**16oz**	***Units***
Top cord depth	a	7.94	7.94	7.94	mm
Bottom cord depth	b	6.35	6.35	6.35	mm
Bottom circumference + seam allowance	c	197.52	194.378	192.807	mm
Top circumference + seam allowance	d	288.638	288.638	288.638	mm
Cup height + Top and bottom allowances	e	96	123	143	mm
Coning Adjacent	f	93.39191	120.9754	141.2623	mm
Bottom cord length	g	190.5	190.5	190.5	mm
Coning Opposite	h	22.225	22.225	22.225	mm
Fan blank width	j	234.95	234.95	234.95	mm
Fan blank height	k	101.3319	128.9154	149.2023	mm
Top cord length	j	234.95	234.95	234.95	mm
Top roll allowance		5	5	5	mm
Bottom seal allowance		8	8	8	mm
Cup height		83	110	130	mm
Cup top diameter		89	89	89	mm
Cup bottom diameter		60	59	58.5	mm
Seam allowance		9	9	9	mm
Blank size mm^2		23807.93	30288.68	35055.09	mm^2

Fig 62 shows the data from Table 29 shown as a PCE CER. The simple equation of best fit is given as:

$$y = 1406x + 12561 \tag{27}$$

A fully developed CER would not be the linear equation shown in (27). A fully developed equation would need to result in no material (ZERO) for a 0oz cup.

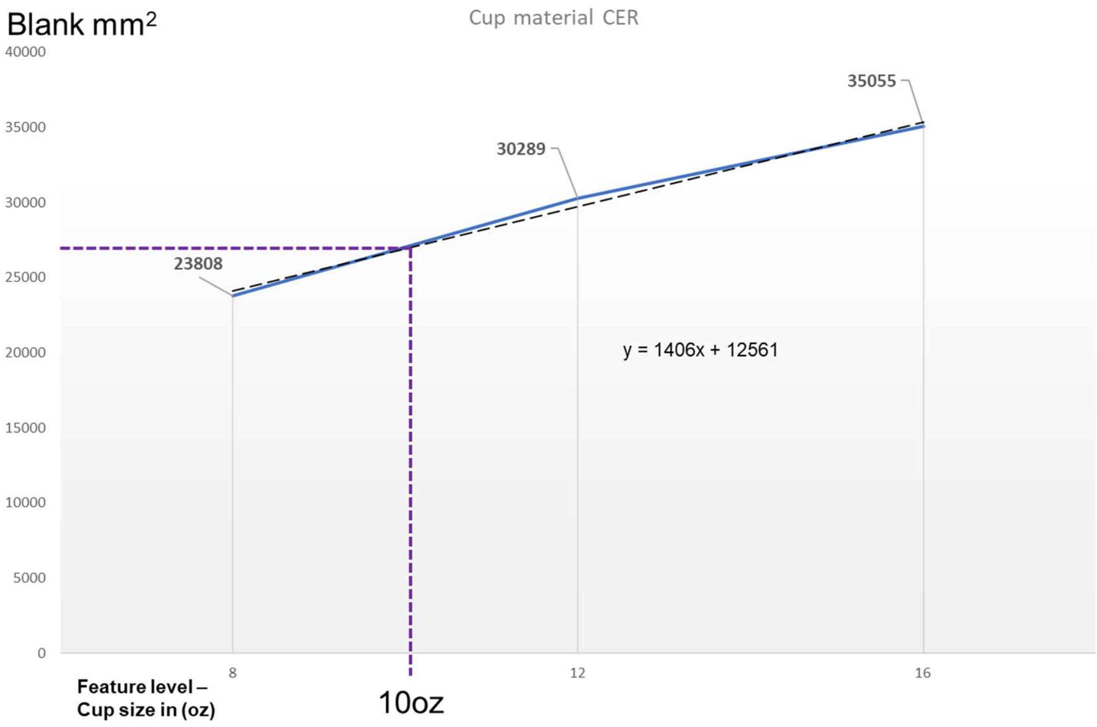


Fig 62: Take away cup material blank CER.

If the requirements of a 10oz blank were required, this simple equation, shown as (27), would be a reasonable estimate. As shown in Table 30

Table 30: Target NPD estimates

Cup size	4oz (mm²)	10oz (mm²)	24oz (mm²)	
CER derived	18,185	26,621	46,305	
SCE derived	16,964	26,697	46,909	
Error (%)	+6.7%	-0.28%	-1.3%	

both the 4oz and the 24oz are outside of the existing CER, drift or an increasing degree of error can be expected when the target point lies outside of the known data range.

Studying the results obtained and shown in Table 30 the simplistic CER being used, (a straight-line regression) is acceptable when the target size is within the existing range of CER data points. It shows weakness above the range but within an acceptable margin of error. For targets below the CER data, a revised regression line should be considered to increase the accuracy.

If the 4oz and 24oz cups were to be produced directly from these conditions, the 4oz would be a very squat cup – more of a shallow tub while the 24oz would be tall and potentially unstable as a result. The top and bottom diameters need to be adjusted accordingly.

The estimate of the takeaway cup sleeve would be a slightly smaller fan shape but in a plain wood pulp rather than PE coated material.

The lids have been established as common between these cup sizes. Lid material is physically marked on sample lids as Polystyrene (PS) ♸.

Details of the manufacturing processes for lids, cup bodies, bottoms and sleeves are available from various internet sources. Cup bodies and bottoms are made in cycle on a common machine. Sleeves are made on a separate machine which also completes the assembly of the sleeve to cup body with a bottom. All target sizes are produced on a common machine and with a common cycle time ranging from *85 - 185pcs/m in the case of the cups.*

5.1.2. Takeaway cup analysis.

With the currently understood application of PCE, using the total cost of the known cups, the materials for the cup and lid cost as well as the manufacturing costs would all be proportionately adjusted by the CER derived from currently known cost data. By taking the metadata into account, it was established that the lid is a constant and therefore only the cost of the cup should be flexed and even then, only the material cost and not the production cost.

The comparison of the CER derived cup body material cost shows favourably against the SCE methodology and in overall terms requires significantly less input. The comparison is shown in Table 30. Fig 63 & Fig 64 show more detailed looking at the breakdown of cost structure and associated CERs for the source data range of cups; 8 oz; 12 oz; 16 oz.

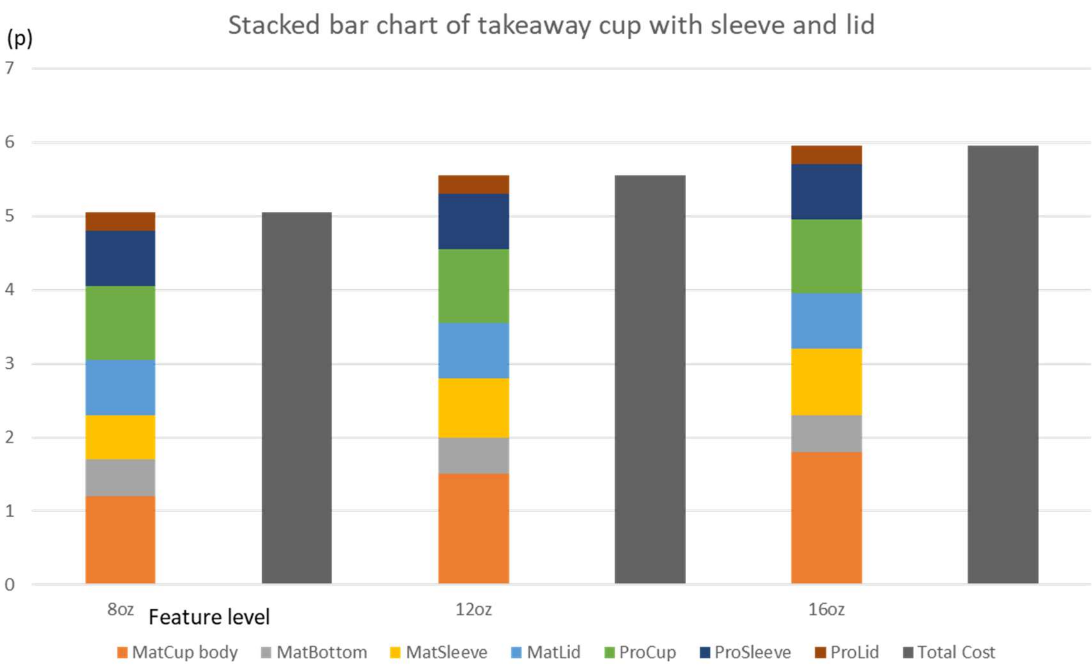


Fig 63: Stacked bar chart cup data by feature level - cup size (oz).

Usefully Fig 63 shows that real products can be represented in the same way as was proposed by Fig 32: Bar chart detailing cost types and total cost of USC-f.

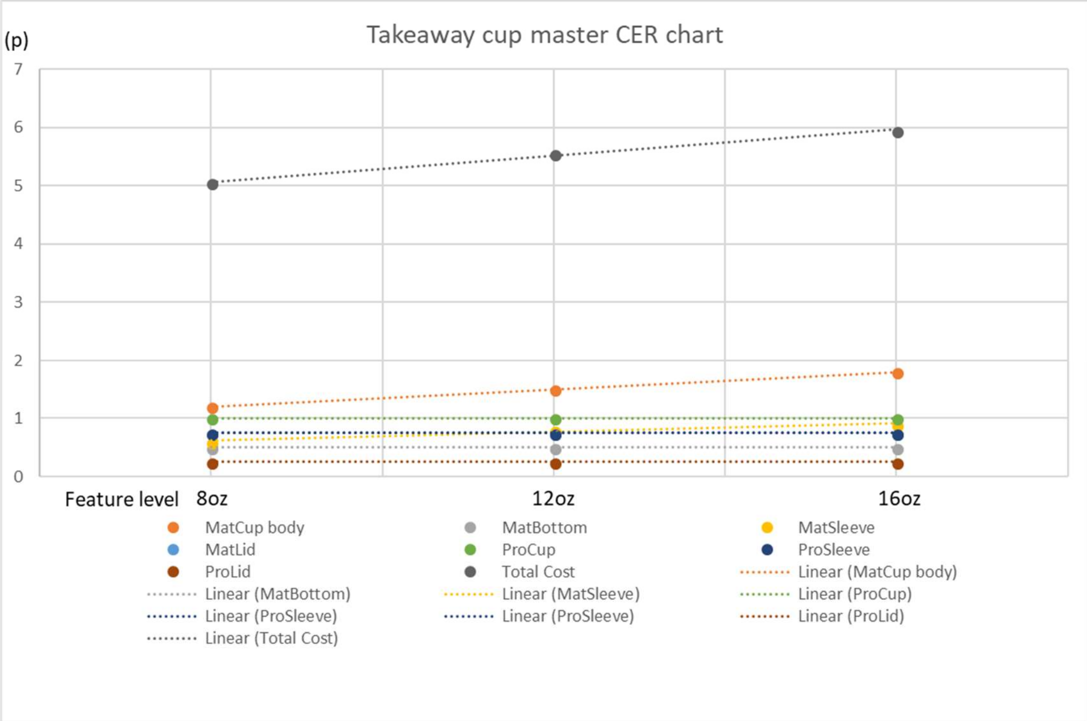


Fig 64: CER scattergram of cup cost type data

Correlation is also shown through Fig 33 and Fig 64 as far as real data representation in detail material CER form.

Fig 65 to Fig 70 show actual price data over time for wood pulp, the main commodity in the paper cup. Shown are the data from three international markets; Asia; European and North American. Also shown, are the virgin and recovered wood commodities, the data was sourced from (Risiinfo, 2018). The existence of different commodity markets

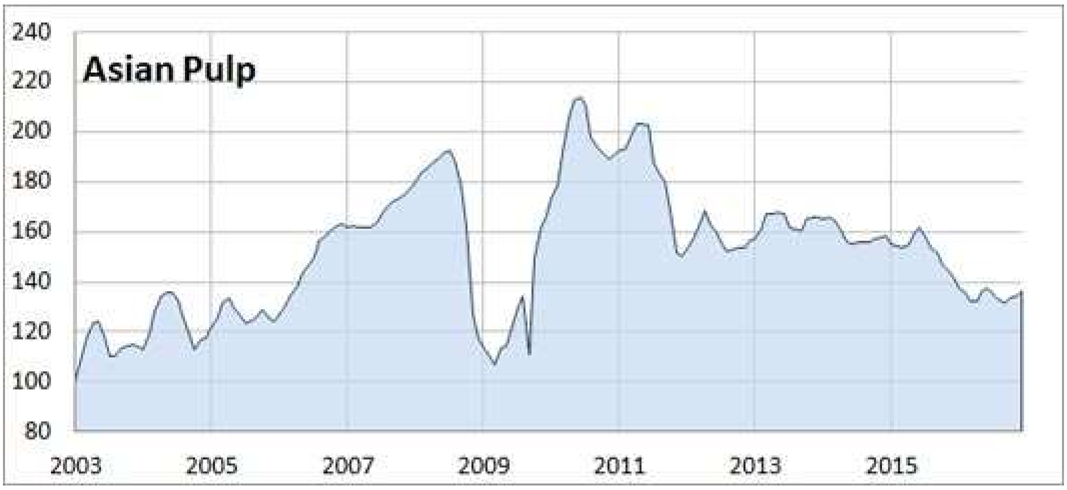


Fig 65: Asian sourced wood pulp pricing over time.

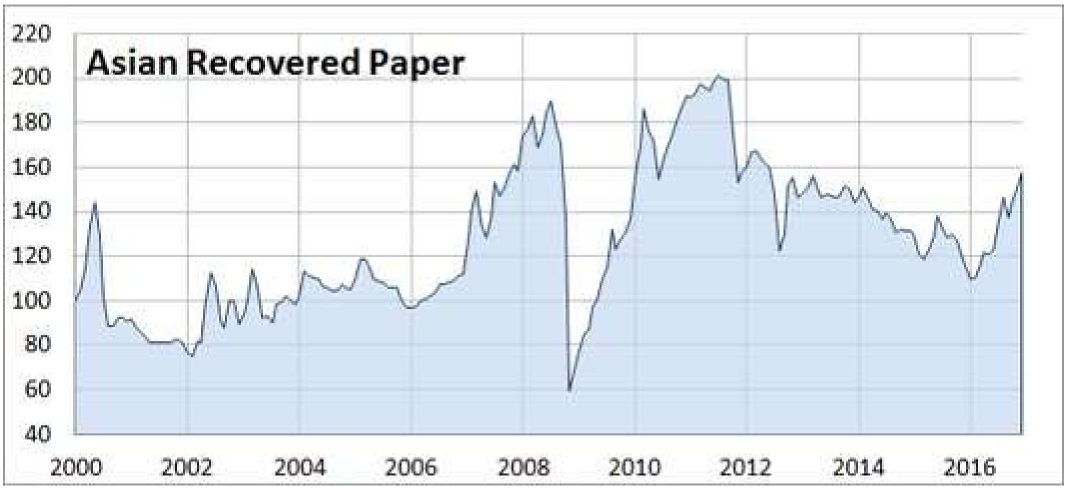


Fig 66: Asian Recovered Paper pricing over time.

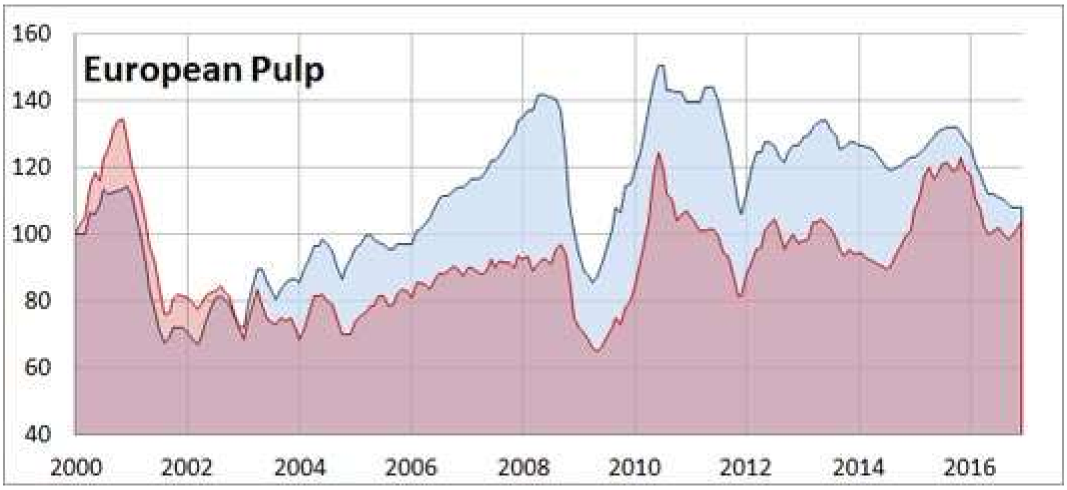


Fig 67: European Pulp pricing over time.

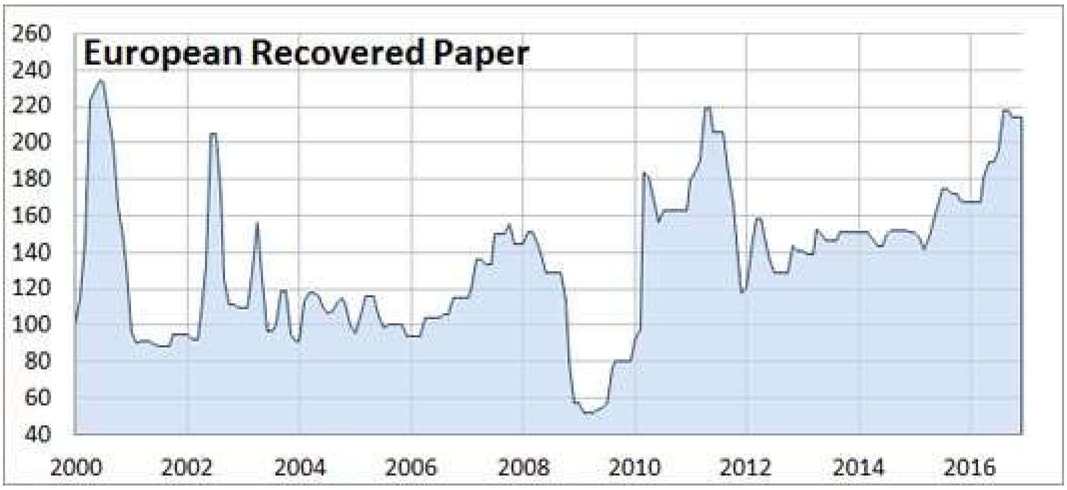


Fig 68: European wood pulp pricing over time.

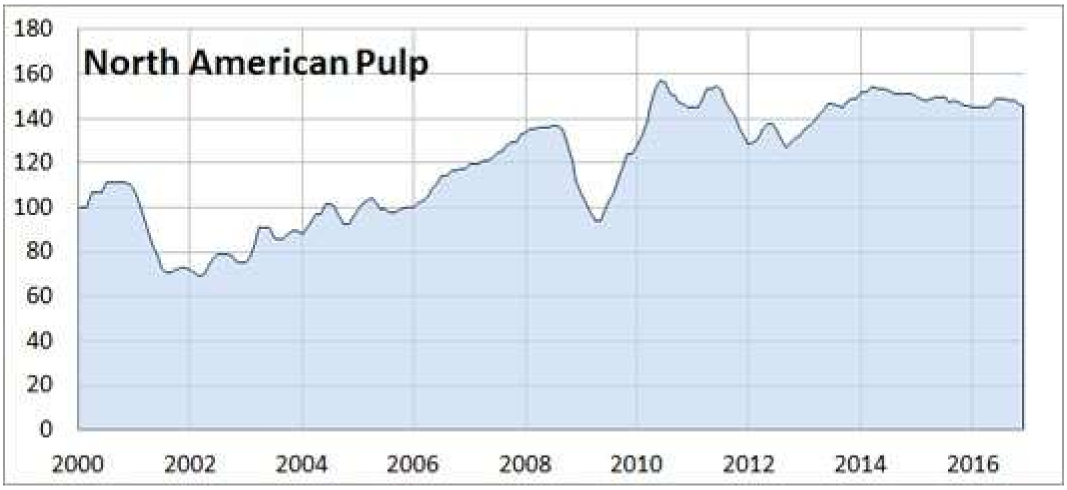


Fig 69: North American Pulp pricing over time.

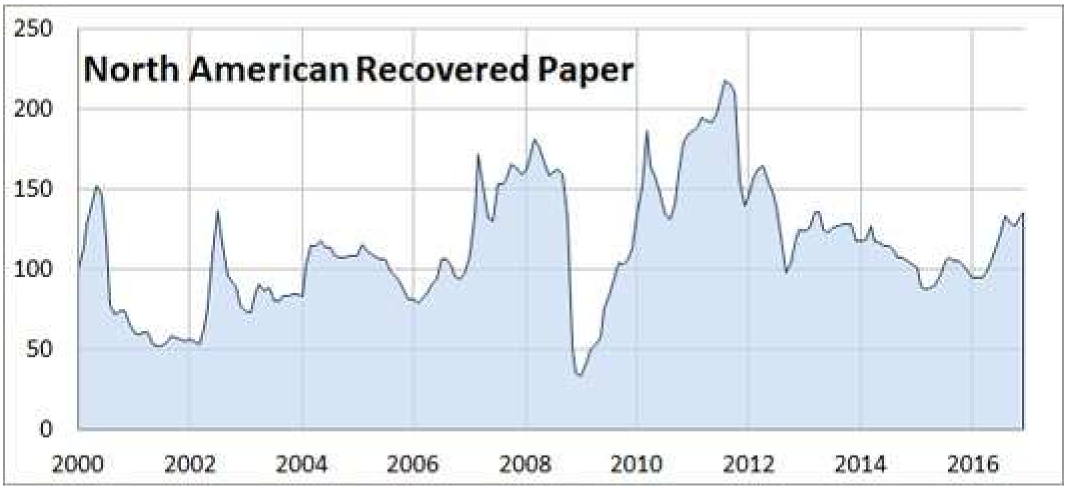


Fig 70: North American Recovered Paper pricing over time.

allows a variety of sourcing to meet point in time pricing, currency and even country of origin should the NPD being developed require some specific mitigation. Fig 69 and Fig 70 show the North American data and the possibility to further adjust the material pricing by introducing recovered pulp as a proportion of the virgin wood pulp. Example: In 2016 Fig 69 and Fig 70 show virgin wood pulp to be approximately 142 cost units, recovered to be approximately 90 cost units. The data shows that adopting recovered pulp might result in a 37% saving for every volume unit substituted.

The takeaway cup lid has already been identified as a constant across the 8oz, 12oz and 16oz cup sizes but as shown in Fig 71 the material that it is made from, typically Polystyrene exhibits price volatility. It is, therefore, a candidate for resourcing, redesign to use recycled materials and or material substitution.

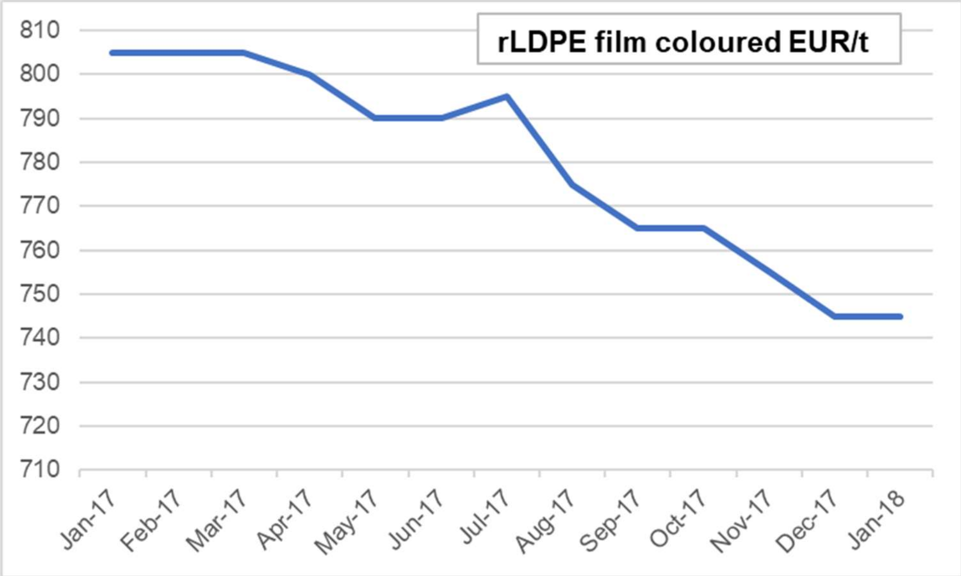


Fig 71: Polystyrene pricing.

The data shown in Fig 71 was sourced from (PIE, 2018).

Takeaway cup review.

Basic SCE methods have been used to develop the amount of, and types of, materials. It is therefore practical to establish the required data to develop all of the CERs.

The approach has shown that CERs representing the individual materials can produce usable results, but the example is very simplistic having very few materials and no requirement to employ allocation of costs to achieve the delivery of multiple features. While the illustrated application of a CER for every material involved is possible, it would not be practical when delivering the NPD of a complex structure such as an automobile.

In the following automotive example, allocation of costs across feature delivery is still avoided but, a CER for a complex cost type is employed and introduces the need for the apportionment described in Fig 27 (pg 75) reducing the required detail to the analysis of two CER data points rather than all contributing data points. The automotive illustration will also introduce the application of composition analysis.

5.2. Automotive illustration.

The paper cup illustration provided in section 5.1 illustrated the principals of the hybrid methodology by attempting to deal with a simple but common everyday item. In this automotive example, a single engineering system known as USC 090101 - rear exhaust systems will be used. The choice of USC is not by chance because there is still a need to keep the automotive example simple to allow the application of the hybrid methodology to have clarity. USC 090101 delivers to just one feature but has multiple parts providing a significant increase in complexity. Because it delivers to just one feature, no allocation is employed.

In Fig 11 (pg 18) and subsequently in Fig 27 (pg 75) the resulting estimate for the desired performance is indicated by the arrow. The USC-f source data points are also shown and are used to establish the regression line also known as the CER. The resulting regression line shown as a chain may not be a straight line as shown in Fig 11. Fig 27 showed a close up of the required data point and the near USC-f Source data points. If the technology being employed in the estimated point is the same as the technology used in the source points, then it is reasonable to assume that it is possible to interpolate from two near source points to the required estimate estimated point. A simple ratio can be applied to apportion the amount of cost movement that might be expected in achieving the required data point. See equations (7), (8), (9) & (8) section 4.3.

The example data shown in Fig 27 has the lower performance source data point at a higher cost than either the required or the higher source data point. While this is counter-intuitive this situation was observed when using historical data during an exercise undertaken in 2010. In an un-published Jaguar Land Rover study, it was observed that higher performance door card from a Jaguar XF was the lower cost when compared to old style Range Rover, Range Rover Sport and Discovery. The increase in costs was counter-intuitive as the XF part was also the lowest volume which should have led to the XF being the highest cost part.

5.2.1. Application of detailed source data.

Each data point within the construction of the CERs is itself made up of a sub-group of historical parts either in whole or parts thereof. An SCE and or Quotation Analysis Form (QAF) are typically constructed using a combination of five elements of data; bought-out parts; raw materials; processing costs; general overheads; services, tariffs and profit.

In Table 27 (pg 124) an exercise was undertaken to allocate the part cost to the delivery of each feature represented within the USC. It was noted that during the allocation process there was a need to record the basis of those allocations regarding material and processes.

Each model line will generate its own source data point. To ensure that the allocations of cost to a USC-f are reasonable it is necessary to validate against several USC-f combinations created by different vehicle specifications.

Within the research presented in this paper, the scope has been restricted to look purely at the tier 1 materials indicated within the NPD. Therefore, there is only a requirement to consider materials allocated to features. The identification of the materials at a detailed level is also available through an additional source, International Material Database System (IMDS). The IMDS data can be substituted for a full vehicle SCE. There are differences which need to be acknowledged. Within the SCE the material data is at gross weight conditions while in the IMDS it is at the net supplied weight. The SCE additionally contains the full processing description; the IMDS does not contain any processing. QAF data could also be a suitable source of data and is closely aligned to SCE data in that it contains gross weights and processing descriptions. It does have a limitation in that it typically only details the data as it relates to the tier 1 QAF supplying source all sub-tier 1 data being shown as bought out.

5.2.2. Application of Composition Analysis.

In section 2.4 (pg 19) (International Material Database System) IMDS was introduced within the literature review. Some of the data content was also presented in Fig 18 (Recyclability) (pg 42). These entries within the literature review presented that if IMDS data is available and correctly completed a manually derived composition analysis may not be required because it would be extractable from IMDS itself. Where IMDS data is not available or is incomplete SCE, QAF, or other metadata may allow an insight into the probable materials but to understand the economic volatility of the material it is necessary to understand the materials composition. Composition analysis is a technique to achieve this. When considering raw materials, they will typically only be known as a grade; this has even been the case with the data sourced from JLR IMDS. All material grades even tradenames have a known chemical composition, most can be found with an internet search, but other materials typically used in aerospace where materials are developed to unique standards internal sources may be required to establish the composition. Once established the composition analysis will allow the raw material used in historical CER data points to be analysed to determine its economically volatile components.

Table 31: Composition analysis for typical vehicle exhaust system materials.

Composition Analysis

Grades (AISI)	409	304	321	441		430	305	309	
Grades (EN)	1.4512	1.4301	1.4541	1.4509	1.4713	1.4016	1.4303	1.4828	
Iron (Fe)	87.67%	69.92%	71.52%	80.68%	91.66%	81.45%	68.87%	61.37%	
Carbon	0.04%	0.04%	0.04%	0.01%	0.06%	0.12%	0.60%	0.10%	
Nickel (Ni)	0.25%	10.00%	9.40%	0.00%	0.00%	0.40%	11.00%	14.00%	
Chrome (Cr)	11.00%	19.00%	18.00%	18.00%	7.00%	17.00%	18.00%	23.00%	
Molybdenum (Mo)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%			
Manganese (Mn)	0.50%	1.00%	1.00%	0.30%	0.50%	0.50%	1.00%	1.00%	
Phosphorus (P)	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	
Silicon (Si)	0.50%	0.01%	0.01%	0.35%	0.75%	0.50%	0.50%	0.50%	
Sulphur (S)	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	
Titanium				0.17%					
Columbium				0.45%					
Proposed useage @ NPD Volumes (Tonne)	**871**	**412**	**279**	**3222**	**179**	**15**	**8**	**281**	**5268**
Proposed useage in Tonnes by Composition.									**Total (Tonne)**
Iron (Fe)	1,986	750	519	6,758	427	31	14	448	10934
Carbon	1	0	0	1	0	0	0	1	4
Nickel (Ni)	6	107	68	-	-	0	2	102	286
Chrome (Cr)	249	204	131	1,508	33	7	4	168	2302
Molybdenum (Mo)	-	-	-	-	-	-	-	-	0
Manganese (Mn)	11	11	7	25	2	0	0	7	64
Phosphorus (P)	1	0	0	2	0	0	0	0	3
Silicon (Si)	11	0	0	29	3	0	0	4	48
Sulphur (S)	1	0	0	1	0	0	0	0	2
Titanium	-	-	-	14	-	-	-	-	14
Columbium	-	-	-	38	-	-	-	-	38

The simple composition analysis shown in Table 31 shows data covering several actual JLR products with grades of material left to right and the composition of those grades top to bottom. By extending the data to the planned business usage through the combination with planned NPD volumes, the resulting business risk can be extrapolated.

The technique was developed within JLR in 2007 to evaluate the risk the company faced from rapidly rising costs of the alloy commodities. However, the technique can also be deployed within NPD, the object being to identify then reduce the usage of higher commercial risk options such as AISI grade 304. Within the data shown in Table 31, 304 is used both for high-temperature resistance and cosmetic appearance. For example, when used in tailpipes it holds a high polish. By redesigning to hide the tailpipes, the attributes required within the tailpipe materials can be reduced, and the commercial risk resulting from the tailpipe material composition can be reduced.

In the following example, the Discovery Sport rear exhaust illustration shown in Fig 72 has been extracted from the JLR parts manual. The rear exhaust is contained within USC 090101 and contains four key part numbers. These are detailed in Table 32 and shown in Fig 72.

Table 32: Key parts in USC 090101

Ref number in Fig 72	Description	USC
5A231A	Clamp 60mm	090101
5A231B	Clamp 55mm	090101
5E217	Bracket - Exhaust pipe mounting	
5F262A	LH Rear Isolator	
5F262B	Rear Isolator	
5K244	Muffler and pipe - rear	090101
5255	Pipe - Exhaust	090101
HB1	Bolt, hex M8x 20mm	

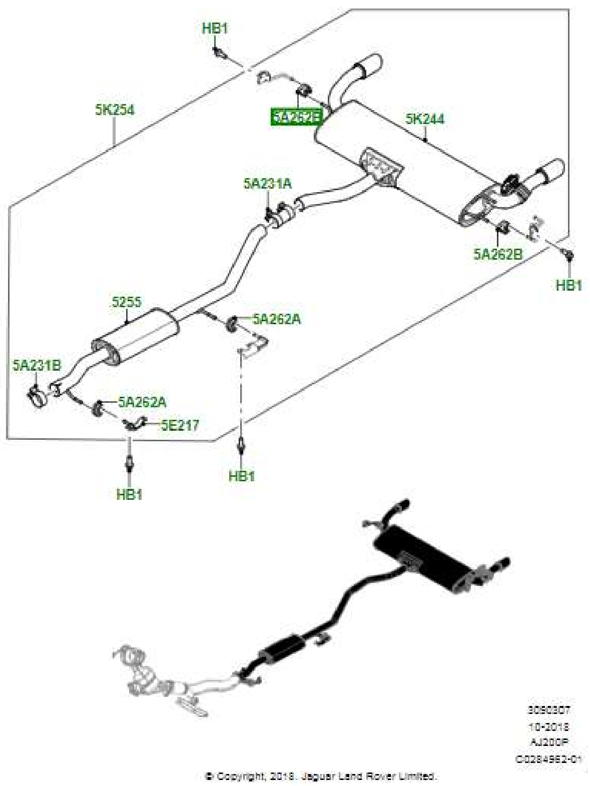


Fig 72: Illustration of the Discovery Sport Rear Exhaust as listed in Table 32

Table 33 shows a material grade view of USC090101, in this form the data provided is not very useful.

Table 33: IMDS material data for the Discovery Sport Rear Exhaust USC090101 above 200g contribution.

IMDS Material	Material Mass (g)
HR4	575.400
MILD STEEL 070M20	225.000
X2CrTiNb18	8215.000
X2CrTi12	5497.000
C10	1496.000
X5CrNi18-10	1560.000

The composition view of Table 33 is given in Table 34.

Table 34: Table 33 in post analysis composition view

USC 090101 Composition	Discover Sport (g)	Scarce list (Fig 18)
Fe	16054.6	
Si	62.7	Y
Mn	60.3	Y
Cr	1186.1	Y
Ni	144.3	
P	6.8	
C	3.9	
S	4.9	
Ti	32.7	
Nb	11.2	Y
N	0.9	

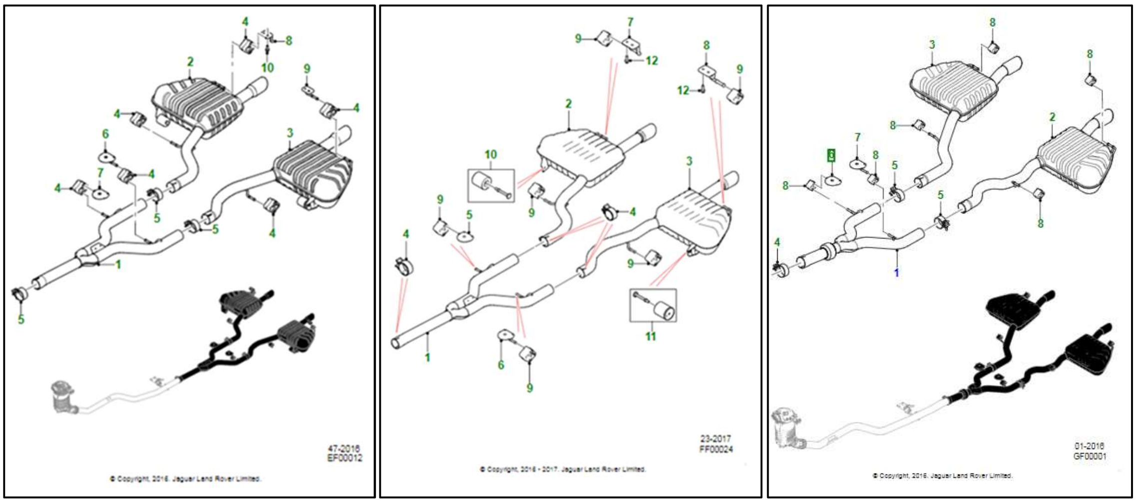
To achieve a complete picture of an NPD material risk the analysis of the composition needs to be completed on the total NPD content or to the limit of the known, probable content. To achieve this requires analysis of each USC group of contributing parts and evaluation for significant contribution of weight and Price Volatility Index (PVI) impact.

Nb: In the example, IMDS data extraction shown in Table 33 an arbitrary cut-off of 200g has been used, but the cut-off needs to consider the commodity volatility Index and the degree of business sensitivity that is deemed acceptable.

It is also interesting to note that as shown in Table 40: Pre-existing JLR monitored commodities none of the identified scarce commodities is included. The implication being that their impact would be a business risk and shock should the quantities of their usage in combination with any price volatility be high.

5.2.3. The hybrid methodology applied to identify NPD material using IMDS data.

Fig 73 provides the physical illustration of the three USC 090101 rear exhaust systems being used in this simulation. Each is taken from a different Model and are for 2.0L diesel derivatives. (The illustrations include rubber mounts, these have been excluded as they do not form a part of the USC 090101 specified bill of materials.).



Model 'A' Model 'B' Model 'C'

Fig 73: Illustration of the three USC 090101 source materials used in this simulation

Fig 74 Shows the basic PCE CER created from the three models for USC 090101. The fig also shows the position of the targeted NPD performance for USC 090101.

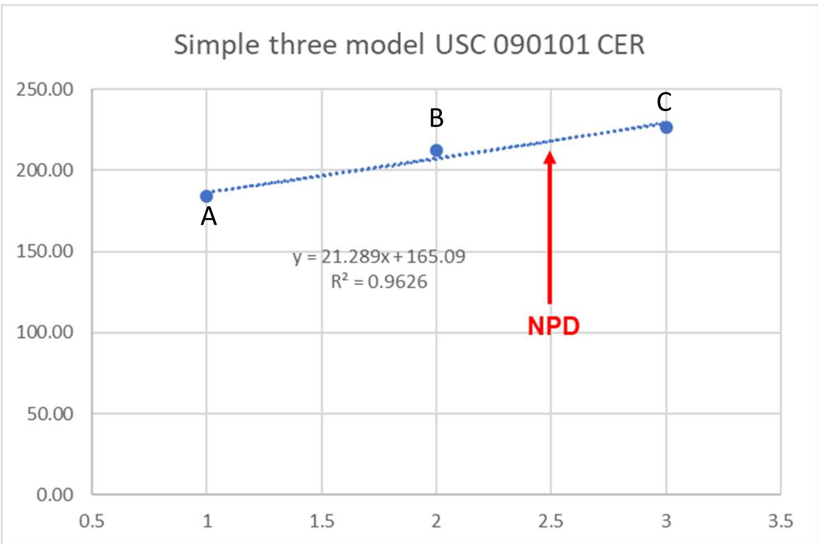


Fig 74: Simple three-point CER representing USC 090101

NPD target, x=2.5 provides a target material value, C_R, of 218.31 as provided by the CER. Without any further analysis using metadata a value of 218 for USC 090101 would be all that is known about this NPD.

The IMDS sourced metadata behind Fig 74 is given in Table 35, and the NPD point is that shown as performance 2.5 in Fig 74.

Table 35 Shows the IMDS sourced metadata behind the three models and the and the simulated data for the NPD the equations (7), (8), (9) and (10) having been applied to generate the weighted data for the simulated NPD. The implication is that the uncertainty within the over simplistic C_R value provided by the CER calculations has been converted into business risk that can be mitigated. This conclusion is unfortunately not entirely correct as only possible grades of material that might be used assuming no technical or sourcing changes are undertaken during the NPD delivery of USC 090101. The identified materials grades need to be converted into traded elements to realise the business risk that might be implied by the hybrid method. Table 36 shows the material composition of the metal material grades shown in Table 35. The compositions if not readily available can be determined from several internet sources. Finally, the material elements are consolidated into a business risk summary as shown in Table 37. Within Table 37 several elements have been identified that co-exist within scarce metals listings (Fig 18) these should cause concern for business stability and trigger an actionable mitigation strategy.

Table 35: Detail data behind Fig 74 USC 090101

Material cost (£)	183.95	212.51	226.53			
Total Material Mass (g)	10664.00	13321.40	12690.10	13698.42	12330.23	13014.33
	Total Material Mass (g)			**Simulated NPD (x=2.5)**		
IMDS Material	**Model 'A'**	**Model 'B'**	**Model 'C'**	**from Model 'B'** C_S=212	**from Model 'C'** C_T=226	**Weighted** C_R=218
11 MnSi 6; 11MnSi6	5.00	5.00	11.00	5.14	11.31	8.23
11SMn30	0.00	890.00	865.96	915.19	890.47	902.83
409 SS	0.00	204.10	0.00	209.88	0.00	104.94
A2-70	0.00	139.80	0.00	143.76	0.00	71.88
adhesive	0.00	0.20	0.00	0.21	0.00	0.10
C10	328.00	339.00	482.30	348.59	495.95	422.27
Carbon Steel (1008)	19.47	0.00	19.47	0.00	20.02	10.01
Carbon Steel (1012)	11.47	0.00	11.47	0.00	11.79	5.90
Carbon Steel (1050)	12.18	0.00	12.18	0.00	12.52	6.26
Coating - Basecoat B06J	0.00	0.00	0.02	0.00	0.02	0.01
Coating - Topcoat B18	0.00	0.00	0.01	0.00	0.01	0.00
Coating - Zinc 8 Microns, Trivalent Black Chromate	0.00	0.10	0.00	0.10	0.00	0.05
Coating -Zinc Rich Organic Paint- MAGNI 565 System	0.04	0.00	0.00	0.00	0.00	0.00
Coating- Zinc Rich Paint	0.00	0.26	0.00	0.27	0.00	0.13
DD11	56.00	56.00	124.00	57.58	119.61	88.60
EN-GJS-SiMo50-10	113.00	113.00	113.00	116.20	109.00	112.60
e-plate Zn (electrodeposited Zinc Coatings)	0.08	0.00	0.08	0.00	0.08	0.04
Glimmerpapier	0.00	7.84	7.84	8.06	7.56	7.81
Graphite	0.00	22.00	0.00	22.62	0.00	11.31
Material for Fasteners Property Class <=12.9 (Flat Bill)	41.01	0.00	0.00	0.00	0.00	0.00
Material for Fasteners Property Class <12.9 (Flat Bill)	0.00	0.00	41.01	0.00	39.56	19.78
PA11 (Patch Seal)	0.00	0.00	0.02	0.00	0.02	0.01
Passivation blue/transp. Zn/ZnFe/ZnNi	0.05	0.00	0.05	0.00	0.05	0.03
Patch, Nylon Patch	0.02	0.00	0.00	0.00	0.00	0.00
PES	6.00	6.00	9.00	6.17	8.68	7.43
Pretreatment-Medium Zinc Phosphate	0.00	0.00	0.02	0.00	0.02	0.01
Sealant Layer	0.00	0.07	0.00	0.07	0.00	0.03
Steel	0.00	40.37	0.00	41.51	0.00	20.75
STEEL 1541	0.00	51.98	0.00	53.45	0.00	26.72
TFS-140 Grade 1035R Steel	0.00	19.70	0.00	20.26	0.00	10.13
VMQ	0.00	97.00	4.00	99.75	3.86	51.80
VMQ Compound	0.00	0.00	93.18	0.00	89.88	44.94
VMQ-Black	108.00	108.00	162.00	111.06	156.27	133.66
X15CrNiMn18-8	139.00	264.00	297.00	271.47	286.49	278.98
X2CrTi12	2913.68	3145.00	2674.50	3234.01	2579.83	2906.92
X2CrTiNb18	6334.00	6507.00	6536.25	6691.16	6304.88	6498.02
X3CrNb17	70.00	0.00	0.00	0.00	0.00	0.00
X3CrNiCu18-9-4	0.00	0.00	92.00	0.00	88.74	44.37
X5CrNi18-10	507.00	1305.00	1121.00	1341.93	1081.32	1211.63
X5CrNiMo17-12-2	0.00	0.00	12.75	0.00	12.30	6.15

Table 36: Material compositions for IMDS identified material grades

IMDS Material	Chemical composition													
	Iron	Silicon	Manganese	Chrome	Copper	Nickel	Aluminium	Phosphorus	Carbon	Sulphur	Molybdenum	Titanium	Niobium	Nitrogen
	Fe, %	Si, %	Mn, %	Cr, %	Cu, %	Ni, %	Al, %	P, %	C, %	S, %	Mo, %	Ti, %	Nb, %	N, %
11 MnSi 6; 11MnSi6	97	0.85	1.45	0.12	0.17	0.12	0.02	0.02	0.11	0.02	0.12			
11SMn30	98.47	0.25	1.1					0.07	0.08	0.03				
409 SS	87.67	0.5	0.5	11		0.25		0.02	0.04	0.02				
A2-70	53.82	1	2	20	4	19		0.05	0.1	0.03				
adhesive														
C10	99.06	0.4	0.45					0.045		0.045				
Carbon Steel (1008)	99.41		0.4					0.04	0.1	0.05				
Carbon Steel (1012)	99.385		0.4					0.04	0.125	0.05				
Carbon Steel (1050)	98.66		0.75					0.04	0.5	0.05				
Coating - Basecoat B06J														
Coating - Topcoat B18														
Coating - Zinc 8 Microns, Trivalent Black Chromate														
Coating -Zinc Rich Organic Paint-MAGNI 565 System														
Coating- Zinc Rich Paint														
DD11	99.19		0.6					0.045	0.12	0.045				
EN-GJS-SiMo50-10	93.95	5									1.05			
e-plate Zn (electrodeposited Zinc Coatings)														
Glimmerpapier														
Graphite														
Material for Fasteners Property Class <=12.9 (Flat Bill)														
Material for Fasteners Property Class <12.9 (Flat Bill)														
PA11 (Patch Seal)														
Passivation blue/transp. Zn/ZnFe/ZnNi														
Patch, Nylon Patch														
PES														
Pretreatment-Medium Zinc Phosphate														
Sealant Layer														
Steel														
STEEL 1541	98.01		1.5					0.04	0.4	0.05				
TFS-140 Grade 1035R Steel	98.71	0.1	0.75					0.04	0.35	0.05				
VMQ														
VMQ Compound														
VMQ-Black														
X15CrNiMn18-8	65.105	0.95	6.7	18.5		8.5		0.035	0.19	0.02				
X2CrTi12	87.37	0.5	0.05	11.5				0.04	0.03	0.01		0.5		
X2CrTiNb18	80.74	0.05	0.05	18				0.02	0.03	0.01		0.35	0.75	
X3CrNb17	81.145	0.5	0.5	17				0.02	0.025	0.01			0.8	
X3CrNiCu18-9-4	67.39	0.5	1	18	3.5	9.5		0.02	0.02	0.015				0.055
X5CrNi18-10	71.315	0.05	1	18.25		9.25		0.02	0.05	0.01				0.055
X5CrNiMo17-12-2	67.115	0.5	1	17.5		11.5		0.02	0.05	0.01	2.25			0.055

Table 37: USC 090101 analysis at composition level (Metals only)

USC 090101 Composition	Model 'A' (x=1) (g)	Model 'B' (x=2) (g)	Model 'C' (x=3) (g)	Simulated NPD (x=2.5) (g)	Scarce list (Fig 18)
Fe	8703	10807	10291	10564	
Si	27	34	30	32	Y
Mn	21	52	50	51	Y
Cr	1605	1870	1762	1812	Y
Cu	0	6	3	4	Y
Ni	59	170	139	155	
Al	0	0	0	0	
P	3	4	4	4	
C	3	5	5	5	
S	1	2	2	2	
Mo	1	1	1	1	Y
Ti	37	38	36	37	
Nb	48	49	49	49	Y
N	0	1	1	1	

5.2.4. Illustration of cost allocation to feature and the application of Monte-Carlo.

The automotive hybrid methodology illustration presented in section 5.2.3 was intentionally simple, loads of materials to process but it did not involve any allocation of metadata the specific delivery of a feature. In this extension of the hybrid methodology, the process will be extended to incorporate metadata cost allocation and the application of Monte-Carlo simulation to stress the allocation providing a probable estimated range for the outcome rather than an inferred value.

The right-hand side of Fig 26 (section 4.3) (pg 73) showed the relationship of USC to feature, equation (5) the accumulation of USC Cost as the sum of allocated feature cost. Table 27 (pg 124) shows the same relationship of data in a tabular form. The sum of the part costs within a single USC equals the summation of the features supported by that same USC. However, while this shows the USC-f combination, the total cost of a single feature may require the accumulation of several USC-f outputs where the feature is common across USCs.

When considering just the Land Rover Discovery Sport, 71 USCs have only one instance of a feature combination feeding into them and are solved by just four parts. 1 USC (150201) however shows its integrated nature and has 279 feature combinations with the potential of 30 part numbers being involved.

The illustration presented in section 5.2.3 (pg 144) might be appropriate for the 71 USCs with only one instance of an associated feature being delivered by the sum of their defined parts. Typically, 269 USCs require a level of cost metadata allocation to achieve their analysis. The illustration, Fig 75 shows the primary source as the engineering data, as already declared in association with equations (4) & (5) the parts per USC and the feature delivered are defined, they are therefore without any ambiguity. The cost data sourced from the associated metadata as declared against equation (6) is allocated. Once costs and other metadata have been allocated against each USC-f CERS are required by cost type. In the case of materials, an apportionment of the allocated cost is required to convert the cost into weight. In the case of process time, this is shown as secondary apportionment in Table 38. (If some specific allocation method has been employed to increase the representation of a specific material or process against a feature a more specific apportionment method will be required but ensuring the accumulation of all costs, weight, time remains the number that was started with.) Ultimately, Composition Analysis is applied as with the unallocated illustration given in section 5.2.3 (pg 144).

The allocation process is less than precise, being in part subjective to which delivered feature is chosen to start the allocation process. Because of this Monte-Carlo simulation need to be applied to the allocation of cost metadata. The ranges applied to the random number generation need to be constrained within the limits of the available costs across the sum of features delivered by the parts within the USC.

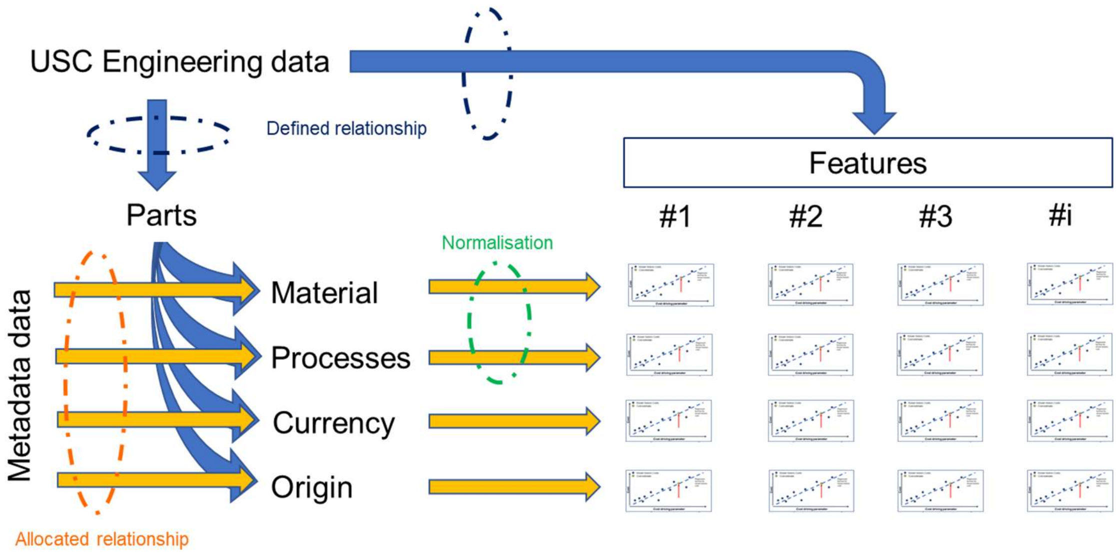


Fig 75: An illustration of complex cost metadata allocation.

Table 38: Data formats as an output of Fig 75.

	Primary allocation	Secondary apportionment
Material	Cost	Weight (g)
Production	Cost	Time (min)
Currency	Cost	NA
Origin	Cost	NA

5.3. Price Volatility Index. (PVI)

Jumping directly to some widely discussed volatility targets can prove useful, but greater rigour can be achieved by using a targeting methodology such as that proposed by the hybrid methodology. The composition analysis technique allows individual engineering raw materials to be decomposed into their essential commodities. An individual commodity may have a relatively high trading value when compared against several other commodities. Having a high-value may indicate that it should be avoided where possible. High-value, however, is not the same as high-volatility. To understand price volatility requires a comparative index to be adopted.

In adopting analytical methods, there is a need to determine a relative index for the economic volatility of different commodities as well as the total planned exposure within the planned NPD. Once PVI and volume data have been applied to the composition analysis, a Pareto analysis can be completed. The resulting risk data is used to direct the application of mitigation actions.

For example, an unstructured targeting methodology might correctly identify Gold within the composition data. Gold is commonly used (in small quantities) within modern automotive components is unquestionably commercially volatile but has a limited total risk to the business due to its total planned usage. The highest risk to JLR using 2015/2016 volumes and IMDS data was 1.753 tonnes/Year.

Fig 76 shows volatility data for three materials, Gold, Cobalt and Vanadium. The data age ranges are over 40 years and shows that material cost volatility is continuous and not active simply in very small time slices.

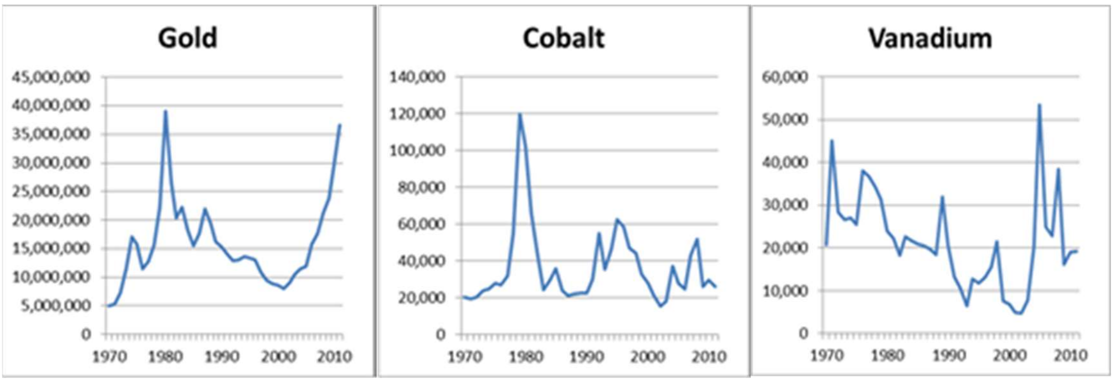


Fig 76: Examples of material price volatility - Gold, Cobalt & Vanadium. Source: USGS

To a degree, all commodities exhibit some level of price volatility over time. In the delivery of this hybrid methodology, there is only a need to consider those to which the OEM business is exposed. Table 39 shows a listing of the top ten and bottom ten from a listing of 48 commodities in Pareto ranked order of volatility. Gold, which in common thinking is volatile and used as an economic indicator only ranks 45th. Rare earths used in electric motors and other proliferated devices within a modern automobile ranks 3rd.

Table 39: Ten-year price volatility

(Data source: Oakdene Hollins / USGS)

	Material	**Volatility ranking (2010)**
Top ten	Vanadium	1
	Selenium	2
	Rare earths	3
	Molybdenum	4
	Rhenium	5
	Tellurium	6
	Indium	7
	Cobalt	8
	Manganese	9
	Tungsten	10
Bottom ten	Borates	39
	Talc	40
	Magnesite	41
	Feldspar	42
	Barytes	43
	Silica sand	44
	Gold	45
	Iron ore	46
	Limestone	47
	Perlite	48

Within JLR there is a pre-existing monitor of some commodities, listed in Table 40. Considering the variety of commodities found in a modern automobile by researchers including (Cullbrand and Magnusson, 2012; Andersson et al., 2017; Field et al., 2017) the monitored list is short.

Table 40: Pre-existing JLR monitored commodities

JLR Monitored commodities		
GBP ~ USD	Copper	PA6
Euro ~ USD	Lead	PA 6.6
GBP ~ Euro	Zinc	ABS
Brent Crude Oil	Nickel	Polycarbonate Transparent
Primary Aluminium	Magnesium	Polycarbonate Glass-filled
Secondary Aluminium	Platinum	Polypropylene Glass-filled
European Hot Dipped Galvanised Steel	Palladium	Polypropylene Talc filled
European Hot Rolled Steel	Rhodium	Natural Rubber
European Cold Rolled Steel		Natural Gas
European 304 Stainless Steel		Electricity
UK Steel Scrap		
EU Steel Scrap		

5.4. Currency distribution.

Throughout this research much has been made of the impact of the transaction currency of the tier 1 materials. Currency has implication in balancing revenue and payment sources, importation duty and preference markets. The currency spread shown in Fig 77 shows the equivalent GBP for a random example of each production Jaguar Land Rover sourced in Nov 2012, the sample data date of the JLR PCE POC. Details of the individual models are withheld due to the confidential nature of the tier 1 cost data but are represented by 1 to 9. The fig is using ISO currency codes a translation of which can be found in the appendix under Appendix 1. The spend currency profile changes over time as the OEM matures, grows and globalises. The data shown in Fig 78 is from 2018, still being taken from the UK build locations; Solihull, Halewood and Castle Bromwich.

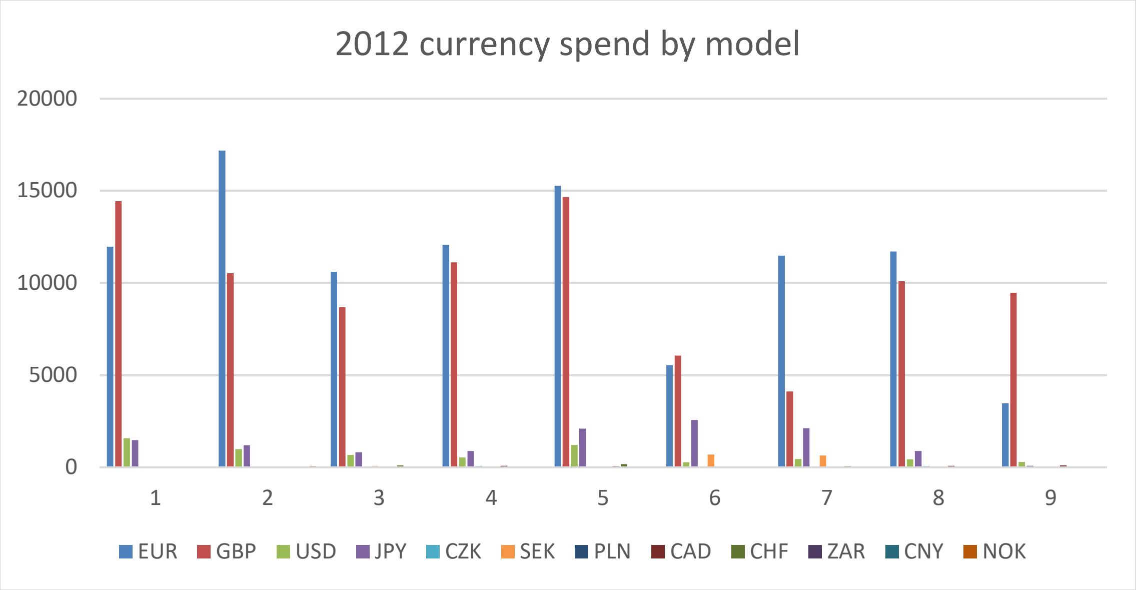


Fig 77: Tier 1 currency spread for single examples of JLR models 2012. Values in GBP

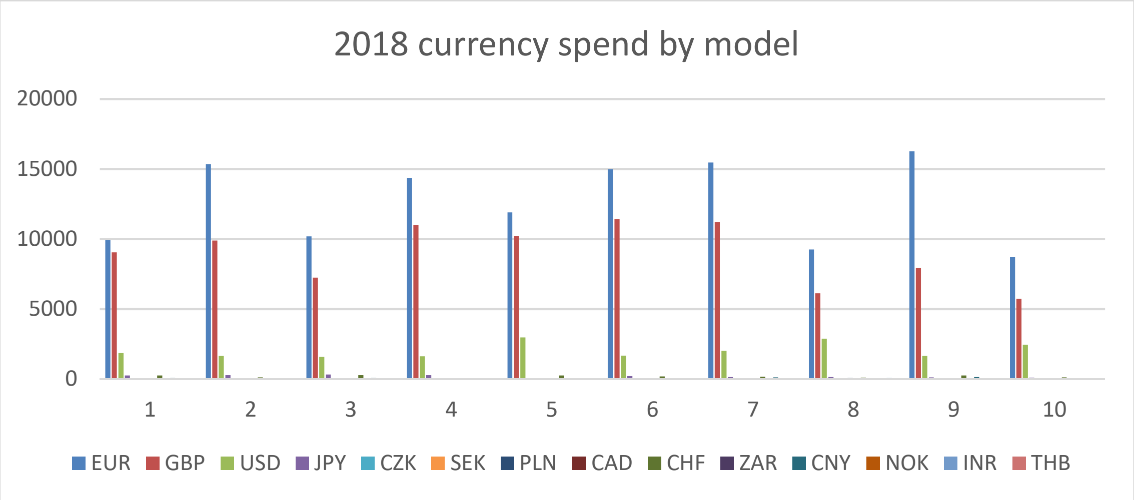


Fig 78: Tier 1 currency spread for single examples of JLR models 2018. Values in GBP

Comparing Fig 77 & Fig 78 the model line-up has increased, one currency (CAD) has been dropped from the tier 1 spend but two (INR, and THB) have been added. Note: PLN is the newer ISO code for PLZ, the original ISO code used in the 2012 data source. Fig 79 is highlighting the 2018 currency spend in non-EUR, GBP and USD.

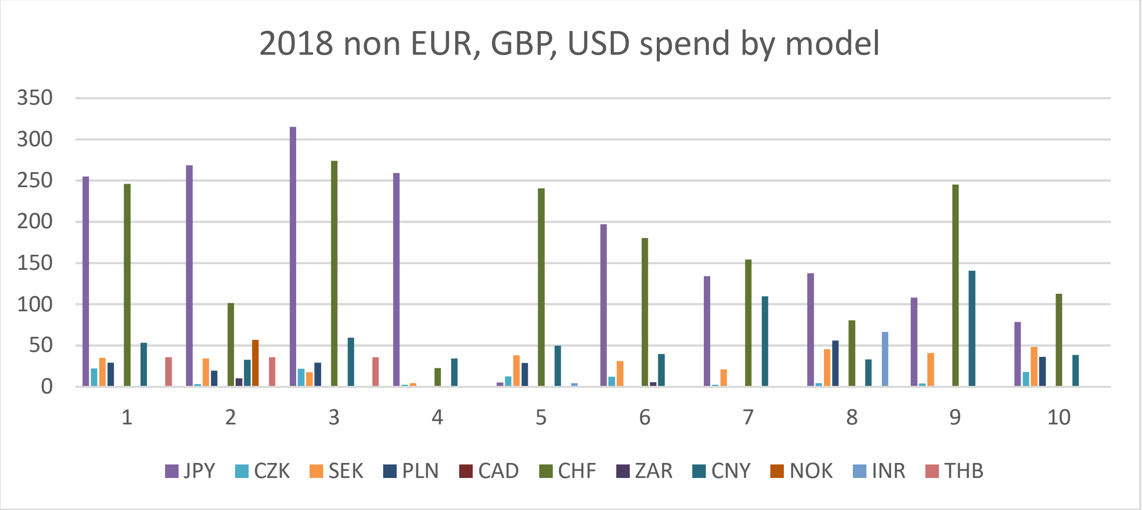


Fig 79: 2018 non-EUR, GBP, USD currency spend

Within the currency data shown in Fig 79, there is a material spend in JPY, 0.75% of the total spend. Sales to Japan to offset the JPY amounted to just 1% in 2016 a potential minor imbalance. This imbalance might be indicating that the business and or NPD is exposed to holding JPY as currency or trading JPY into currencies where it is short of revenue derived currency, either way, it does represent a risk to business and NPD.

The currency balance might be marginal for some currencies, but markets are being sold into where there is no material spend at all. Also, there is still an implication to achieving preference balance where the USD & JPY + others are classed as non-local. These will also attract importation duty where the eventual vehicle sale is local. (Importation duty on export of a vehicle sale to non-local markets can be reclaimed.).

Chapter 6. Results, validations, limitations.

6.1. Reflection upon the stated Aims.

In (Ullman, 2010) the author attempts to show a simplified view of the controllable variables within product development, referred to as NPD within this research. The illustration that Ullman uses makes a reasonable basis upon to build the upon. Fig 80 shows a recreation of Ullman's illustration but with one addition. The modified Ullman illustration has an added feedback loop shown as a red dotted looping link as a linkage between Product design and the variable cost/risk.

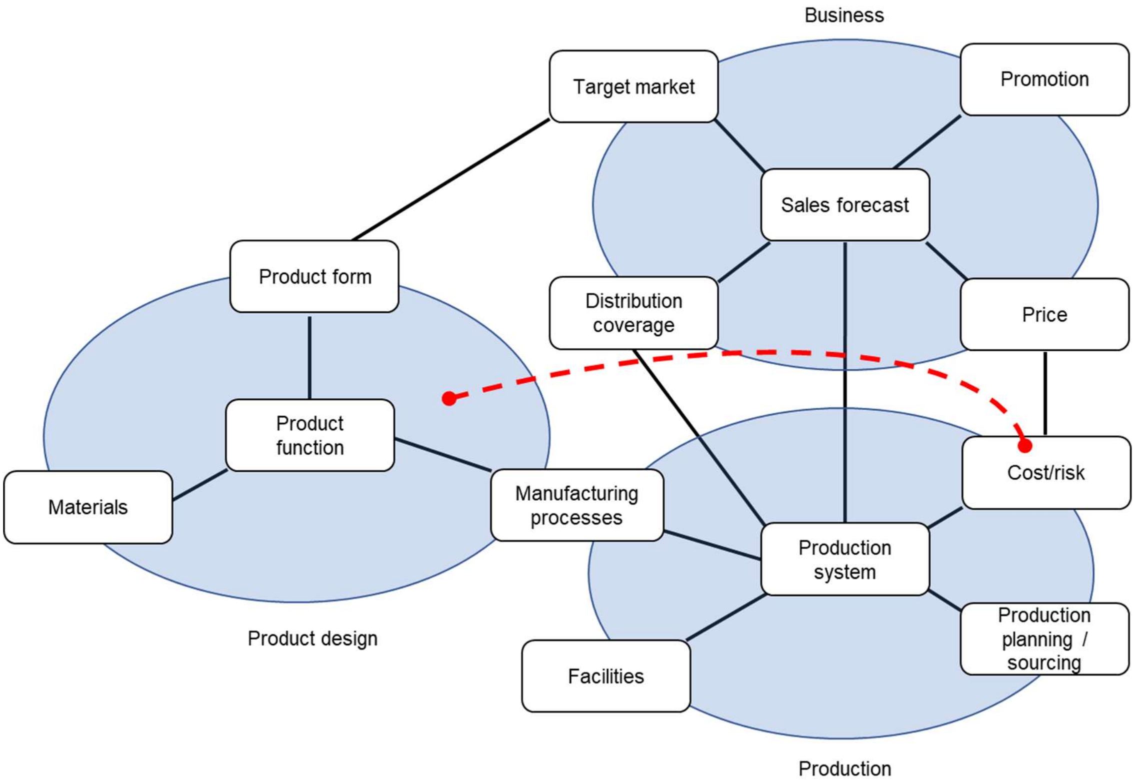


Fig 80: Controllable variables in product development adapted from (Ullman, 2010).

What Ullman has presented is the classical structure of most OEMs, create the product design and then deal with the resulting risks once into production. There is no indication in Ullman's representation of an intention to attempt to address cost during the product design other than those inferred by manufacturing processes. Within this research, there is a stated aim to identify uncertainties at the early concept phase of an NPD allowing the uncertainties to be translated into mitigatable risks ahead of and during the later volume production and disposal stages. This research adds the feedback link shown as red-dotted in Fig 80.

The stated aim of this research has been to establish a new and original methodology to identify uncertainties at the early concept phase of an NPD allowing the uncertainties to be translated into mitigatable risks ahead of and during the later volume production and disposal stages. Rush and Roy, (2001) showed the scope for production cost reduction post 70% commitment is limited, this point is consistent with the start of product design in Fig 81. Ullman, (2010) and later (Saravi et al., 2013) propose product cost optimisation within the conceptual design phase. The research presented in this research moves the discussion into the specification development, concept phase as shown in Fig 81.

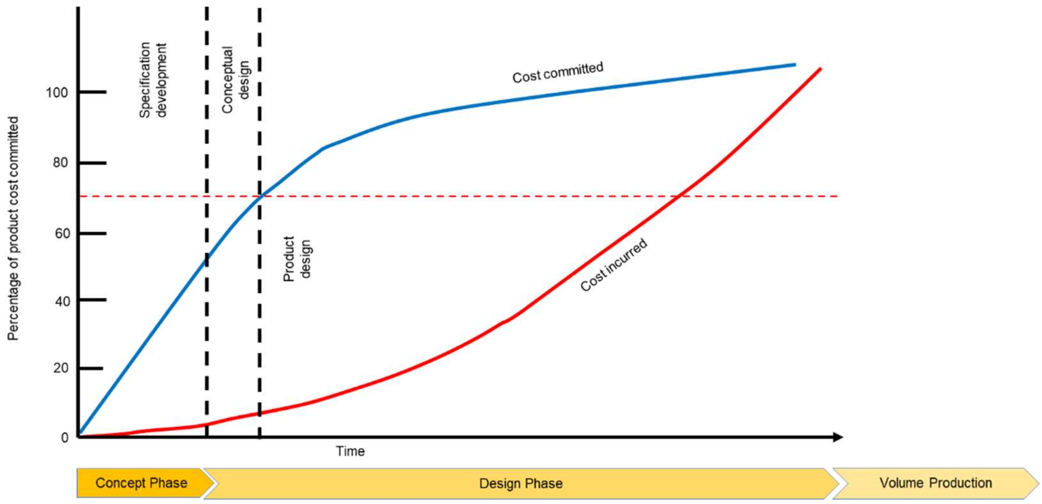


Fig 81: Manufacturing cost commitment during design adapted from (Ullman, 2010).

6.2. Summary of results.

Table 41 provides a summary view of the data sources found while undertaking this research. As can be seen from the table key pieces of data are cross associated with secondary sources.

Table 41: Summary of data sources

	Detailed source									
Data source	IMDS	SCE	QAF	Raw material claim	MSDB	Composition	PVI	NPD Engineering Attributes	Engineering Bill of Materials	
Part number	x	x	x	x	x				x	
Feature								x	x	
USC								x	x	
Material(s)	x	x	x	x	x	x	x			
Nett weight	x		x		x				x	
Gross weight		x	x	x	x					
Process(s)		x	x		x					
Quantity of process		x	x		x					
Country of Origin	x	x	x	x			x			
Currency		x	x	x			x			

The results of this research are that as shown by the results obtained by (Cullbrand and Magnusson, 2012 the modern vehicle even at the end of life is full of materials which at the start of life had the potential to have both high prices and volatile prices. The research presented within this thesis has also shown a correlation between the (Cullbrand and Magnusson, 2012 prime data source, IMDS, and SCE data sources.

Fig 23 (SCE) (pg 65) and Table 14 (IMDS) (pg 68) are of the same part and show the same materials being incorporated. Table 31 (pg 141), composition analysis, was constructed using source data from raw material claims and yet gets to the same material composition granularity as (Cullbrand and Magnusson, 2012 were able to show in their IMDS source data. Where these data sources do differ is that the weight of the material shown within IMDS is nett weight of material post the part processing by the tier 1 supplier. The weight shown in the SCE sources is gross weight. For NPD cost and business risk purposes, gross weight drives the part requirement and is to be preferred to the use of nett weight. The use of nett weight will return a result within the hybrid methodology developed within this research but will understate the risk. In most automotive applications the result might be small because the industry makes a high usage of semi-finished material stock such as; castings; forgings; mouldings. The wheel

QAF, shown as Fig 23 (pg 67) has a material utilisation of 60.7%. In the case of a casting where the in-process waste is recycled into the smelt, the physical material utilisation is questionably closer to 95% with only a small fuming loss accruing. The utilisation in cost terms, however, is less due to the recycled material credit being at a lower rate than the gross weight material rate. In the case of presswork and Body-In-White (BIW) the material utilisation, as shown in field 88 of Fig 82, is just 35.5% and in some cases the utilisation is lower. The example shown in Fig 82 is a typical body side pressing where holes are formed for doors and windows. Each hole reduces the material utilisation and nett weight contribution to the finished vehicle but still contributes towards the material cost.

To improve the NPD material utilisation due to parts such as body sides, the blanked-out door apertures or offal can be used as material to make other parts. Where this takes place, it should be recorded because the gross weight contribution has already been included within the donner part such as the body side.

Metal Specification EU2066

For Production, Service Parts and Blanket Order Requisition

Spec No. 41912 | Page 1/1

1) Panel-ID	2) Item Number (Model No.)	3) Blank. Plant	5) Stamp. Plant	4) Release-Level		7) Prod Part X / 8) Service Part
	[redacted]	[redacted]	[redacted]	Production		

21) Local Name	22a) Prefix	22b) Base	22c) Suffix	23) Model	24) Derivat	25) PpM	27) Assy. Plant	26) PSM	28) Fin Part Wgt	29) T/C
Bodyside Outer	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2126A		6.42708 kg	C

Specified Material	30) Coil Order No.	a)	b)	c) B No.
		[redacted]	[redacted]	[redacted]

31a) Thickness	31b) + tolerance	31c) - tolerance	31d) Coil Width	31e) Supply Type	38) Inspected Surface	42) Testing direction	41) To order
1.1	0.045	0.045	1675	COIL	-	transverse	100.0 %

32) Grade	33) BH/reforce	34) Coating	35) Pre-phos	36) Surface	37) Coating Wt.	39) STJLR.50.5011 / 40) STJLR.50.5002 TYPE C	43) Texture
AC170 PX		ALPT		1			

44) Yield min	45) Yield max	46) Yield Pnt Rat	47) UTS min	48) UTS max	49) Ra min	50) Ra max	51) El % min	52) El Gauge Len	53) r min	54) n min
90.0	130.0		185.0	260.0			23.0	80.0	0.6	0.26

Offal Source (only if this Spec is an Offal Spec)

184) Offal Code	182) Source Part (Item No + Panel Id)	185) Parts/Offal	186) % Prod covered by Offal

Lubrication

Prim Lub	ALUBE VS			82) Hit = 84) Blank = 86) Parts	1 = 1 = 1
Lub Wgt (g/m2)	min	max		80) Eng. Tol.(%)	0.0
Alter Lub				85) Avg RM Part Wgt (kg)	18.083
Lub Wgt (g/m2)	min	max		87) Avg. Fin Part Wgt (kg)	6.427
				88) Avg Utilisation (%)	35.542

Supply Information

101) Additional Data

103) Estimate Data

100) Coil Size Information	
100a) Inside(mm)	100b) Outside(mm)
600.00	2000.00
100c) Coil Weight min.(t)	100d) Coil Weight max.(t)
6.03	10.05
100e) Tech. min Coil Wgt (t)	100f) Tech min Coil Len (m)

102) Remarks
EU55 try-out to E1
EU55 dated 20.05.2015

104) Material also used on

Actual & Previous Metal Specifications

120) Date	124) Spec-No	125) Material Dimension	126) Pitch	127) Grade / Coating, 32) - 37)	128) Avg RM Part Wgt	129) B-No.	130) Comments
01.04.2016	41912	1.1 X 1675.0 X COIL	3635		18.083 kg	JZ406A	

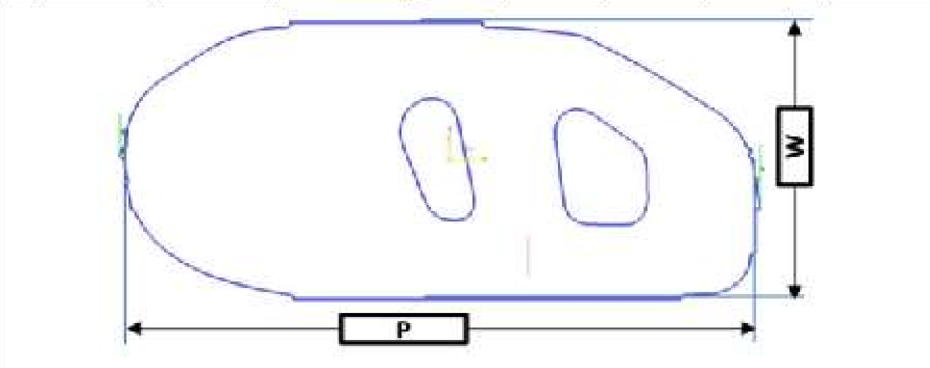
Fabrication Information

140) Op	141) Press	142) Presscode	143) Toolnumber	144) Tool Desc	147) Cut Size1 (J)	148) Cut Size2 (K)			150) Radius
1st cut									
2nd cut									
3rd cut									

140) Op	151) Cut Width	156) Pitch	153) Real Blank Wgt	154) Act Blank Wid	155) Act Blank Len	157) Hits	=	158) Blanks	=	159) Parts
1st cut	1675	3635				1	=	1	=	1
2nd cut							=		=	
3rd cut							=		=	

140) Op	152) Raw Blank Wgt	161) Prefix	162) Base	163) Suffix	164) Turn Over	165) Make "RH"	166) Make "C"	167) Make "LH"	168) Unit
1st cut					No				
2nd cut					No				
3rd cut					No				

151z)=31d) Coil Wid (mm)
(W)= 1675
156z)=90) Pitch (mm)
(P)= 3635
147z)=147a)
Cut Size 1 (mm)
(J)=
148z)=148a)
Cut Size 2 (mm)
(K)=
160z)=160a) Radius (mm)
(R)=
168z)/168a) Unit (mm)
(U)=
149z/150z) = 149a/150a)
Blade Angle
(A/B)=



220) Reasons for changing

221) Fields Changed | 222) F.P.V. =

223) Date 01.04.2016 13:28 | 226) Prime Steel Supplier | 224) Mailing Symbol | 225) Processed (Owner) AKHAN43

EU2066 This is an uncontrolled paper copy

Fig 82: Metal Stampings specification sheet for a typical body side.

As has been shown, detailed source data is a rich source of metadata for materials, material gross weights, process sizes and varieties of processes, countries of origin, currencies. This data, in the form of purchase costs, contributed to the tier 1 material costs used to create the standard CER used in the PCE process. It is reasonable that the metadata underpinning the purchase costs either in the form of SCE, QAF or raw material claim can be used to provide analysis of the PCE output, identifying the uncertainty and converting them to business risks that can be mitigated.

6.3. Limitations.

The amount of metadata to be obtained and analysed must be a concern when large complex developments are being undertaken. Accessing data that is incomplete such as the coverage of pre-existing should cost data and or quotation analysis forms is a concern. Due to the terms and conditions under which IMDS data is made available to an OEM, achieving access to IMDS data for the purposes of NPD evaluation is a concern. Fortunately, as has already been shown within this thesis, Table 18 (pg 71), the IMDS data can be substituted by either SCE or QAF data QAF data is preferable when assessing cost based metrics as QAF data is at gross weight, IMDS is at the nett weight. Gross weight, the weight driving the quantity bought and paid for in the tier 1 material cost is required. If the two metadata sources are available and aligned, the weight should be taken from the QAF, the composition from the IMDS.

Achieving an understanding of the materials down to their composition may be hindered by knowledge of proprietary name materials. The use of hand-held Low-intensity X-Ray spectroscopy devices that provide visualisation of the material composition may be a solution to lack of data or inconsistent data.

While there are positive impacts, there are negative impacts that need to be considered. As this is a new action involving metadata, there will be a significant resource investment associated with the hybrid methodologies establishment. According to IMDS data for a recently launched (2017) JLR model, a vehicle can have 6,264 *(Pre-normalization)* different materials only 2,425 *(Pre-normalization)* 38% being classified as metals.

Table 42 is showing the raw data size counts, in Table 43 the business risks are defined using the data sizes and variables from Table 42.

Table 42: Known data sizes of metadata

Data type	Data size.
Products (Models)	10
Tier 1 part numbers to be analysed per product	2,158
Typical IMDS materials per part	17
Typical Feature count per product	609
Typical Unique System Codes per product	340
Typical Features per USC	2.5
Typical part count per USC	7
Tier 1 Countries of Origin (Current sourcing)	26
Tier 1 Countries of Origin (non 'local')	10
Customer countries	97[16]
Preference Markets	20

Table 43: Data sizing by business risk

Tier 1 Business Risk	Data sizing source.	Potential data size
Material Price	Unique materials cited in IMDS.	14,539[17]
Material Price volatility	Unique materials cited in IMDS.	14,539
Manufacturing Process	Facilities in JLR CAPPe (SCE)	1,300
Importation Duty	Customs commodity codes actively used by JLR	1,260
Currency	Purchases Revenues	15 74
Preference Market		20
Recyclability	Unique Materials cited against IMDS models.	14,539

[16] Public data accessed via the internet shows various values from 130 to 169. A physical count of JLR 2016 Wholesale data shows 97.

[17] Stated number is pre-normalization and would be expected to reduce.

The issue of the amount of metadata to be assembled, manipulated and analysed has already been raised. The sheer volume of data will make short-term adoption of the new methodology impractical. However, a more targeted approach where full analysis is avoided might be an acceptable proposition (target the degree of metadata analysis to the specific business risk requirements.). Such an approach must start from the sum of knowns; known materials, currencies and country of origins that cause concern that exists with existing products. The same existing products whose detail metadata will be used to create the PCE CERs for the future NPDs.

Table 44 shows the accessed degree of analysis required to achieve good quality results for each business risk. The table has been developed on the principle that if the metadata that was normalised out of the current parametric cost estimate was not considered to create a business risk by meeting a pre-set NPD threshold for risk, then the assessment is unlikely to change having passed through the methodology proposed by this research. The fundamental change to current practice is that potential to create a business risk needs to be recognised within the source data that feeds the creation of the parametric cost estimates CER generation.

Table 44: Accessed degree of analysis required to achieve good quality results.

Tier 1 Business Risk	Degree of metadata detail required
Material Price	Very detailed but can be limited to a reduced set where material price x quantity indicates a raised business risk above a set threshold.
Material Price volatility	Very detailed but can be limited to a reduced set where material price volatility x quantity indicates a raised business risk above a set threshold.
Manufacturing Process	Can be restricted to cover known manufacturing processes where capacity issues exist.
Importation Duty	Requires a basic understanding of existing customs commodity code classification where parts are carry-over or modified. Establishment of customs commodity code in the case of new technology. Attributed cost and country of origin. Analysis can be restricted to a known reduced set created from non 'local' sourcing.
Currency	Only requires a basic currency & CER adjusted data plus acknowledgement of target sales revenues.
Preference Market	Follows Currency plus requires preference criteria that need to be met.
Recyclability	Requires knowledge of EOL materials and current recycling industry capability; where it does not exist to feed a demand driven by design specification.

Chapter 7. Discussion and data quality issues

The discussion and data quality presented in this chapter focuses on the metadata itself and what it can bring to the NPD concept phase that might not exist until much later in the NPD delivery.

Section 4.2 (pg 57) explored the available secondary / metadata within the available historical sources. These sources provided data covering; material at gross and nett weight; manufacturing process and their consumption; Import duty; currency; country of origin data.

Within the literature review attention was drawn towards 'historical risk' (pg 31). The observation being made was that if PCE is perpetually applied, NPD over NPD predicted costs could increase. There is a need to reset the process back to a known baseline using SCE rather than QAF data. As illustrated in Fig 15 (pg 31) applying the hybrid methodology using separate applications of QAF and SCE data does provide additional inferred information as to the nature of the resources required to bring the NPD under control.

Why is any of this research important? This question is best answered with a physical assessment created using data visible within this research.

- *Demo Material substitution – material price & recyclability.*

Taking the example of material substitution, the designed in use of more recycled materials being identified at the concept phase ahead of the design phase being started provides NPD financial benefits and direction to the required deployment of available design resources. The evidence provided by the wood pulp example showed a potential 37% material cost improvement for every unit of material that is substituted. The IMDS fuel tank assembly example showed a possible ≈ 50% substitution, see Table 15 (pg 69). A more reasonable expectation might 25% substitution[18]. For discussion purposes,

[18] Although a 50% substitution has been evidenced with supporting data it is a single piece of data relating to a fuel tank. Because it is typically accepted that some material strength is lost when recycled and virgin material are mixed a more robust finial evaluation will be obtained using a 25% substitution of recycled for virgin material. Also, some materials such as metals already use recycling in their manufacturing process when cast or going through a slab mill to produce sheet materials.

a tier 1 material cost of £30,000 will be assumed with 70% raw material content across all tier 1 + levels.

Saving per vehicle = 30,000 x 0.70 x 0.25 x0.37 = £1,943 (6.47%)

Plus, environmental & sustainability benefits.

- *Demo Preference Markets.*

Based upon 2016 wholesale volume data sales within preference markets make up ≈5% of the total sales. Missing a preference condition could result in a 7% in market cost penalty when compared to other OEM offering within that market. The level of this self-imposed 'penalty' may price the NPD out of these markets losing 5% of planned sales when all that was required would be increased planning into the sourcing structure.

The value of the potentially lost revenue is, assuming 2016 wholesales; preference advantage of 7% and a landed average value of £35,000.

Potentially annual lost revenue = 35,000 x 23,804 = £833.14 million.

Potentially annual lost contribution to fixed costs = 5,000 x 23,804 = £119.02 million.

- *Demo Currency Balance.*

Establishing currency balances between the value bought through variable cost and the revenue received through vehicle sales in various markets is a sourcing difficulty, very dependent upon the location of the required technology. To fail to establish a currency balance is to guarantee exchange penalties for the NPD and business. Even if an exchange/hedging contract were to only cost 1% of the value the penalty to the NPD and business would be in the order of; the value of Euro buy, £5,773.757 million; the value of Euro wholesales (2016 assuming an average vehicle value of £35,000.).

Cost of annual contract (Euro) = 1% (35,000 x 93,162 – 5,773,757,000) = £25,130,870

In this illustration using approximately real data, there is a greater material buy in Euros that the revenue generated through wholesales.

Other currencies will have their own currency balance cost if balanced by hedging contract alone.

- *Demo identification of scarce/volatile materials.*

Although it takes the added complication of applying composition analysis the example given in Table 34: Table 33 in post analysis composition view (pg 143), in combination with the Table 39: Ten-year price volatility, and the Table 40: Pre-existing JLR monitored commodities (pg 153), show that there are scarce commodities in use within existing product that are not monitored forming a business risk.

- *Demo market exclusion.*

Country of origin data can cause the exclusion of a product, NPD into a specific market. The inclusion of a source within the tier 1+ structure can be the cause. Such data has been missed in the past with tier 1+ data showing in the QAF declaration, misreported on the IMDS declaration. The result was an embarrassing rejection and return of a shipment of cars. Early recognition of this metadata could have avoided the embarrassment, transportation costs and rework. Fig 83 shows an extraction from a QAF showing tier 1+ parts from Israel mistakenly included in an NPD due to sell into Arab states where the specific inclusion is not allowed.

1. Procured Parts		Supplier / Country of Origin
QAF Y/N	Part number/ Description	
	Sealing Ring Viton	USA
	Encapsulated Ring (Mild Steel)	USA
	Locking Ring (Mild Steel)	USA
	Encapsulated Vent Assembly	UK,EUR,ISRAEL
	Passive Sender Guide Assy	UK, EUR
	Blow Pin Cover	Germany
	FDM Bayonet Fitting	Germany
	Foam Pad	UK
	Leak Test CAQ Label	Germany
	Flip Test CAQ Label	Germany
	Weight & Wall CAQ Label	Germany
	Inlet Check Valve LEV1	ISRAEL
	Triple Clip	UK
	FDM	CZ ex-w orks
	FDM Handling	UK
	Dust Cap ICV	
	Dust Cap FDM Breather	

Fig 83: Extraction from QAF clearly showing a country of origin issue

Ultimately while the potential rewards available from the application of the hybrid methodology can be considerable, they do not come for free. The available rewards are dependent upon significant and upfront effort. There is, therefore, a need to prioritise mitigation efforts. Prioritisation can be approached in several ways. An example might be to deploy existing Value Analysis (VA) tools to assess mitigation potential can be deployed. These VA tools seek to direct mitigation through the ranking of potential and ease of delivery.

It is not within the scope of this research and thesis to be prescriptive as to which of the business risks poses the highest risk out of the seven risks that have been presented and discussed through section 4.4 (pg 89 to 116). Each business risk has its own criteria whereby to meet the criteria does not present a risk but to exceed carries penalties. Exchange rates, importation duties and preference treatment can change with political whims. Material market pricing and volatility of that pricing can be political but can also be influenced by supply factors such as recycled material alternatives becoming available in the market place.

7.1. Reflection upon the Literature review.

The literature review provided in chapter 2 (pg 7) was necessarily involved, being structured in four distinct parts and the last having some substructure.

- In the first element, the research was positioned against existing literature in a matrix of Early NPD to EOL and area of focus; People to business risk.
- The second element looked at the positioning of the research within business literature.
- In the third element, mind mapping was used to determine the potential pre-existing tools; data; and impacts required to establish the hybrid methodology.
- Finally, in the fourth element followed the mind-map identified individual tools; data and impacts were considered within existing literature.

Fig 84 shows a pictorial view of the literature review contribution towards the development of the hybrid methodology:

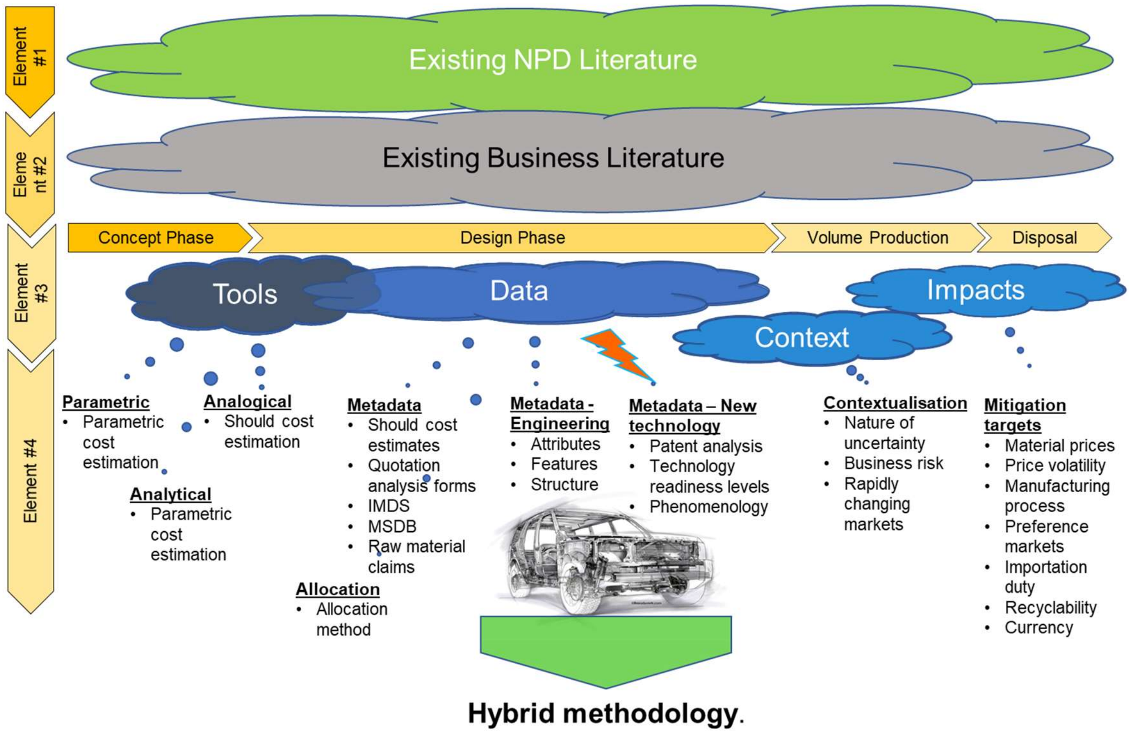


Fig 84: Reflection on the literature review of Chapter 2

In many respects the key to the establishment of the hybrid methodology is building upon the demonstrated use of IMDS data within literature and the demonstration of comparable alternative data sources from within OEM secondary data sources that can replace IMDS data IMDS data has already been shown within the literature to be able to quantify EOL automotive material. Table 18 (pg 71) confirms that QAF data can be aligned with IMDS data. It is, therefore, reasonable to assume that the additional data contained within a QAF and the SCE metadata sources can also be brought forward.

The establishment of the existing tools through literature enabled the hybrid methodology to obtain a solid foundation and the establishment to become one of reasonableness to re-join pre-existing data to allow the original data granularity to flow through the existing parametric cost estimate rather than being 'normalised' out.

7.2. Data quality issues.

Some formalisation does exist when considering 'data quality', (ISO 8000-8, 2015).

In ISO 8000-8 three types of information and data quality issues are considered and defined; Syntactic; Semantic; Pragmatic. These are defined as;

> **syntactic quality**, which is the degree to which data conforms to its specified syntax, i.e. requirements stated by the metadata;

semantic quality, which is the degree to which data corresponds to what it represents;

pragmatic quality, which is the degree to which data is found suitable and worthwhile for a particular purpose.

The metadata sets employed in the delivery of this hybrid methodology are not without their share of data quality issues. Pragmatic quality issues are being ignored as the data being used is pre-screened for applicability to the successful delivery of the research aim and objectives. Semantic quality is also largely ignored as the stated values are not being checked against a physical master. Semantic quality issues are however inferred when inconsistencies exist between and within datasets. Semantic quality issues do occur within the metadata sets being considered within this research and results in a requirement to 'normalise' all data.

Data normalisation within the context of this research is mainly confined to the list shown in Table 45.

Table 45: Metadata normalisation

Data type	Normalising action.
Material Price	Contribution should be adjusted to a common 'set' across all metadata. Suitable for source economic region.
Exchange rates	Contribution should be adjusted to a common 'set' across all metadata.
Labour & Facility rates	Contribution should be adjusted to a common 'set' across all metadata. Suitable for source economic region.

By implication, most data quality issues identified in this section are by nature, syntactic.

Table 46 presents a summary of the data issues cross referenced across secondary data sources.

Table 46: Summary of data issues across metadata sources.

	Detailed source									
Data	IMDS	SCE	QAF	Raw material claim	MSDB	Composition	PVI	NPD Engineering attributes	Engineering Bill of Materials	
Part number	1	1	1	1	1				1	
Feature								2, 3		
USC								2, 3		
Material(s)	4	4	4	4						
Nett weight	5				5				5	
Gross weight			5		5					
Process(s)		7	7							
Quantity of process		7	7							
Country of Origin	6		6							
Currency										

Data issues: Table 47 describes the data issue between the sources as identified in Table 46.

Table 47: Legend of issues -Table 46

Data Issue	Description of data issue
1	Part numbers inconsistently formatted within and across metadata sets
2	Attributes maintained to individual NPD rather than OEM values.
3	Attributes not maintained/cross-referenced to USC and features.
4	Materials inconsistently declared.
5	Weight / Mass declaration inconsistent within and across data sets.
6	Inconsistent declaration between metadata sources.
7	Inconsistent process, facility type and quantity.

Evidence of data issues.

Across SCE, QAF and engineering BoMs alignment issues exist. Think part number formats, representation of all parts, too often SCE and even QAFs are only completed for a representative sample of parts.

Part number issues. The part number forms the vital common data link between secondary data. The systems that it is held in don't always conform to a common standard. Production JLR part numbers have three elements; Prefix, Base, Suffix. Within engineering systems most will represent the three elements in the correct order and with a space between each. In procurement, they leave the spaces out. In manufacturing, they mostly put the Base element of the part number first.

Engineering data.

As clearly indicated by the engineering data shown in Table 9 (pg 60). All data sources require careful examination and where data is concerned an understanding of the correct format of data is an essential first step in the source validation. Within the small data sample shown is a part number CHCH2M-06202-AA, this was initially thought to be an error because it has a duplicated prefix of 'CH'. It is a nonphysical part being an engineering chart of data relating to the physical part CH2M-06202-AA.

NPD Engineering Attributes.

The NPD Engineering attribute values assigned to the delivery of a feature is used within the Hybrid Methodology to provide the x-axis value for the PCE CER. During the JLR review of data for the PCE POC, it was considered that these attribute rankings could form the basis of the PCE performance indicator, the independent variable. It was noted that each NPD controller sets their unique ranking baseline causing no two NPD rankings to be comparable to each other. This independence of ranking across NPDs renders the ranking unhelpful as an independent variable within PCE.

Cost-type mapping to USC-f.

As feature delivery increases against a single part or USC, there is an increasing need to stress the cost allocation to each USC-f. Stressing can be achieved using an application of Monte-Carlo simulation to flex the key variables. Ideally, the result from the analysis should remain stable.

Accounts data.

Accounts data has not explicitly been discussed within the body of this research, but it is a potential source of data when considering currency of costs. However, all data should be expected to be flawed. Even the currency data shown in Fig 77 (pg 154) and Fig 78 (pg 154), which was sourced from accounting costed BoMs of built vehicles. Some of the models shown include costs in the old ISO currency code; others have it in the new ISO code for Poland, PLZ and PLN respectively. One model in the 2018 data has both.

Establishing and maintaining PVI data.

Establishing and maintaining PVIs is a complex task and beyond this research paper. Commercial sources do exist an example of which is available within the GRANTA product suite.

IMDS data quality.

To be usable, the submitted data needs to reflect the materials used in the physical part correctly. A spot check undertaken by the author in 2009 showed that this was not always the case. It also needs to be correctly created at the material data sheet (MDS) within IMDS. IMDS data quality issues have been identified by (Cullbrand and Magnusson, 2012). Noted as a data quality issue by some such as (Field et al., 2017) some authors are perhaps misinformed by industrial SMEs and can cause misidentification. Such was the case when Field et al. Identification of multi-sourced parts within the IMDS database having different materials when sourced from different suppliers. In the case of 'black box parts', only the volume envelope and functional specification are defined by the part number. The specification of black box parts allows individual, local, suppliers to change materials provided the fit and function is maintained.

What is harder to comprehend is that data supplied by the tier 1 supplier separately into both IMDS and QAFs can be presented differently. Specific materials take on different names, even countries of origin can be presented differently. As a result, care must always be exercised.

There is a problem attempting to use secondary data, data already collected for a different purpose. The secondary data may not have been checked to the quality expected by its new application and usage. The examination of IMDS data is a case in point. The currently identified literature that has attempted to make use of IMDS data (Cullbrand and Magnusson, 2012; Du et al., 2015; Field et al., 2017; Tarne et al., 2017) only Cullbrand and Magnusson, Field et al. have raised issues with the data. In respect of the IMDS data Du et al., 2015 reflects that the database was incomplete with some parts missing.

The IMDS data for JLR products as at 2017 contains some 17,952 supplier identified materials. The absolute quantity of IMDS materials results from the data being entered in free form. For example, both "ZA130 (hot-dip zinc-aluminium coated)" and "ZA130 (hot-dip zinc-aluminium coated)" are included as unique due to spelling mistakes. The data also includes some 26 variations of Gold. Considerable normalisation is required before the data can be reliably used. If normalisation is required, then there is a need to normalise into commonality with a second database which will result in the practical application of a usable Price Volatility Index (PVI).

When first extracted Table 33 (pg 143) showed the raw data as retrieved from the IMDS database for the discovery sport rear exhaust USC 090101.

It should be noted that the data shown shows the need to normalise and consolidate the raw IMDS data. The last two entries in the table read as the same IMDS material, X5CrNi18-10. Table 33 as shown has been normalised to correct the data error. This fault shows the need to consolidate the common IMDS material entries before the data can be efficiently used.

Data quality issues as highlighted need not end the adoption of the proposed hybrid methodology. The most likely metadata anomaly will occur in the material data. If the material data behind a PCE CER data point is not known through any of the identified metadata sources non-destructive data collection can be undertaken. Fig 85 shows such a device - Portable X-ray Fluorescence (XRF) also known as Positive Material

Fig 85: Alternative material identification.

Identification (PMI). Follow-up material on this non-destructive method is provided by (XRF, 2018). Within Fig 85 the insert shows the readout for a sample of stainless steel which is identified as 304 stainless steel the data for which is also included in Table 31: Composition analysis for typical vehicle exhaust system materials. (pg 141) X-ray Fluorescence may also be known by an older name, Low-intensity X-Ray spectroscopy.

While the portable XRF tool shown in Fig 85 is suitable for the identification of metal alternatives, the requirement exists for the identification of plastics including composites. Terahertz, (2018) provides an example of this technology. On-line literature shows other technologies are available and in active use such as Raman Spectroscopy. If all else fails additional data may be available in sources such as; CAD; Drawings; lab reports and other ad-hoc sources.

The introduction of non-destructive material analysis techniques to supplement existing data might also enable the introduction of competitor parts and systems into the mix. Creating a source of new technology metadata sourced from other industries who are hostile to data sharing.

In the face of the identified data quality issues decisions need to be undertaken to either take immediate action to improve the data quality putting the introduction of the hybrid methodology on hold until 100% corrective action has been achieved or introduce the hybrid methodology with an acknowledgement that data issues exist. The effort required to achieve a retrospective 100% correct secondary data situation is considered to be unacceptable in the face of continuously evolving products, new part releases are made each day against existing and future, NPD products. Effort expended on retrospective correction and alignment would only ever be playing catchup. Effort such as might be available is considered better applied to re-enforcing correct data alignment of part new releases. Table 46 (pg 171) and Table 47 (pg 172) show the types of issues that need to be addresses. Table 42 (pg 162) and Table 43 (pg 162) provide an indication of the potential scale of the data issues that require attention. Some selective retrospective data alignment action should be considered where specific critical issues are identified that might put the NPD at risk.

Chapter 8. Conclusions

This chapter summarises the presented research, considers its contribution to knowledge and its impacts. The introduction to this research proposed a hypothesis that would seek to identify the uncertainties in concept NPD cost estimates. Through the literature review, it was established that the area to be covered by this research had not been covered by existing literature. As there was no known existing tools or methodology covering this critical area within an NPD mind-mapping was used to determine what should be reviewed within existing literature. The review of existing literature showed that several pre-existing tools are in common usage during the concept phase, of the available tools PCE was the favoured tool during the concept phase. PCE is the favoured tool of aerospace and defence, but SCE is favoured by automotive. These two methods are opposites; PCE does not need a design, SCE must have a design; PCE does not carry deconstructed costs, SCE is all about deconstructed costs.

Fig 86 provides a visual reference to the aspects of impact resulting from this research. If PCE is applied in isolation, then throughout the NPD development and production life only a cost will be known. Therefore commercial tier 1 uncertainty will always be a flat line at 100%. Even if the data points used within the PCE model are flexed to accommodate forecast variations such as the currencies and material prices the PCE output will only show the impact of a possible uncertainty and on the uncertainty itself. SCE cannot start until a design exists but within its detail will be the clues that turn uncertainty into mitigatable business risk. Creating a hybrid methodology as proposed in this research allows the uncertainty to be identified, named as a business risk and mitigating actions to be taken either through design, sourcing or other action.

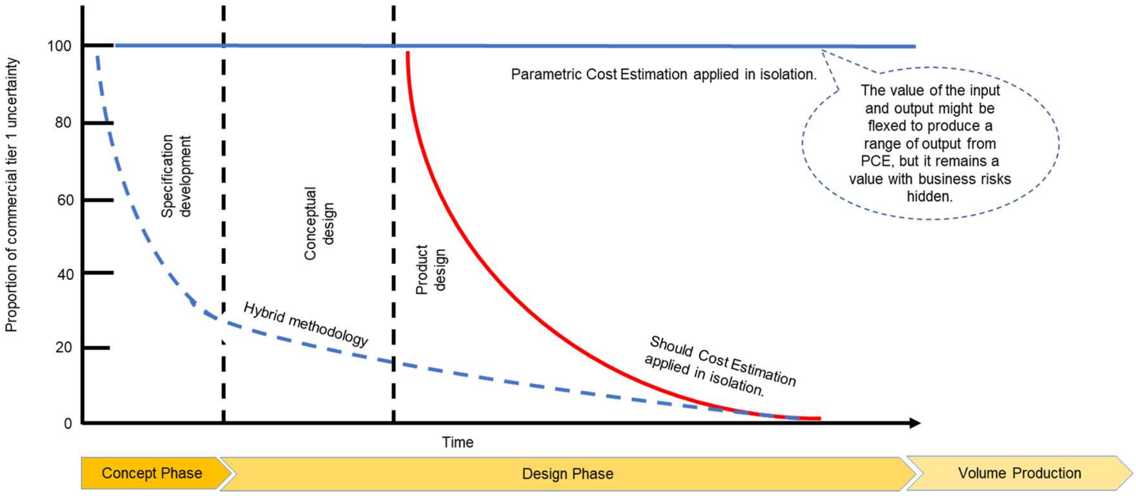


Fig 86: The impact expected from the application of the methodology described in this research.

Fig 87 provides an impression in the relative terms laid out by Mirdamadi et al. for the potential performance of hybrid methodology compared to Parametric and Analytical methods in isolation.

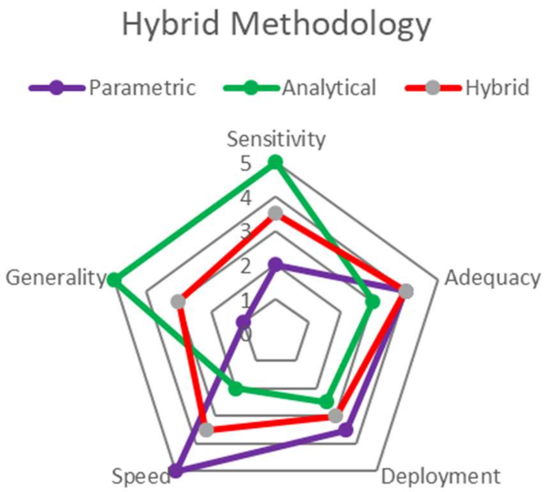


Fig 87: Possible outcome of the establishment of the proposed hybrid method presented within this research.

As cited in section 2.3, see Fig 10 (pg 16), Mirdamadi et al. assert that the weaknesses of Parametric and Analytical cost estimating are effectively opposites. The hybrid methodology proposed by this research might deliver the resulting combination of Parametric and Analytical cost estimating as shown in Fig 87. Realistically the outcome is not going to be informed by only the ‘good’ bits from each method; for example, the speed achieved by parametric rated as five cannot be expected in the hybrid methodology unless all the metadata feed into the hybrid method is pre-existing and available ‘off-the-shelf’. Generality and Sensitivity are unlikely to jump from 1’s & 2’s to 5’s, but Sensitivity (repeatability and robustness) might be expected to improve.

To achieve successful delivery of the proposed hybrid methodology, the metadata would need to be pre-existing and analysed. Notwithstanding the fundamental need to ensure that data syntactic, semantic quality is maintained. (It is assumed that pragmatic quality has already been analysed out of the contributing metadata.) Table 48 shows the five key recommendations that might be required to achieve the hybrid methodology; retain parametric speed; grow the sensitivity as proposed in Fig 87.

Table 48: Recommendations for successful delivery of the hybrid methodology

	Metadata set	Action	
1	NPD engineering attributes	Need to be developed, and the attribute ratings created as a continuous OEM set rather than discrete by OEM NPD.	
2	NPD engineering attributes	Need to be developed attributes cross-referenced to USC-f requirements.	
3	IMDS	There is a need to ensure that all tier 1 parts are represented with an appropriate representation of the constituent material grades.	
4	SCE, QAF, MSDB, Raw Material claims	Allocation of cost for each cost type is ‘off the shelf’ against each USC-f.	
5	Composition Analysis	Needs to be maintained for all known material grades designed into the OEM models.	

In chapter 7 several data issues were identified with the existing secondary data; incomplete; inconsistency across data sources. Practices issues were also identified which added difficulty to cross-referencing between NPDs such as attribute measures were reset by each NPD management team rather than retaining a consistent scale of attributes across NPDs. Table 48 has identified several requirements to achieve the successful introduction of the hybrid method as defined within this thesis but it is the recommendation of this research that the hybrid methodology is introduced with the acknowledgement that these secondary data faults exist and are allowed to improve over time through the application of improved governance rather than hold up the introduction of the hybrid methodology for improved secondary data. Based upon the secondary data accessed to support this research the data improvement will be co-dependent upon both engineering and procurement stakeholders.

Much has been made of the application of the hybrid methodology, that ‘new’ information can be established by looking at how the ‘old’ data can inform the NPD. Section 4.6 Hybrid Methodology Framework (pg 119) shows how using four cases the hybrid methodology can be applied to all NPD situations The third framework case is the most intense of the four cases and as discussed in section 6.3 (pg 161) needs to be supported by pre-determined cost type and attribute allocation and contribution to the delivery of a feature within a USC. By adopting the allocation of cost type to the delivery of feature during the engineering release process the ‘speed’ attributable to the hybrid methodology would increase further towards that shown for parametric in Fig 87 (pg 178).

In section 4.4 (pg 89) CLDs have been used to draw attention to the potential ‘new’ NPD information that could be created through the application of hybrid methodology. Through the CLDs insight into the application of the new information can be visualised and as a result used to reduce the commercial business risks faced by NPDs. More specific summarised discussion is undertaken in section 8.1 Impacts.

8.1. Impacts.

The impacts that are there to be achieved by the adoption of this metadata rich hybrid methodology include reduced exposure to:

- High material prices through a targeted redesign to use lower price materials; increased inclusion of recycled materials where possible.
- Materials with high economic volatility through a redesign to a lower volatility material; stabilising the volatility through increasing recycled material as a substitute.
- Reducing the risk of missing the achievement of preference market requirements and advantages through appropriate sourcing.

- Reducing the cost of importation duty through recognition of how duty is incurred relative to the country of origin, raw material types, manufacturing processes incurred and the technology sector.
- Recyclability targets for the end of life; through a redesign to achieve and the creation of recycling markets to supply recycled materials into a circular economy.
- Early acknowledgement of the processes required within the tier 1 structure, the demands of process capacities, quantities. Early confirmation of the tier 1 + requirements has been confirmed by senior Jaguar Land Rover purchasing management as an enabling tool when seeking to obtain capacity within the marketplace.
- In general, early acknowledgement of business risks that might necessitate re-design and or resourcing actions will reduce the overall time to market.

The potential to achieve improved NPD outcomes can be identified through the application of the hybrid methodology put forward in this research. The material-based challenges will need to be targeted at the parts and vehicle systems where the concern arises. In cases of currency; import duty and preference markets, there may be a need to undertake indirect mitigation to control and optimise the imbalances between the business risks. Indirect mitigation will be the case where direct action is not possible due to a single source constraint is identified.

8.2. Contribution to knowledge

The research undertaken and presented in this thesis and by its aims has shown that it is possible to bring forward available metadata to highlight previously hidden uncertainties during the early concept phase of a New Product Development. It is considered that there is still a place for the current highly normalised early evaluation to undertake a preliminary assessment of necessary NPD profitability. However, the more detailed hybrid methodology, supported by the application of metadata, as proposed by this research should be introduced once the early assessment of the concept NPD is considered viable for progression and before progression into the design phase.

The early insight into potential business risks resulting from the introduction of a metadata rich analysis will allow resources to be targeted at the delivery of the NPD and concurrently at the areas of business risks that can be avoided. By implication, this early knowledge will reduce the need for re-design and resourcing loop which are typically encountered in that late stages of the NPD delivery, pre-volume production. Precisely how much rework reduction might be expected has not been evaluated within this research.

Chapter 9. Recommendations and future work.

The research into the ability to recognise aspects of uncertainty within an NPD at concept phase has included the establishment of a hybrid methodology to allow pre-existing metadata to flow through the existing methods of early concept evaluation tools such as Parametric Cost Estimating. The research presented in this thesis has extended beyond the methodology to attempt to show how the resulting new information might be used to quantify business risk in the areas of included; material price; material price volatility; manufacturing processes; import duty; preference markets and currency. While it might be felt that this is a complete list, aftermarket parts pricing and other aspects have not been addressed.

Extending the business coverage that is influenced by design.

Aftermarket part pricing is not directly accumulated within the tier 1 material costs of the product but due to competition law is indirectly linked to the individual costs being rolled up within the tier 1 material costs. In short, competition law (European) and antitrust law (USA), goods cannot be sold below cost. The cost of aftermarket parts impacts upon the retail customer's insurance rating for the purchased NPD which itself has an impact upon the total sales volume of the NPD. Further research should be undertaken to establish how and if aftermarket parts and the serviceability of the parts can be taken into the optimisation of the NPD at the concept phase.

If it is possible to assign trends to identify some uncertainties held in the should cost metadata could the methodology also be used to reflect the potential of other life-cycle issues; serviceability and warranty? Within the context of this research, a scope restriction was applied that limited the research to tier 1 material cost. Conceptually though while attempting to influence the reduction of business risk during the very early NPD concept phase, the principles developed in this research could be applied to serviceability, warranty and accident repair. All of which have an impact on insurance rating, residual value, desirability, price and volume of sales and can be influenced during the design phase of the NPD if the requirement to do so is recognised. Fig 88 shows a causal loop diagram of this potential further work that could be applied through the application of additional metadata at the concept phase using the methodology described in this research.

Within this research, the relative importance of an NPD cost has been established using the income statement model with cost as a percentage of revenue. Serviceability, accident repairability, insurance rating, residual value, and desirability do not have an internal cost line within the income statement of the NPD. Price and volume of sales, however, are the revenue line. Warranty does have its own cost line, and every effort is made to limit it to <4% of revenue. Early recognition of historical warranty and consideration for a redesign, even if only to make the failing components more accessible and or a replaceable module at a reduced cost.

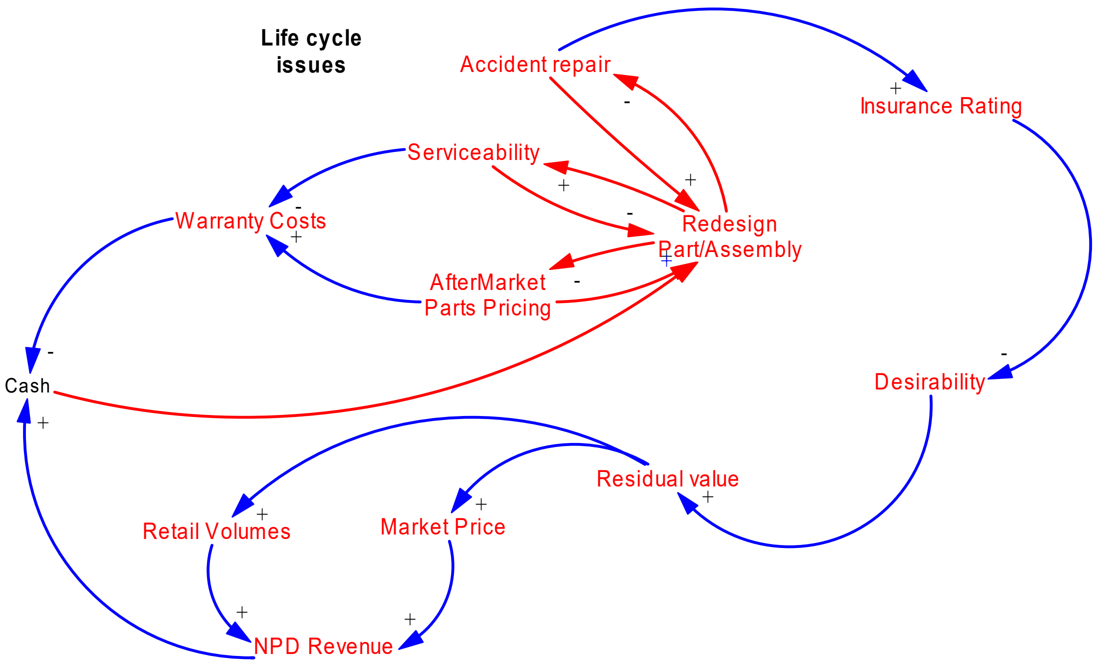


Fig 88: Causal Loop Diagram of potential further work - Life Cycle Issues.

Establishing the recyclability and the recycling activity of the 2018 fleet.

The technology and material being used to deliver the technologies are changing over time, as is the ability to recycle the materials at the end of their products life. The literature review undertaken within this research has shown some relevant pre-existing data covering this aspect of the NPD and across the product life-cycle. It is noted that data is ageing and fragmented by material type; metals; composites and electronics. A consolidating study should be undertaken to identify materials consumed in current products, materials recycled, materials recycled into current products, and forecast trends for future NPDs.

The data to undertake this exists as far as the materials included within each model in the 2018 fleet although it would need to be brought up to date. While undertaking the research presented in this thesis, it was noticed that a model still in production does not appear to have been refreshed since 2012. Engineering change records shown thousands of recorded changes since the model was launched.

Reworking within the design phase.

“Right first time” has long been a business mantra but in truth rarely achieved. This research has increased the amount of data available to direct the design and the sourcing towards an improved NPD outcome. The impact regarding engineering hours and even purchasing hours needs to be evaluated.

Data sources exist to be able to undertake this activity but must be treated with caution. Timesheet booking records are such a source but are also known to be ‘manipulated’ to ensure that targets are met. Engineering change management records exist but, these only list the changes as a single entry from the official NPD programme start and after the programme has been approved to commit engineering and purchase resources. A single entry in these records could be for a single part or 100 parts; they are listed and analysis is therefore possible.

While it would appear to be possible to design a research programme to seek a confirmation that reworking is reduced as a direct result of improved data at the start of the design phase, it might need to run for more than six years. The establishment of an accurate baseline comparator might become an additional concern.

Tool management.

The establishment of a successful NPD is reliant upon the invested capital as well as the variable cost and revenue. Within the automotive industry, it is normal to fund the vendor tooling, the part/component specific tooling that is unique, up front. Within the income statement shown in Table 6 there is a specific row of data that called ‘vendor related’, it is this row that contains the allocation of vendor tooling. It is an allocation purely because of accounting treatment under the Generally Accepted Accounting Principles (GAAP) rules applicable to the OEMs home location. In most cases, though the treatment will be an apportionment of the vendor tolling cost for the life of the tooling. No apportionment is perfect, and any remaining asset value of the vendor tooling at the end of its life is written-off using a treatment known as impairment within accounting circles.

- Parts change during the tools lifetime, so do their part numbers, is the tool(s) initially laid down still in use or should they have been written off?
- If a carry-over or modified part is included within the NPD is there enough tool capacity already laid-down and is it in the right location?
- If an existing vendor tool is modified to make a modified part for the NPD can aftermarket spares still be produced?

Evaluation of potential mitigation dominance.

Out of scope for this research and thesis (pg 168) interest in the determination of the potential mitigation dominance has been expressed thesis reviews. The dominance of a mitigation will be dependent upon several variables unique to the business, the NPD and the technologies involved in the NPD delivery.

Some mitigations and their dominance will be dependent upon a ‘ramping’ function. Others such as preference markets trigger against as a ‘step’ function, the meeting of a given criteria.

An evaluation of mitigation dominance is of both academic and business interest. Both are and should be interested in the determination of where to apply their typically stretched resources for best effect.

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References 2. Reference age analytics.

In Fig 89 a histogram of the age profile of the literature cited in this research is provided. ≈51% of the literature is less than five years post-publication.

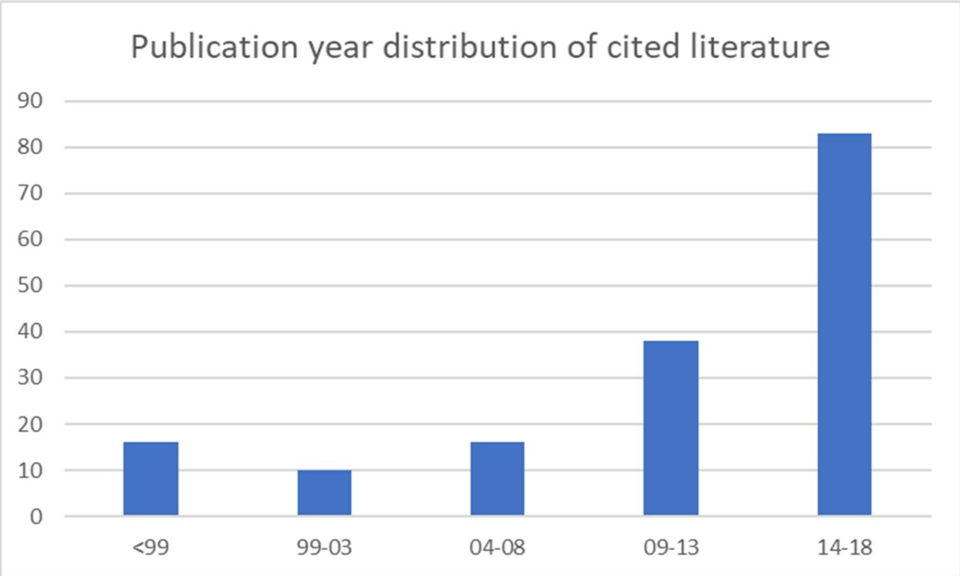

Fig 89: Age distribution of cited literature

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Appendix 1 Currency ISO codes

The official translations of the currency ISO codes used in Fig 77 and Fig 78.

ISO Codes	Currency
EUR	Euro is the official currency of several countries; Andorra, Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Kosovo, Latvia, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, Portugal, Slovakia, Slovenia, Spain, Vatican City.
GBP	UK Pound official currency of the United Kingdom.
USD	US Dollar official currency of the United States of America.
JPY	Yen is the official currency of Japan.
CZK	Czech Koruna is the currency of Czechia.
SEK	Krona the currency of Sweden.
PLZ	See PLN.
CAD	Canadian dollar is the currency of Canada.
CHF	Franc is the currency and legal tender of Switzerland and Liechtenstein; it is also legal tender in the Italian exclave Campione d'Italia.
ZAR	South African Rand is the currency of South Africa.
CNY	Renminbi (which may also be used for the yuan) is CNY (an abbreviation for "Chinese yuan"), or also CNH when traded in off-shore markets such as Hong Kong. The currency is often abbreviated RMB
NOK	krone is the currency of Norway and its dependent territories.
INR	Indian rupee is the official currency of the Republic of India.
PLN	Polish Zloty is the currency of Poland.
THB	Thai Baht is the currency of Thailand.

Correct at 16th July 2018.

Appendix 2 JLR SME interviews.

(Interviewed 5th Feb 2018, confirmed as true reflections 6th Feb 2018)

JLR SME questionnaire.

(Alan Fennelly and Chris Robottom)

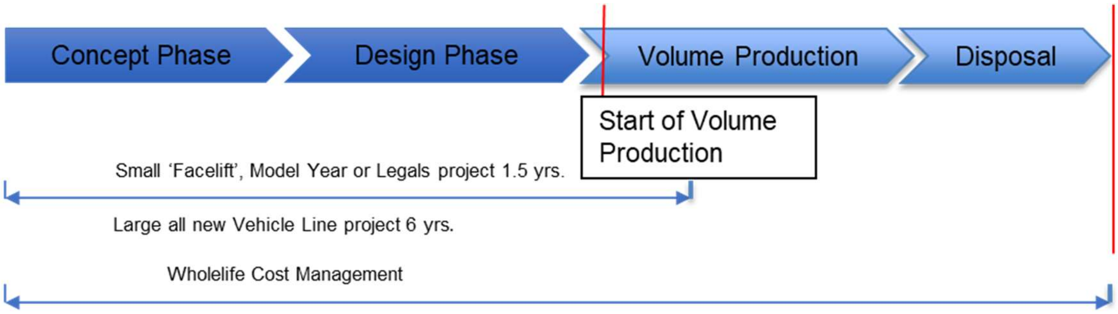


Figure 1: Generic timeline of an NPD.

Assuming the generic timeline shown in figure 1 at what phase does a company such as JLR currently have knowledge of:

1. Economically volatile materials that will be required in the "Volume Production" phase because of the NPD?
   Ans. Current practise is that 'buckets of materials' will be known during the early concept phase which get refined during the Design phase. These 'buckets' will only usually be informed by high level material definitions around materials that have been historically monitored. Materials associated with the delivery of new technology typically emerge as business shocks during the late design or start of volume production.
2. At what point in the NPD would knowledge of economically volatile materials be an advantage to the delivery of a successful NPD?
   Ans. There would be a business advantage to increasing the knowledge of NPD driven materials at the earliest point in the concept phase but, the inferred knowledge would need to have a quality indication before a business could rely upon it for decision making.
3. How much impact does the need to manage "End of Life" recyclability have on NPD material selection?
   Ans. Currently there is very little sight of early interaction between the needs of the NPD volume production drive on materials and the implication that might be drawn from the considerations of the need for recyclability. It is reactionary rather than a proactive activity.
4. At what point within the NPD is material substitution considered?
   Ans. Current practice would see material substitution being considered to address issues around NPD decision to achieve deliverability at around 1/3 into the design

phase. Iterations would continue throughout the NPD design phase. Considerations that might drive material change could be weight balance, crash capability, etc. Rarely is it considered directly to achieve lowest cost whilst maintain engineering performance.

5. It is assumed that product based precious metals such as, Platinum; Rhodium; Palladium, are financially hedged. Other key materials such as Aluminium are also financially protected. What other materials currently receive 'special' treatment either through a treasury or purchasing contract action?
   Ans. Alongside Platinum; Rhodium; Palladium and Aluminium special attention is given to Copper and fixed annual pricing contracts for Steel. As new material requirements come to the teams' attention mitigation actions are reviewed including direct discussions with the London Metal Exchange (LME).
6. At what point in the NPD does treasury develop knowledge of the materials that need to be financially hedged?
   Ans. Predictions are generated for known material tonnage requirements as a part of the annual business plan cycle. These predictions are three to five years out including the budget year, (next year). Internal treasury rules currently limit mitigation actions such as hedging to a maximum of three years.
7. If early, during the concept phase, knowledge of other NPD volume production requirements were known would this be a business advantage? (I'm thinking here of production facility requirements such as processes, facility capacity and facility quantity.)
   Ans. Knowledge of predicted production volumes is considered unreliable at best. Knowledge of the known point in time internal and supplier 'bottlenecks'; production limitations by supplier by process mapped against known commitments of current volume product and other NPDs might give a more informed overall position and impact of NPD change.
8. Would early knowledge of other commercial aspects such as currency, location of manufacture, importation taxes, any "should Cost" metadata, be an advantage?
   Ans. Yes, if it could be achieved.

Other thoughts shared by the SMEs.

- Could the proposed methods provide insight of logistics issues where fuel volatility is becoming an increasing problem?

Appendix 3 Parametric Cost Estimating SME interviews.

(Interviewed 3rd Mar 2018, confirmed as true reflections 19th June 2018)

PCE SME questionnaire.

(Professor A. Langridge)

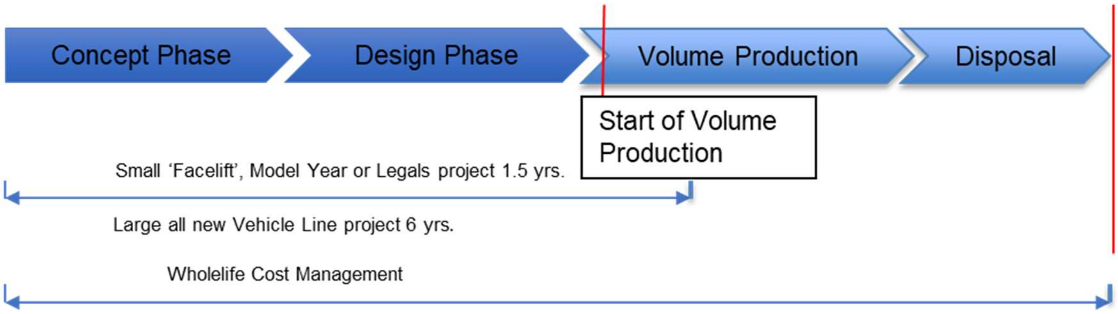


Figure 1: Generic timeline of an NPD.

Parametric Cost Estimating (PCE) has been successfully used to evaluate New Product Developments since the 1930's. Within this questionnaire there is a desire to explore the known practical application of PCE against the simplistic timeline shown in figure 1.

1. Can PCE be successfully applied throughout the timeline shown in figure 1?
   Ans. Most existing PCE toolsets are being applied in the pre-concept and concept phase to assess the 'perceived value' of the potential NPD offering. The main usage of PCE has been military, government departs who follow the CADMID cycle for costing new capability. The application of PCE within the automotive sector and to facilitate understanding of the end of life (EOL) disposal stage should be considered to be a new application of the PCE methods.
2. Given current PCE application knowledge would there be an expectation of granularity difference in the outcome of PCE applied at concept verses PCE applied at Design phases?
   Ans. The short answer is 'yes'. At the pre-concept and concept phase of current PCE application the method employs high level blocks of data. These high-level blocks of data could be too course to use deploy across the total design activity. The data used within the application of the PCE methods needs to reflect the level of detail required in the output. Highly blocked up data cannot create lower level data, whereas the collection of and manipulation of low to mid-level data sets can be aggregated for use at any level granularity higher than the collected state.
3. Does the normalisation of the source data during the PCE input effect the quality and range of the data available in the output of PCE?
   Ans. The effect of normalisation is will not directly impact the quality of the available data, but the fidelity and range of the usable data may well be restricted. The degree to which the output is impacted can only truly be established by

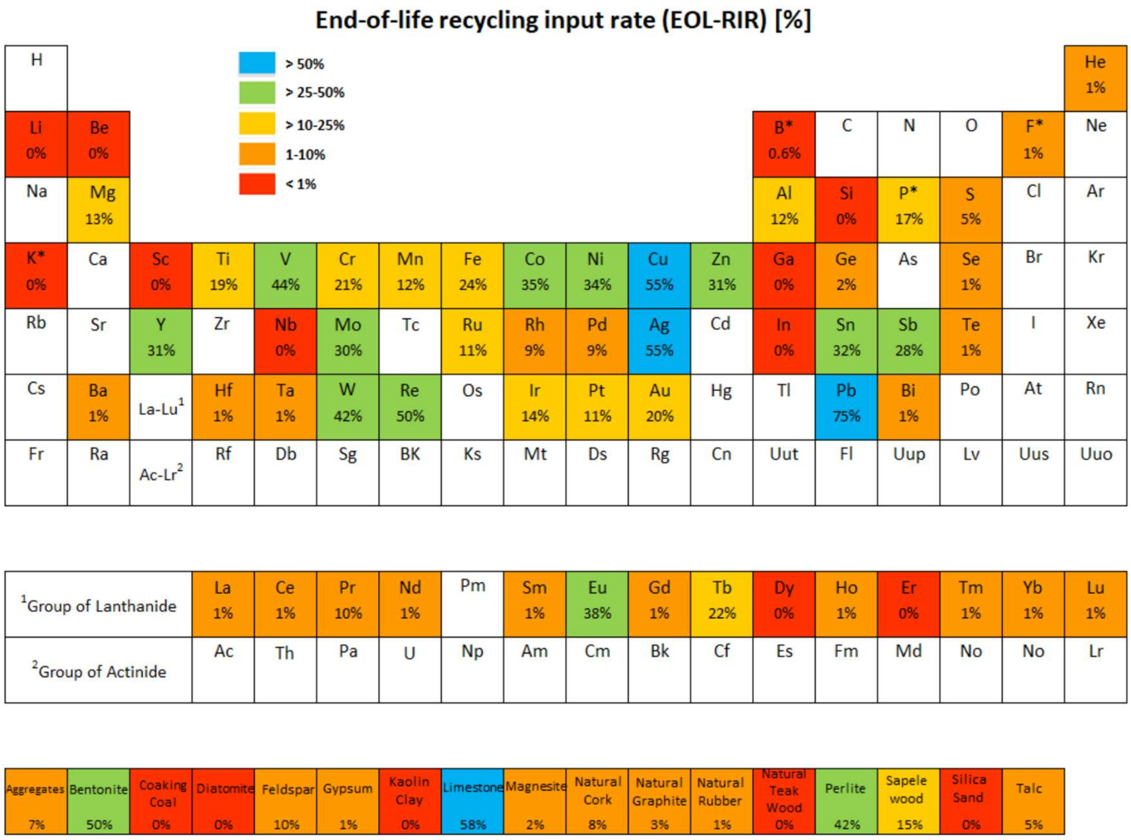
comparing a dataset for a common ‘system’ that required and has been normalised verses a comparable data set that required no normalisation. The fidelity of the data available in the PCE output data would be directly dependent upon the nature of the normalisation that has been undertaken – normalisation of all cost data to a common currency through the application of a currency conversion rate immediately eliminates any potential currency fidelity. Blocking up all material costs into a single cost group eliminates any fidelity relating to the cost of any specific material.

4. Assuming that the normalisation does have an effect would the reapplication of the source metadata, perhaps obtained through apportioning the source data, provide additional useful insight in excess of current PCE methods used in isolation? It is assumed that the metadata would be provided from should cost type sources.
   Ans. It is safe to consider that the normalisation does have an effect and that the reapplication of source metadata could be helpful under some circumstances. There would need to be a recognition of the usefulness to support decision making to ensure that the required effort provided value to the NPD. One area where this might be advantageous even within the early concept phase is in the establishment of a ‘circular economy’, recognising the EOL requirements and the ability to reuse the recycled materials in the NPD to both a social and economic advantage.
5. To the best of your knowledge have PCE methods been applied to the automotive sector?
   Ans. Taking automotive mechanical interests in isolation to the best of my knowledge PCE methods as defined within the research has not been applied outside of Jaguar Land Rover Ltd. PCE methods are applied to on-board software within the automotive sector and an example of the is within Ford. The defence industry has applied and continues to develop application of PCE methods to wheeled and tracked vehicles.

Other thoughts shared by the SME.

- It is considered that there is a difference between PCE methods and the commercially available PCE software tools; SEER-H from Galorath; and TruePlanning for hardware from PRICE Systems being examples. Both of the identified PCE tools provide the ability to construct data into sets that can be applied to all stages of an NPD but, even these tools cannot create lower level data that has not been first input into the tool at the more granular level consistent with the required output.

Appendix 4 Recycling



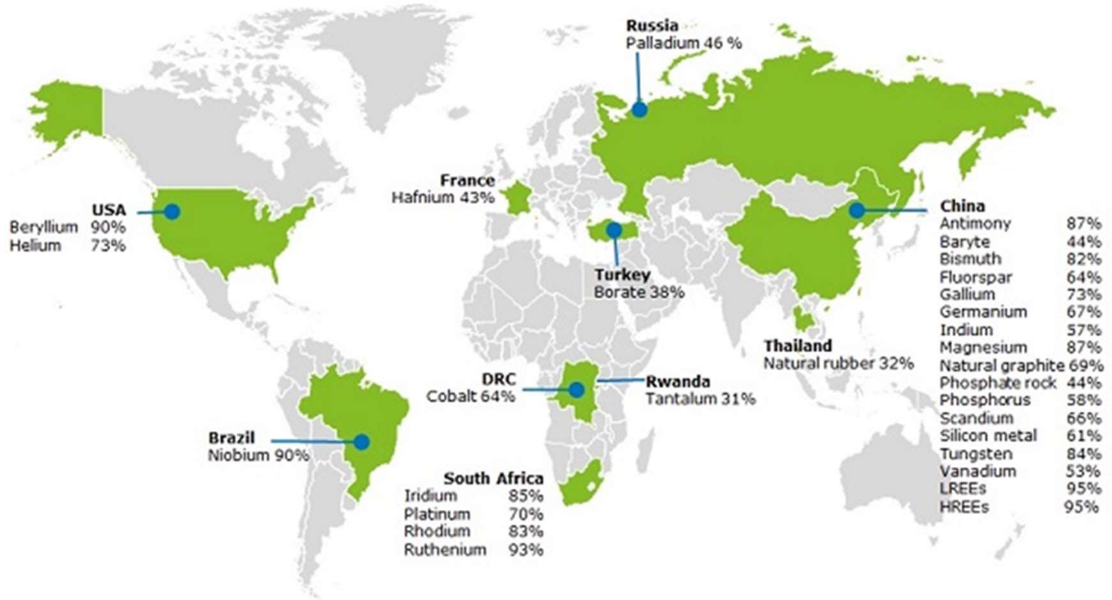
* F = Fluorspar; P = Phosphate rock; K = Potash, Si = Silicon metal, B=Borates.

Appendix Figure 1: Periodic table recyclability

Source: EUROPEAN COMMISSION, 2018. COMMISSION STAFF WORKING DOCUMENT. Report on Critical Raw Materials and the Circular Economy

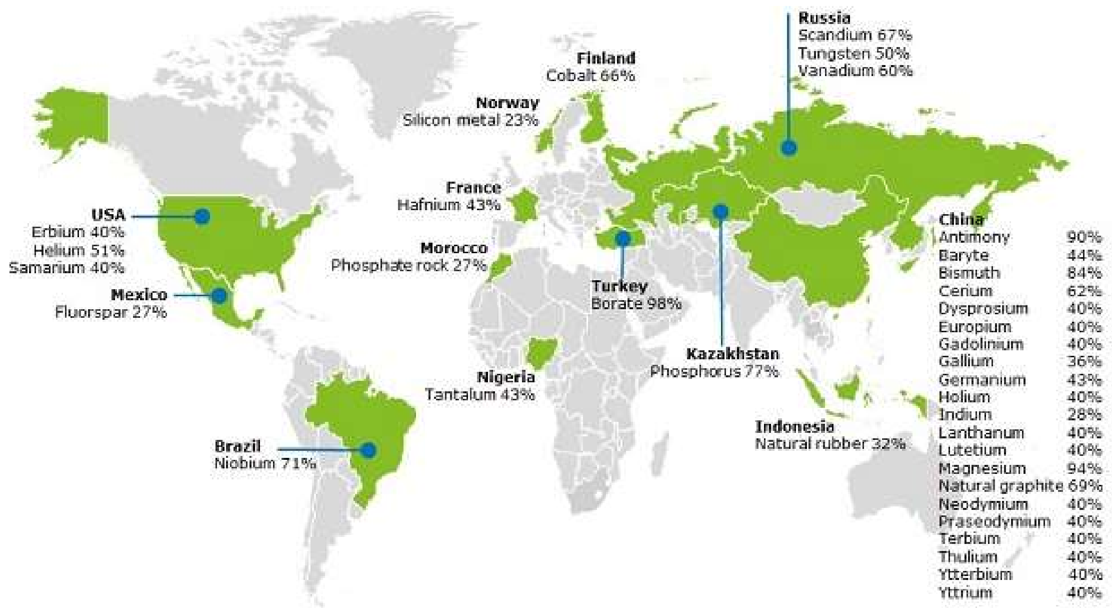
To gain a better understanding of the state of recycling at the commodity/element level the periodic table reproduced as Appendix Figure 1 gives an indication of the recycling coverage by element. When cross-referenced with the results of a composition analysis, it will indicate the ability to redesign to include a higher level of recycled material. Where there is a lack of recycling indicated, but the composition analysis indicates a significant demand Appendix Figure 1 can also indicate where greater interaction with the recycling industry to create a suitable recycling industry.

Appendix 5 Materials

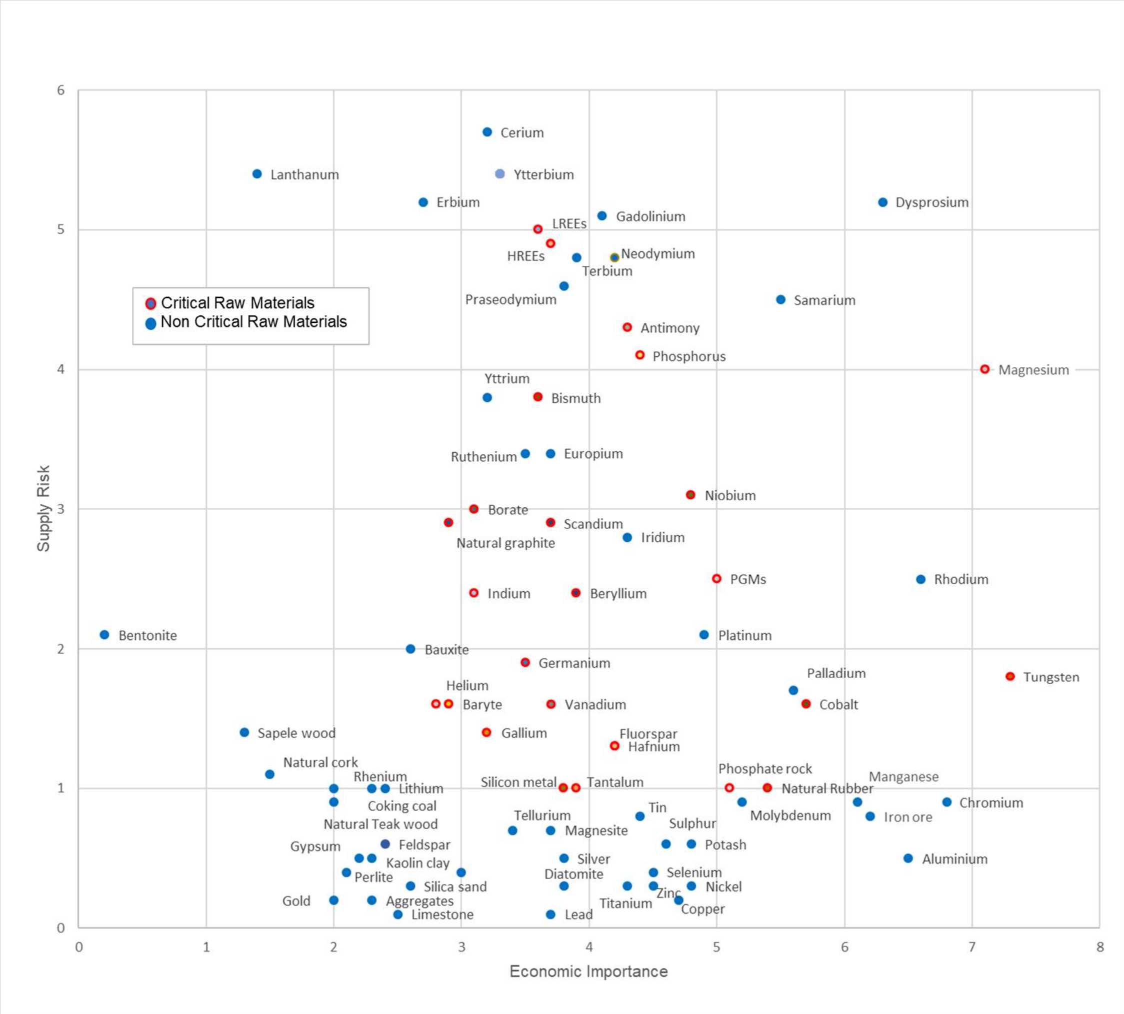


Appendix Figure 2: Countries accounting for the largest share of global CRM supplies

Appendix Figure 2 shows a global map of critical raw materials (CRMs). Its inclusion is only as a point of interest but might infer a source for material price volatility resulting from economic/political pressures within key source countries.



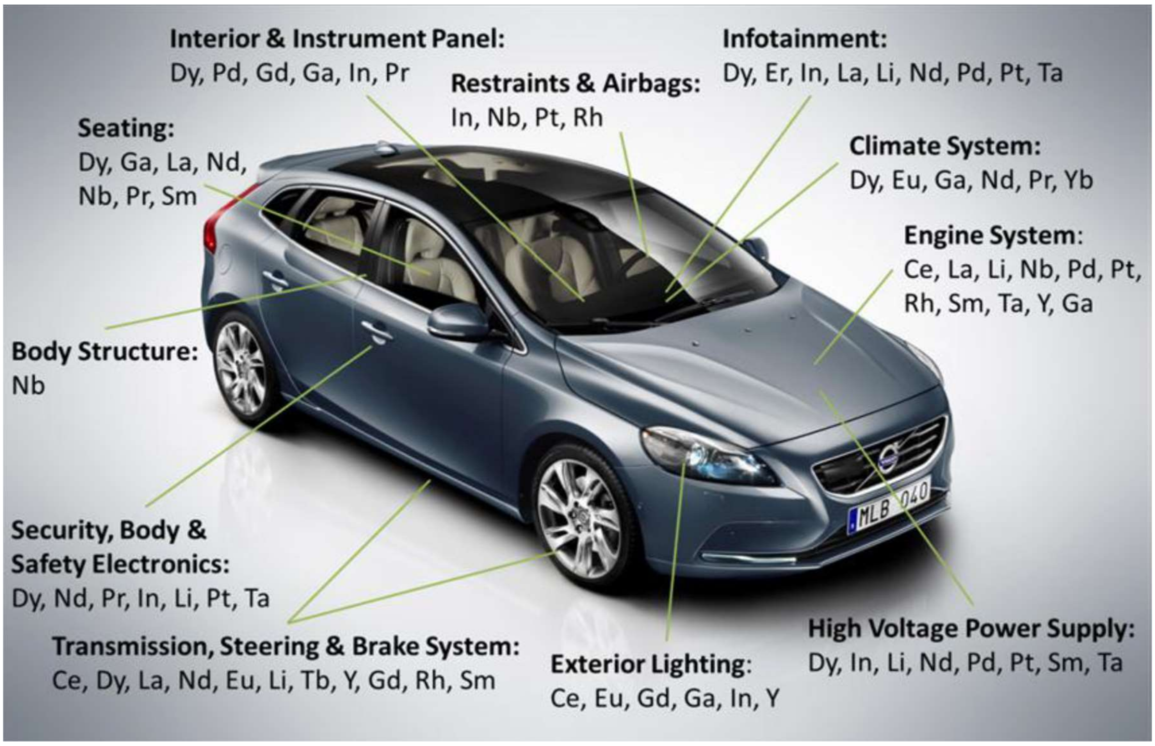
Appendix Figure 3: Countries accounting for the largest share of EU CRM supplies



Appendix Figure 4: Economic importance and supply risk 2017 EU assessment

Source for Appendix Figures 2 to 4 inc: EU Study on the review of the list of Critical Raw Materials (2017)

Appendix 6 Materials identified in the Cullbrand et al., 2012 IMDS study



Appendix Figure 5: Metal element distribution within an end of life vehicle

The material that follows in this appendix section has been reworked for grammar only from Cullbrand, K., Magnusson, O., 2012 all rights remain with the authors.

This section of the appendix describes the materials studied in short summaries.

Rare Earth Metals (REM's)

Rare earth metals (REM's) is a collective term that refers to the seventeen elements: cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, erbium, dysprosium, holmium, thulium, ytterbium, lutetium (the lanthanides) together with scandium and yttrium. Since no parts in IMDS were found to contain promethium, the material is excluded in this study. The mining activities are cost-intensive, and the elements can only be economically mined together, most commonly from the minerals bastnaesite and monazite. In 2009, the world production of REM's was 124kt, and China alone stood for 97% followed by India (2%). However, since Chinas rapidly growing economy is expected to require all of its production of REEs shortly, new mining projects have started in North America, India, Australia and Malawi (European Commission, 2010).

Cerium [Ce] Is a lustrous greyish metal and the most abundant of the REM's with an estimated concentration of 66 mg/kg in the earth crust. It is most common in the mineral's monazite, allanite, cerite, bastnasite and samarskite and often together with thorium and lanthanum (Patnaik, 2002). The main usage of cerium is in catalytic converters for the automotive industry, petroleum refining, metal alloys, glass manufacturing, polishing, ignition devices and gas lighters (Patnaik, 2002; Humphries, 2011).

Dysprosium [Dy] Is a silvery metal with an estimated concentration of 5.2 mg/kg in the earth's crust. It is most common in the mineral's xenotime, gadolinite, euxenite and monazite, often as a by-product of yttrium production (Patnaik, 2002). The main usage of dysprosium is in magnets, hybrid engines, nuclear reactors and as fluorescence activator in phosphors (Patnaik, 2002; Humphries, 2011; European Commission, 2010).

Erbium [Er] Is a silvery metal that is often found together with other rare earth metals and the concentration in the earth crust is 2.8 mg/kg. Erbium is used in a phosphor that converts infrared light into the visible light. It is also used in nuclear reactors in the control rods as a neutron absorber. (Patnaik, 2002)

Europium [Eu] Is a soft silvery metal and one of the rarest of the REEs. It is most common in the mineral's xenotime, monazite and bastnasite (Patnaik, 2002). The main usage of europium is in nuclear power stations and as a red light for television and computer screens (Patnaik, 2002; Humphries, 2011)

Gadolinium [Gd] Is a colourless or light-yellow metal with an estimated concentration of 6.2 mg/kg in the earth's crust. It is most common in the minerals bastnaesite and monazite. The main usage is in magnets. (Humphries, 2011)

Holmium [Ho] Is a soft shining silver like metal that can be found in the mineral's monazite, gadolinite, xenotime, euxenite, fergusonite, and bastnasite. Holmium has an estimated concentration of 1,3mg/kg in the

earth crust. Holmium has limited usage areas but is used to a small extent in magnets, glass colouring and laser technologies (Patnaik, 2002).

Lanthanum [La] Is a silvery-white metal and are most commonly found in the rare-earth mineral's monazite and bastnasite with a concentration of 15-20% in the minerals. In the earth crust lanthanum has an estimated concentration of 30mg/kg. The main use is in metal alloys, phosphor lamp coating, optical glass and in glass polishes (Patnaik, 2002).

Lutetium [Lu] Is a silvery-white metal and occurs in yttrium rich minerals in small amounts. Lutetium have few commercialise application; one is to catalyse organic reaction (Patnaik, 2002).

Neodymium [Nd] Is a silvery-white soft metal that occurs with other rare earth metals and most commonly with cerium group elements. Its concentration in the earth crust is estimated to 24mg/kg. The main usage is in metal alloys together with cast iron, magnesium, aluminium, zirconium and titanium (Patnaik, 2002). It is also used in glass colouring, autocatalyst, petroleum refinery, laptop hard drives, headphones and in hybrid engines (Patnaik, 2002; Humphries, 2011).

Praseodymium [Pr] Is a pale-yellow metal with an estimated concentration of 8.2 mg/kg in the earth crust. The main uses for praseodymium are in glass colouring and magnets (Patnaik, 2002).

Samarium [Sm] Samarium is a yellow hard metal which is widely distributed in nature, and the concentration in the earth crust is 7.05 mg/kg. Samarium is always found together with other rare earth metals in typically in minerals such as monazite and bastnasite. The uses for samarium are in optical glass, capacitors, thermionic generating devices, lasers, carbon arc lightning and in permanent magnets. (Patnaik, 2002)

Scandium [Sc] Is a silvery-white metal which is soft and light. Scandium is widely spread in nature, but in low concentration, the concentration in the earth crust is estimated to 22mg/kg. It can be found in most soils and in numerous minerals but in very low quantities. The uses for scandium are used to create very high-intensity light. (Patnaik, 2002)

Terbium [Tb] Is a silvery-grey soft metal that is found in the mineral's xenotime, euxenite, cerite, monazite and in gadolinite. The concentration of terbium in the earth crust is 1.2 mg/Kg. Its limited usage can mostly be found in phosphor and permanent magnets (Patnaik, 2002).

Thulium [Tm] Is a silvery lustrous metal and one of the least abundant rare earth metals in nature. Thulium can be found together with other rare earth elements in yttrium rich minerals. The concentration in the earth crust is approximate 0.52 mg/kg. The uses of thulium are few due to the high production cost; thulium is used in portable x-rays tools as medical and dental diagnostic tool (Patnaik, 2002).

Yttrium [Y] Is a shining grey metal that is most commonly found in the monazite sand which consist of approximately 3% yttrium. The concentration in the earth crust is estimated to 33mg/kg, and it has also been found in moon rocks. The main uses are as red colour in televisions, fluorescent lamps, ceramics and metal alloy agent (Patnaik, 2002).

Ytterbium [Yb] Is a silvery lustrous, soft metal. Ytterbium occurs in different minerals such as euxenite, monazite, xenotime and in a complex titanium niobotantalate. The concentration in the earth crust is estimated to 3.2 mg/kg. The uses for ytterbium are; as a laser source, portable x-ray source, additives in steel, and in glass. (Patnaik, 2002)

Platinum Group Metals (PGM):

The Platinum group metals consist of six metals: ruthenium, rhodium, palladium, osmium, iridium, and platinum. The metals have similar chemical properties such as high melting point, low vapour pressure, high temperature coefficient of electrical resistivity, low coefficient of thermal expansion and strong catalytic activity. The reserves are distributed unevenly in the world with approximately 88.5% is in South Africa and 8.7% in Russia (European Commission, 2010). The three selected PGMs for this report are palladium, platinum and rhodium.

Palladium [Pd] Is a silvery-white metal with an estimated concentration of 0.015 mg/kg in the earth crust. In nature, it is always found together with other PGMs, and it is three times more abundant than platinum. Important applications for palladium are in autocatalysts, electronics, dental care, jewellery and telecommunications (Patnaik, 2002). In 2009, the world production of palladium was 195 t where Russia and South Africa accounted for approximately 41% each (European Commission, 2010).

Platinum [Pt] Is a silvery-white lustrous metal with an estimated concentration of 0.005 mg/kg in the earth crust. In nature, it occurs together with other PGMs. Important applications for platinum are, e.g. in autocatalysts, jewellery, dentistry, electronics, as a catalyst, e.g. hydrogenation and as a coating for jet engines and missile parts (Patnaik, 2002). The world production of platinum was 178 t in 2009 where South Africa and Russia accounted for 79% and 11% respectively (European Commission, 2010).

Rhodium [Rh] Is a greyish-white metal with an estimated concentration of 1 mg/kg in the earth crust. In nature, it occurs in small quantities together with other PGMS. A large number of its application is as an alloying or hardening agent for platinum and palladium. Other important applications are in, e.g. electronics, jewellery, glass manufacturing, auto catalysts and several other catalytic reactions. (Patnaik, 2002). In 2006, South Africa accounted for 89% of the world's supply of rhodium. (U.S National Research Council, 2008)

Other materials:

Cobalt [Co] Is a silvery white metal, widely distributed in small concentrations in nature. Its concentration in the earth crust is approximately 0.0025%, and it is most commonly found in rocks, coal and soils (Patnaik, 2002). Of the world production of cobalt, 85% arises from nickel and copper production and only 15% from pure cobalt production (European Commission, 2010). A large share of the usage of cobalt is in superalloys with high resistance to oxidation, corrosion and high temperatures (Patnaik, 2002). It is also used in high-speed trains, lithium-ion batteries and synthetic fuels. Cobalt is considered to have limited substitution options (European Commission, 2010). Figures from 2010 show that 53% of the mine production comes the Democratic Republic of

Congo, followed by China and Russia with around 7% each. In 2010, the world production of cobalt was estimated to 87,400 tones.

Copper [Cu] Is a reddish-brown metal. In nature, copper can be found as sulfides, oxides, arsenides, arsenic-sulfides, carbonates and as native copper (100% copper). Copper has good characters especially for heat and electricity transfer and is therefore used in electric wiring, switches and electrodes. Other uses for copper are plumbing, piping, roofing, cooking, and electroplating protective coating. (Patnaik, 2002) The world production 2008 was 15,427,000 tones, and the main producing countries were Chile (34.5 %), USA (8.5 %) and Peru (8.2 %). The demand in the future are expected to increase due to the expansion of renewable energy that needs more cables and generators than non-renewable electricity production also electric vehicles requires significant more copper than conventional vehicles. Coppers good qualities make it hard to substitute in an electrical application, but copper that is used as a construction material can be substituted with aluminium or non-metallic substances. (European Commission, 2010)

Gallium [Ga] Is a silvery white metal similarly to aluminium but with a lower melting temperature of nearly room temperature 30 °C. The concentration in the earth crust is 19mg/kg and in the average concentration in the sea is 30ng/L. Gallium is found in ores of other metals and is being produced as a by-product from bauxite and zinc ores. In much of the ore, the concentration of gallium is too low to be economically feasible to extract. The main primarily producing countries are China (75%), Germany, Kazakhstan and Ukraine. The main use of Gallium is in integrated circuits and laser diodes/LED other uses of gallium is in photodetectors and solar cells. In the future, the demand for gallium is predicted to double to the year 2015 due to the rapid increase of use of gallium in photovoltaic technologies. Gallium is not being recycled from old scrap due to there is almost no old scrap available yet, but new scrap is being recycled. In future, 40-50% of the produced gallium would come from recycling and that most of the recycled will take place in Japan. Substitution availability is available for most of the technologies but not in some integrated circuits for defence-related systems. (European Commission, 2010)

Gold [Au] Is a yellow metal. Gold is widely distributed in nature, but in small concentration, the concentration on the earth crust is 4µg/kg. It occurs in its elemental form as metal or as an alloyed with silver often found in copper ores. (Patnaik, 2002) The world production 2009 was 2,350 tones; the main producing countries were China, Australia, USA, South Africa, Russia and Peru (U.S. Geological Survey, 2010). The main usage of gold is in jewellery, gold plating of electronics, brazing alloy and photographs.

Indium [In] Is a silvery white soft metal, that is widely distributed in small concentrations. It is estimated to 0,1mg/kg in the earth crust and is found mostly in zinc sulfide ores and to a lesser extent in sulfide ores of iron and copper (Patnaik, 2002). The production depends on the production of lead and zinc since there is no primary production of the metal itself. The main end-use markets for indium are flat screen panels to the extent of 74% of the total end use. Other common applications are low melting point alloys for temperature indicators, minor alloys for dental application and architectural glass and windscreens. Less than 1% of indium scrap is being recycled (European Commission, 2010).

Niobium [Nb] Is also known as Columbium and is a soft greyish metal. Its concentration in the earth crust is estimated to 20mg/kg, and it can be found in several minerals often together with tantalum and rare earth metals. World production in 2009 was 61,7kt with 92,4% of the production in Brazil and 7% in Canada. The amount of recycled niobium is not known, but estimation from [USGS Mineral Commodity Summaries 2011] states that up to 20% could be recycled with the right measures. The main usage for niobium is as metal alloying both for ferrous and non-ferrous metals. The main alloy is high-strength steel for construction of car bodies, off-shore platforms and pipelines but also as high-strength steel in aircraft and the nuclear sector (European Commission, 2010).

Lithium [Li] Is a silvery metal and is the lightest metal. Lithium is widely distributed in nature, and the concentration in the earth crust is 20mg/kg and in the sea 0.18mg/L. The use of Lithium is many such as medical uses, metallurgical as alloys in lead, magnesium, aluminium and other metals. Lithium is used in high energy batteries for electronics, and in cars, it is also used in glass and ceramics and as lubricating grease for the automotive industry. (Patnaik, 2002) In the future Lithium car batteries is projected to be the dominant use for lithium to 2050. The main producers of lithium are Chile with 41.7 % of the total production in 2009 other large producing countries are Australia (24.8%), China (13.0 %) and Argentina (12.4 %). (European Commission, 2010)

Magnesium [Mg] Is a silvery white metal. Magnesium is one of the most common metals in nature, and the concentration in the earth crust is approximately 2.4%, but it does not exist in its elemental form it exists in different mineral forms. Magnesium can also be found seawater with a concentration of 1,350mg/L, Magnesium also occurs in all plants and are and are an important nutrient for humans and recommended daily intake for adults are 300mg/day. Magnesium is used in chemical, electrochemical, metallurgy and electronic industries. Magnesium is alloyed with aluminium, zinc, copper, nickel, lead, zirconium and other metals as well. The alloys are used in almost all industries for example in the automotive industry. (Patnaik, 2002) The world production 2009 was 30,190,000 tones, and the main producing countries were China (56.1 %), Turkey (12.0 %) and Russia (7 %). (European Commission, 2010)

Manganese [Mn] Is a reddish grey metal. Manganese is the twelfth most abundant metal in nature, and the concentration in the earth crust is 0.095%, and the average concentration in seawater is 2µg/L. Manganese exists mostly in the form of oxides, silicates and carbonate ores and is often found together with iron ores in small quantities. (Patnaik, 2002) The world production 2009 was 9,664,000 tones, and the main producing countries were China (24.8 %), Australia (16.6 %), South Africa (13.5 %) and Brazil (10.2 %). Approximate 90% of the usage for Manganese is in steel metallurgy where it is used as a deoxidising and desulfurising agent. Other uses are in copper for the same reason in steel, corrosion protection. (European Commission, 2010)

Molybdenum [Mo] Is a silvery white metal. Molybdenum does not exist in nature in free element form. Molybdenite (MoS2) is the most important ore and the one that is commercially mined. (Patnaik, 2002) The concentration in the earth crust is between 1-1.5 ppm and is mined both as primary production and as a byproduct of copper. The world production 2009 was 202,000 tones, and the main producers were China (37.9 %), USA (24.6 %) and Chile (15.8 %). The main usages for molybdenum are in metallurgical used as an alloy mainly in different steels, but it is also used for catalysts, pigment, corrosion inhibitors and lubricants. (European Commission, 2010)

Silver [Ag] Is a white metal with brilliant metallic lustre. The estimated concentration of silver in the earth crust is 0.075mg/kg, and in seawater, the concentration is 0.014µg/L. Silver can be found in its elemental form commonly together with gold and can be found in most lead and copper ores. (Patnaik, 2002) The world production in 2008 was 21,300 tones, and the main producing countries were Peru (17.3 %), Mexico (15.2%) and China (13.1%). The main usages for silver are in the jewellery, electrical and photography industries. It is also used as catalysts, clothing, dental, solar panels, water treatment and plasma displays. Recycling of silver depends on where it has been used, silver that been used as jewellery is recycled up to 90%, but silver that has been used in electronics are only recycled up to 10-15%. (European Commission, 2010)

Tantalum [Ta] Is a grey heavy and hard metal. The concentration in the earth crust is estimated to 2mg/kg and are never found as a free element form; tantalum is occurring most often in the mineral columbite-tantalite (Fe, Mn) (Nb, Ta)206. The properties of tantalum and its alloys are the high melting point, high-strength, ductile and high resistance to chemical attacks. Due to the properties tantalum are used in alloys for high-strength and heat-resistant materials for aircraft, missile, automotive and gas and steam turbines industries. Tantalum is also used in capacitors, medicine and optical industries. (Patnaik, 2002). Few countries that produce tantalum in 2009 Australia stood for 48,3%, and Brazil for 15,5 % of the world production other countries that produced tantalum is Canada, Democratic Republic of Congo and Rwanda. Recycling of tantalum exists from cemented carbide and alloys sectors where tantalum is recovered in mixed or alloy form. Recycling from capacitors which is the main usage of tantalum does not exist due to it is difficult and expensive. For many technologies' tantalum can be substituted or there is work in progress for substitutions but when tantalum is substituted most of the application's loose ineffectiveness. (European Commission, 2010)

Tellurium [Te] Is a silvery-white lustrous metal. Tellurium occurs in nature in very small concentration and can be found together with gold, silver, lead, nickel minerals and less common as tellurite (TeO_2). The estimated concentration of tellurium in the earth crust is 1µg/kg. (Patnaik, 2002) The tellurium primary producing countries are China (33%), Belgium (33%), Philippines (16%), Japan (12%), Canada (4%) and Russia (2%) of the world production in total. The world capacity for production of tellurium is high and is 74-78%. The main usages for tellurium are as an alloy element in steel, copper, lead and cast iron. Other uses are in chemical and pharmaceuticals, electronics and in photovoltaic thin-films technologies but the use of tellurium in photovoltaic are predicted to decrease due to other materials are used instead. The recycling of tellurium exists in small amounts but is growing.

NB: (Ares, 2015) added several materials in addition to those shown in the (European Commission, 2010) report. Borates, Chromium, Coking coal*, Magnesite, Phosphate Rock*, Silicon Metal*. * - denotes new material in scope.

Appendix 7 Additional Appendix Bibliography (References)

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Appendix 8 Letters to JLR and IMDS re access to IMDS data.

A Postgraduate enquiry in pursuance of a PhD usage of IMDS sourced data within a proposed methodology.

Robert Mills [redacted] 11:20
To imds-helpdesk-english@dxc.com

Dear Sir/Madam,
First, let me introduce myself.

I am a postgraduate PhD student at the University of Bath, [redacted] and a now retired Senior Manager from Jaguar Land Rover after 33 yrs service.

It was during my Jaguar Land Rover service that I originally came across your IMDS service, the data it contains and the restricted usage under its terms and conditions. (My function within Jaguar Land Rover was principally in a Cost Estimating role for tier 1 + supplied components.)

I am currently seeking to complete a part-time PhD at the University of Bath where I am researching into the identification and quantification of commercial uncertainties that would manifest during the volume production and disposal phases and addressing their impact during the concept phase of a new product development (NPD). The aim being to establish early confidence that once in volume production the risks to NPD profitability due to volatile economic forces can be reduced.

At my research core is the application of Parametric Cost Estimating during the early concept phase and the re-application of metadata from Should Cost and other sources such as IMDS to highlight uncertainties such as the ability of the New Product Development to achieve its legislative recyclability targets and the inclusion of economically volatile materials. My concern and why I am contacting you is that I would like to know if this proposed potential inclusion of IMDS data would be permitted under the terms and conditions of use of IMDS data?

If you consider that the usage of the IMDS data in the stated context is permissible I'd also like to confirm if direct access is available to the data?
Thank you in advance.

Regards
Robert Mills

Request to Jaguar Land Rover Material Sustainability team.

From: **Robert Mills** [redacted]
Date: 26 April 2018 at 14:15
Subject: Access to IMDS data in support of replications of VCC and Ford findings using JLR data for PhD research.
To: Cedwards4[redacted], Pcassell[redacted],
iellison[redacted]
Cc: afennel2 [redacted] rmills10 [redacted]

Christopher, Paul, it has been a while, about a year, since we last spoke, and I don't think we have spoken as yet Ian.

When we last spoke, it was as a follow-up on a conversation that you had overheard between myself and a PhD student from Birmingham City University that was taking place in the Gaydon canteen.

Whilst I'm now [redacted] I am also a postgraduate student finishing my own PhD @ the University of Bath, a PhD that I'd started whilst still working for Alan Fennelly. I'm now retired from JLR but still attempting to finish my PhD.

One of the objectives of my PhD is to forecast the use of economically volatile materials and the ELV recyclability whilst still in the very early stages of the Concept phase pre-Design of a New Product Development (NPD).

During my literature review, I have encountered a few papers that originated out of VCC and Ford using IMDS data to show the metals content at end of life. I'd like to access JLR IMDS data to validate the findings of these papers. If validated, it would allow me to establish that if I can get my output from a concept analysis of the NPD into the same IMDS format it is reasonable to assume that the properties normally associated with IMDS data as sourced from OEM tier 1 suppliers will hold true.

It is already understood that the usage of IMDS data is restricted under the DXC-IMDS T&Cs, It cannot be shared with Purchase functions and used in any way as leverage with OEM tier 1 suppliers.

I look forward to hearing from you and perhaps arranging a face to face in the near future.

I've attached copies of the papers referenced by VCC and Ford.

Regards

Robert Mills