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Inspection Models for Automotive Parts Remanufacture

By

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Abstract

Remanufacturing can be classed as the act of bringing end-of-use products back to "like new" conditions with warranty to match. The field has been steadily growing in recent years due to a cultural shift towards sustainable practices. *'Inspection'* is the action of assessing parts in order to determine the needed actions to bring them back to standard, and is a critical factor. Previous work by Errington and Ridley in this area have shown the necessity of increased structure and tools to aid automotive remanufacturing inspection. This aim of this research was to investigate the inspection issues faced by automotive parts remanufacturers within the UK and develop tools to alleviate the lack of guidance on inspection activities. Case study methods were used at five different companies to identify the issues, this included over-reliance on inspector expertise, difficulties in knowledge share, and an aging workforce. A 4-part model was developed to combat these issues, and was later validated through both industry and academic review, and an expert panel to ensure robustness and rjgour. This research was unique in that it approached inspection by focusing on the practices and methods rather than a business or strategic perspective targeting cost effectiveness rather than operational efficacy. The beneficiaries of this research include academia and industry, with academia furthering the building of benchmarking for inspection, and a new method of investigating inspection within remanufacturing. Industry can use this research to further refine their inspection practices and in training with new staff.

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Glossary

Aftermarket	*The broad term used to describe all operations involving EoU/EoL products (Recondition, Repair, Remanufacture, Recycle etc.).*
Core	*Core refers to the product or sub-assembly acquired for remanufacture*
Contamination	*Contamination describes the impurities that can be found on or in core, including dirt, liquid residue, plant growth, and foreign substances*
Contamination	*Contamination describes the impurities that can be found on or in core, including dirt, liquid residue, plant growth, and foreign substances.*
Degradation	*Degradation refers to the material breakdown on core surfaces and structure caused by factors such as poor storage, elemental exposure, age, and treatment.*
End of Use	*End of Use refers to a product that has reached the end of its functional life but can now enter the recovery process and undergo aftermarket activities rather than End Of Life and final disposal.*
End of Life	*End of life refers to products that have reached their final end point and cannot be further recovered in any format, and are ready for final disposal.*
Internal Remanufacturing Specification	*IRS refers to the reverse engineering activities undertaken by remanufacturers who don't have access to the necessary technical specification s to carry out remanufacture.*
Methodology	*Methodology refers to the structure and techniques used to investigate, collect, and analyse data in this research.*
Model	*Model in the context of this research refers to the visual and text based guides to inspection activities that have been developed.*
Rebuilt	*Rebuilt refers to core that has reached the reassembly stage and is now complete and ready for its performance assessment.*
Recondition	*The act of bringing a product back to functional working condition with some warranty - Reconditioned products will work largely as expected but will be to a much lesser standard than remanufactured equivalents.*
Recovery	*Recovery is the action of acquiring End of Use products (core) for the purposes of remanufacture/recondition.*
Refurbishment	*Refurbishment is the term used by parts of the world (Asia) to describe remanufacturing/recondition activities. Lack of common terminology has necessitated this term be used to mean both as it cannot be always counted on to mean that a product has been remanufactured to standard.*
Remanufacture	*Remanufacture is defined as the process of returning an End-of-Use (**EoU**) product back to OEM standards and New Warranty.*
Remanufacturing Activity	*A remanufacturing activity describes the specific remanufacturing stage (i.e. cleaning, inspection, disassembly).*

Remanufacturing Operation	*The remanufacturing operation refers to the entire remanufacturing set of activities from core acceptance into the process through to packaging and distribution.*
Rework	*Rework in this case refers to the activities undertaken to bring the core back to standard. This occurs between "Inspection" and "Reassembly".*
Repair	*Repair refers to the act of fixing a specific fault in a product back to functional operation; there is no guarantee of full functionality but more acceptable functionality.*
Tacit Knowledge	*Tacit knowledge in this context refers to the skilled experience that remanufacturing inspectors possess. This expertise allows parts assessment to be very successful but makes knowledge share difficult and lacks any impartial point of reference.*
Wear	*Wear refers to the reduction of material due to handling, usage, storage or miscellaneous factors. It is one of the most common forms of damage found on core.*

Terms and Abbreviations

Abbreviations	**Full Terms**
DATF	*Damage Assessment Tracking Form*
EoU	*End of Use*
EoL	*End of Life*
HDOR	*Heavy Duty Off Road*
IICEA	*Internal Inspection Comparative Evaluation Analysis*
IR	*Independent Remanufacturers*
MM	*Maturity Modelling*
MPI	*Magnetic Particle Inspection*
NDT	*Non-Destructive Testing*
POM	*Pyramid of Methods*
R "1/2/3 etc."	*Questionnaire Response number "1/2/3 etc."*
RaPID	*Remanufacturing and Process Inspection Database*
WEEE	*Waste Electronic and Electrical Equipment*

Publications

Publications by the author include:

1. A study on the heavy reliance on personal knowledge and opinion within automotive parts remanufacture - Submitted
2. New definitions for Inspection sub-stages in Automotive Remanufacturing - Submitted
3. Review and Evaluation of DATF Models through Industry - Submitted

Conference Papers and presentations include:

1. International Conference of Remanufacturing (ICOR) 2015 – *A study into existing issues and potential improvements in IR Automotive Remanufacturing (Author)*
2. International Conference of Remanufacturing (ICOR 2017) - *Novel Inspection Model for Automotive Remanufacturers – DATF; Development & Review (Author)*

CHAPTER 1: INTRODUCTION:

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The modern world consumes large quantities of raw resources in order to allow global manufacturing demands to be met. However these natural resources are finite and in recent years it has been noted that they are diminishing at ever increasing rates (Deckert 2016; King et al. 2006). If no '*safety net*' of alternative manufacturing methods are in place to cushion the impact this will have on industries across the world then we leave ourselves highly vulnerable to issues to address such as sudden shortages of materials that are necessary for manufacturing.

Remanufacturing is a field within sustainable engineering that has become more prominent over the last few decades. Remanufacturing is a core concept of '*sustainability'* – and is defined as the process of returning an End-of-Use (**EoU**) product back to OEM standards and new Warranty (Ijomah, et al 2004; BSI 2009). This field developed as an industry due to the scarcity of manufacturing resources post-WW2 and focuses on bringing products back to a suitable standard through an approach that uses far less material and energy than standard manufacturing. While the field may have begun as merely a temporary measure to combat material scarcity its usefulness in aiding long-term sustainability ideals has ensured that it has remained active to this day.

While no large-scale solution has been put in place, multiple avenues of research are being explored across the world in order to combat the situation. Remanufacturing is a significant part of this research under new development and as such has risen to greater prominence over the last decade (Ijomah et al. 2007; Fadeyi et al 2017; Chakraborty et al, 2019).

The level of 'waste' produced across various manufacturing sectors can be very harmful to both users and the environment. New awareness of both the vulnerability and degradation of our natural resources and environments due to human action has prompted call for a shift towards a more sustainable society.

This focus on the conservation of our natural resources has lead to new legislation and policy, such as those regarding the suitable disposal of **EoU/EoL** products. In particular "Directive 2000/53/EC" known as the ELV Directive (EU 2003) on end-of life vehicles aims at making dismantling and recycling of ELVs more environmentally friendly across all of Europe. It sets clear quantified targets for reuse, recycling and recovery of the ELVs and their components. This gives manufacturers goals to aim for and a clear form of self-assessment to ensure that they are moving towards such targets. Legislation of this kind has aided in displaying clear targets that OEM's can strive for as they undertake remanufacturing practices, either in–house or through external contractors. (Chen and Zhang 2009; Gerrard and Kandlikar 2007; Kim et al. 2004)

Investigative studies conducted across the UK, Europe and the US have shown that within the Remanufacturing and aftermarket sectors Aerospace, Automotive & EEE typically make up the largest segments of the market. (Parker et al 2015)

Remanufacturing is still vulnerable to 'detrimental factors' that can hinder a larger-scale uptake in society. Many of these obstacles relate to issues of either core movement between borders, differing understanding surrounding terminologies of waste, or a lack of consensus in the remanufacturing practices themselves. (Teunter and Flapper 2011; Andrew-Munot and Ibrahim 2013).

Ambiguity or a difference in definition terminology has lead to products undergoing lesser forms of recovery such as recondition and repair but still be classed as *remanufactured*. As such these outputs are far below the expected standard of truly remanufactured product (Watson 2008). The lack of a consensus of terminology from the outset of the field has allowed such operations to take place, however in recent years multiple authors have aimed to reduce ambiguity in processes and-terminology with an aim of creating an easier flow and understanding of remanufacturing principles and information (Ijomah et al. 2007).

In the case of the automotive sector, poor perception has remained a significant barrier. If a remanufactured product is inferior serious boldly harm or worse for a user is a very real possibility. As such the reputation of excellence in terms of the quality of output from companies operating within this sector is of paramount importance.

There are 3 different types of remanufacturing operations; these are Independent, Contract and OEM.

1. OEM in-house aftermarket operations occur entirely within the purview of the scope of the business, access to original specification and technical data is

easily acquired. They are typically large-scale operations with a high turnover, though they only make up a small segment of the aftermarket.

2. Contract remanufacturing occurs outside of the OEM but under their supervision, with key data supplied to the contractor undertaking the remanufacturing work on their behalf. Contractors may undertake work for multiple OEM's concurrently. They can range in size depending on the level of turnover required by contracts, though they make up a larger segment of aftermarket sales.
3. In the case of independent remanufacturing companies, they are completely separate, and can require reverse engineering or data gathering from external sources (i.e. Technology consultancies) in order to develop an IRS (Internal Remanufacturing Specification). This is a term referring to full technical understanding of the product, ensuring that it can be brought to the standard of 'as-new with as-new guarantee'. Usually independent remanufacturers are small-scale in size but can also be very adaptable due to the uncertainty of incoming core volume and type. The majority of automotive remanufacturing performed in the UK is believed to be undertaken by independents (European Remanufacturing Network 2016).

Contract Remanufacturing can provide an effective option to OEM's that wish to become more sustainable but lack the infrastructure currently to undertake their own remanufacturing. This set up benefits both parties as the remanufacturing activities can be undertaken at the Contractors facility with skilled labour and suitable technology already in place, while the Contractor gains valuable technical data protected by the OEM.

However in this type of scenario the stability in the output quality of the contractor to the OEM is a critical factor to the continued success of the business (Rahimifard et al. 2009; Ayres et al. 1997). It is when that quality drops that the relationship between the OEM and the Contractor becomes tainted, and can lead to serious issues for the Contractor's continued success.

A key feature of this research was to provide improved agreement on best/good practice for specific remanufacturing activities, specifically automotive parts inspection. This work is essential as greater understanding and standards within the remanufacturing sector aid its overall uptake in society (Ijomah et al. 2005).

The initial stages of this research involved a systematic literature review covering key data regarding the remanufacturing field as whole, followed by automotive remanufacturing practices, before focusing in on key inspection literature..

1.1 Remanufacturing Process overview:

Remanufacturing activities: **Disassembly, Cleaning, Inspection, Rework, Reassembly** and **Testing** (Ijomah et al. 2005; Lund and Skeels 1983). These activities are the '*key*' features that define a fully realized remanufacturing operation. Variation in effectiveness or quality within these activity stages can signal that a company may not be able to meet the remanufacturing standard, potentially compromising the entire remanufacturing process.

1.2 Research aim:

The aim of this research was to investigate the inspection issues faced by automotive remanufacturers and alleviate the lack of structure and guidance in inspection activities.

This involved satisfying the following objectives:

1. Investigate the activity of inspection in automotive remanufacturing.
2. Identify the key problems faced by both existing remanufacturers and new entities moving into the sector.
3. Develop a 4-part model (DATF) to combat the main issues.
4. Ensure the model data is valuable to both remanufacturers and academics.
5. Validate the findings.

1.3 Research question:

Below are the 3 key research questions that drove this work forward;

- *What are the common inspection practices and procedures used by automotive remanufacturers?*
- *What issues currently affect inspection practices, as they remain ill defined?*
- *Can these issues be rectified with new knowledge or thesis output, specifically a structured guide to inspection for the entire automotive remanufacturing sector?*

These research questions provided a scope of limitations and a clear direction for the research to follow.. The scope of the research was very clearly defined as within the remanufacturing field by the initial question, the addition of the '*automotive'* aspect ensuring that the research kept this factor as a key focus.

With each subsequent *research question* the thesis output became more defined, first the identification of the issues, then the possibilities at combating them, and finally the validity of the proposed solution.

1.4 Research novelty:

The core output of any PhD is new knowledge. The identification of such knowledge is the most critical feature of the research (Booth et al. 2008). To aid this search a literature review is conducted during the early stages; this provides the reader with a more comprehensive view of the available knowledge within the area of research (**Automotive Remanufacturing Parts Inspection**) as encountered by the author, highlighting any key gaps to be further investigated later in the research

In terms of the novelty of this research, this could only be truly '*pinned down'* once a significant portion of the literature review had been undertaken. It was at these later stages that the concepts and perceived knowledge gap could be fully understood in the wider context (Phillips 2010).

The novelty of the research is directly tied to the DATF (Damage Assessment Tracking Form) models. The DATF models are designed to combat the issues faced by automotive remanufacturing inspectors across the several stages of inspection activity (core), as such the novelty or new knowledge delivered through these models includes;

- A more comprehensive and detailed overview of all inspection stages that occur throughout the typical automotive remanufacturing process than has been previously detailed in existing literature**.** **Novelty 1**
- A purpose designed criteria based damage grading assessment system that allows for greater impartiality from the point of view of the inspector, while also providing a specialized data gathering tool that aids in classifying damages in core, promoting knowledge sharing in-house and assessing the possible loss in value of external long term core storage. - **Novelty 2** (Chapter 7)
- A structured breakdown of the available methods and procedures that may be used by the inspector. Including new technologies that may be used to further improve inspection activities. The methods are structured into different tiers of a pyramid, with each tier ranking the increasing complexity and expense as the user moves up through the tiers of the pyramid. Factors such as “cost of required technology”, “level of training needed”, and “lead times for each method” are all taken into account. - **Novelty 3** (Chapter 7)
- An internal assessment system that can be utilized by the automotive part remanufacturer to evaluate both the efficiency and effectiveness of the staff. This system involves a highly detailed ‘stage by stage’ method for

ascertaining the characteristics of a successfully inspected part as it moves through the various stages of automotive remanufacturing. - **Novelty 4** (Chapter 7)

- An analysis model that uses data gathered through grading stage to display common issues and conditions of core by make and model. This would allow inspectors to predict likely areas of failure before core enter the facility. - **Novelty 5** (Chapter 7)

Seen below is a pictorial of the DATF model, displaying four sub-models that comprise it, and showing how they build upon each other. This allows them to cover multiple areas of automotive parts inspection, and be as valuable to the user as possible:

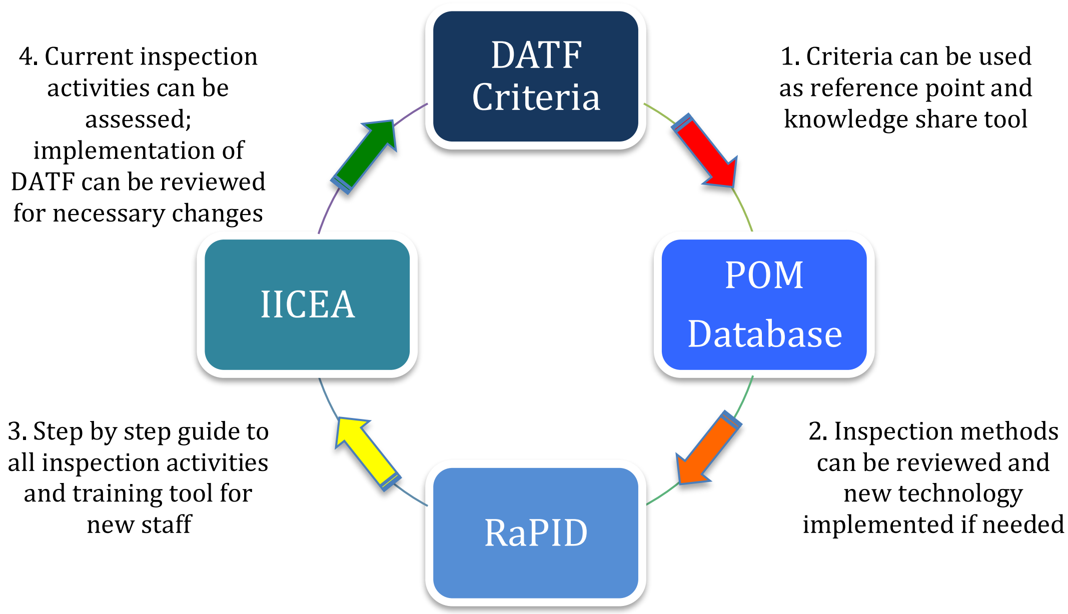

Figure 1 – Visual Overview of DATF Models

1.5 Thesis layout:

Thesis Structure

The overall structure of the thesis can be observed below.

Introduction	Key Literature Review	Methodology	Case Study Results	Theoretical Models	Validation	Conclusions	References	Appendix				
								Extended Literature Review	Extended Methodology	Case study Data	DATF Model Data	Interviews

Figure 2– Structure of Thesis Content

This thesis is presented with the view that the reader will not be familiar with the field of remanufacturing, or its specialized terms. The purpose of the thesis is to present the data in a manner that the reader can easily digest, gaining an understanding of the field as the chapters move forward, with the importance of the research output being clearly communicated (Dunleavy 2003).

A significant level of terminology is present in the thesis. Much of it unique to the remanufacturing sector, with new terminology associated with the DATF models also being introduced. As such a glossary of terms has been included.

Following chapters include a systematic literature review which acts as cornerstone for the existing data within this sector of academia. Subsequent chapters address the research methodology, initial primary research, and industry case studies. The detail regarding the observations made during case studies begins to deepen as the initial understanding of the various factors is quickly superseded by the in-depth discussion and feedback from those operating at the most hands on level of these processes. The breakdown of the case study subjects (Company's A- E) can be seen below:

Company:	**Size**	**Type**	**Products**
Company A	Small - Medium	Independent	Gearboxes/Transmissions
Company B	Small	Contract	Transmissions
Company C	Medium - Large	OEM	Full Engine
Company D	Large	Independent	Full Engine
Company E	Large	OEM/Contract	Steering & Braking systems

Table 1 – List of Case Study Companies

This first hand data allows for more complex assumptions and hypotheses to be posited as the available data and its understanding to both user and author evolve. Key assumptions such as the perceived reliance on personal experience on the part of the assessment operator are identified during these sections and the building block for several of the papers related to the work conducted during this thesis can be found here.

Towards the end of the thesis the remaining chapters focus on the development, validation and verification of the DATF models by academia and industry. The validation chapter of the research details the initial workshop used to gradually refine and improve the DATF from the academic perspective, this in turn was then assessed by external industrial groups and companies in order to ensure that it was rigorously examined but also modified and to reach its potential when final full scale validation occurs. Validation through an expert review panel was used to prove the inherent value of the research.

The final chapters of the thesis include the conclusion of the entire research, with the 'flow' of data throughout the work clearly noted as well as the outcome of the validation studies conducted on the final output (DATF). The potential future application of the DATF models to other areas of remanufacturing is briefly explored, with the outcome being that with some modification the DATF models could be adapted to other sectors of remanufacturing (Aerospace, HDOR, Naval).

CHAPTER 2: LITERATURE REVIEW

2.1 Overview of Remanufacturing

Remanufacturing is a rapidly expanding sector as we, as a society, take steps to make the shift towards a sustainable, eco-friendly and environmentally safe way of life (Lund and Hauser 2010; Ayres et al. 1997; Daraba et al. 2008). The reduction of CO_2 Emissions and the increased investment into alternative energy sources and manufacturing processes are attempts to slow down our civilisations speeding course towards a future where fossil fuels are depleted and the basic needs of society are thereby imperilled. This is a future which is potentially closer to reality than many would believe (Deckert 2016; Dhingra et al. 2014; Gerrard and Kandlikar 2007).
As Remanufacturing is a major part of the idea for a more sustainable form of manufacturing the investment and awareness of this particular field has risen and in recent years a substantial uptake in the countries adopting remanufacturing principles and aims can be seen. This implementation of 'remanufacturing' is most prevalently seen within the automotive sectors and has expanded into many other areas. (Amelia et al. 2009; European Remanufacturing Network 2016; Guidat et al. 2015).

A report in 2012 calculated that by 2015 the Global Industry for Remanufactured products would measure in at $**104bn**, this equates to €**78.2bn** and £**62.6bn** (Commission 2012). A more recent report in 2015 showed that the Global Market had risen to **$160bn** while the EU turnover for all remanufacturing activities measured in at **€30bn**, with a predicted upward climb to **€90bn** in the EU by 2030 (Parker et al 2015). With this level of financial incentive it is clear why in recent years the majority of developed countries have taken great strides to integrate areas of this new industry into their country's existing economy (Chaowanapong et al 2018; Lund 1985).

2.1.1 Global Automotive Remanufacturing

A systematic literature review has shown that the approaches to remanufacturing and other recovery activities can differ significantly due to geographical area. In part this appears to be due to the different cultural approaches to manufacturing, as well as the existing infrastructure and internal push for greater sustainability and recycling in country.

Key features noted from the extended literature review include China, which has taken significant steps towards advancing its own remanufacturing capacities over the last decade and a half. Chinas Association for Automotive Manufacturing calculated that a record number of vehicles were purchased in 2010 at a staggering **18,264,700**, meaning that the total number of vehicles on the roads across China is estimated at around **90,860,000** (Tian et al. 2014; Zhang et al. 2011). The issues surrounding emissions and pollution are a very serious concern for a country struggling with numerous health problems because of excessive vehicle emissions (Xiang and Ming 2011).

Also in 2006 in Japan it was estimated that **76 million** vehicles were on the road and that every year over **3.5 million** are treated as ELVs, by 2010 those numbers are estimated to have risen to **80 million** and **4 million** respectively (De Souza et al.

2014). By 2015 the potential for over four and a half million waste vehicles to be in Japan, which if not disposed of properly could result in serious pollution issues.
In 2008, the Korean Vehicle Recycling rate was estimated at around 40-45%. With the act in play the aim was to reach 65% by 2010, 85% by 2012 and 95% by 2015 (Platzer 2010). More recently in 2017 the total estimated recycling rate for South Korea was stated as 58% with an expected target of 65% by 2020 (Eunomia 2017).

Additional data pulled from other areas such as Singapore, India, Malaysia and Brazil all showed interesting commonalties. Remanufacturing and recycling activities are growing, with new terminology and increased research investments occurring across Asia in the last few years. For example changes in Japan's movement of waste vehicles (in country storage rather than pure disassembly and disposal) as well as increasing government targets for material recovery display an increased likelihood that Japan's automotive remanufacturing sector will continue to grow and develop quickly in the oncoming years.

Automotive Remanufacturing activities in the US show a slightly different landscape within the sector as in recent years as conversely while steps towards greater sustainable legislation has developed, the number of automotive remanufacturing companies across the country has decreased (Vlaanderen 2018). The decrease may be explained by the fact that with higher investment and more involvement from OEM's in this area many of the smallest companies have either been forced to shut down or have been integrated/absorbed into the newer larger companies taking over their market share.

2.1.2 EU Legislation

In the UK in 2006 it was reported that over **160 companies** operated under remanufacturing claims with over **50%** of these considered small scale, often only sourcing and distributing to local areas. Based around London and the South East of England however larger companies with a higher output coordinate with suppliers to have parts and products shipped in. The majority of these larger remanufacturers are focused on the automotive sector. (Subramoniam et al. 2009; Buxcey 2006).

The main legislation is the European Union ELV (End-of-Life-Vehicle) Directive (EU 2003); put in place by the EU to address the end of life/use situation for automotive products. The directive has been a significant aid in promoting sustainable action and remanufacturing activities over the last decade and a half. The reuse and recovery targets set by the directive were targeted at **85%** by weight in 2006 with the hopes that by 2015 that number would rise to **95%**. The average for the EU overall was estimated at **84.1%** in 2006 which is higher than the expected value of **80%** (Gerrard and Kandlikar 2007; Sakai et al. 2014). A more recent report stated that the UK hit its target in 2015 with **96.9%** but missed its target in 2016 only reaching **92.25%** of the desired reuse and recovery target(Eurostat 2016).

2020 is a significant milestone for many directives with goals potentially being reached; there have been encouragements (such as tax incentives and tax breaks) to increase the level of remanufacturable materials in cars. In particular the metals in the vehicle fame and bodywork, this has met with some success as more Aluminium in now present in the structure of most cars than previously used (EU 2003; Sakai et al. 2014; Gerrard and Kandlikar 2007).

A survey of Electrical Rebuilders

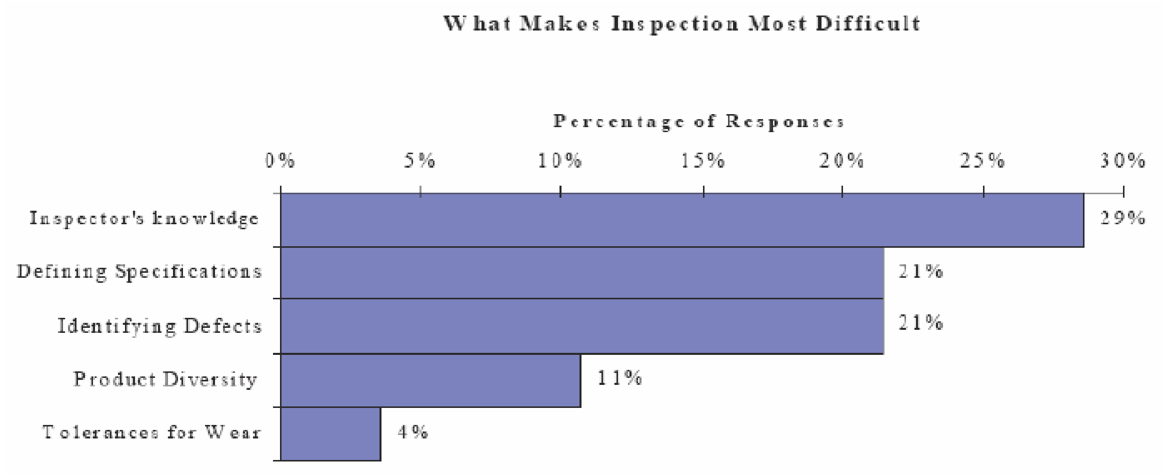

Figure 5 – Responses to Question 5: Difficulties to Inspection

Figure 3 – Hammond Questionnaire

Seen above are the responses to Professor Hammond’s questionnaire from his paper investigaing the problems and issues present in remanufacturing activities in 1998. He states that it can be extremely difficult to obtain a clear ranking of design and remanufacturing process issues. This in turn hinders the development of methods for assessing both how to rectify these issues and for assessing a product remanufacturability. This is further evidence that a thorough exploration into the remanufacturing issues (particular automotive industry) is needed.

Although this was published over 25 years ago and technology and manufacturing methods have moved on and developed this need for definition is still valid. At the end of the paper Hammond even says himself that as technology develops new issues and new problems will rise, regular investigation and assessment of the state of remanufacturing activities in the automotive sector is the most effective way of maintaining quality, energy and time constraints. Also leaving room for potential improvements to further free up resources and time (Nasr and Thurston 2006).

Hammond finds that the inspectors knowledge of the incoming parts and the required quality of the output are significant factors, as well as the lack of adequate training tools or criteria to effectively reference against, means the inspectors could overlook things on more than one occasion and their desire to maintain product quality could lead to less-extensive testing to be conducted (Hammond et al. 1998; Bras and Hammond 1996; Ijomah and Childe 2007).

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2.2 Non-Destructive Testing and Automotive Remanufacturing

Non-Destructive Testing and Evaluation is a series of technologies that are used to assess aspects of a component or product in a non-invasive and (as the name suggests) non-damaging manner. One of the main types of situations where this is used is when the aim is to discover weakness or damage in the material structure of a product. Often this damage is not visible to the naked eye and can be very difficult to detect.

From that idea it only makes sense that NDT would become a vital part of remanufacturing, NDT technologies cover a variety of different techniques (such as X-Ray, MRI, C-Scan etc.).

NDT could be introduced at either the Inspection or Testing stages and would aid the assessment practices within automotive remanufacturing, one the main benefits to the introduction of NDT involve potential savings from the early identification of parts or components that can be classed as '*untreatable*' (inherent weakness or damage rendering it incompatible with remanufacturing). Another benefit is the reassurances of quantifiable quality and reliability that the public and other areas of industry would be able to acknowledge with greater acceptance than the current methods. Another potential benefit from this is that this approach would be a basis from which to create a tangible training tool that teaches those in the inspection stage or remanufacturing how to more effectively and accurately assess the products in question without relying entirely on their own assumptions and experience (which can vary significantly from person to person and result in conflicting opinions).

2.3 Literature relating to inspection

The next section details the literature research conducted as the scope and aim narrowed down to the final focus. Though the key research aim was understood at the beginning of the work it was necessary for the information and concepts discussed during the previous literature sections to have an impact on the authors viewpoint in relation to future research.

Inspection within the remanufacturing process is a critical aspect of its successful operation, since suitable and effective assessment allows for any existing issues with core, such as damage or defects to be recorded and then anticipated during the processing stages of remanufacturing (Hammond et al. 1998; Steinhilper 1998). Without suitable inspection any problems present within the piece in question will not be addressed till much later within the process, potentially at the 'testing' end of the operation, which can cause further damage to the overall piece if a part experiences failure during this stage. As such inspection occurs throughout all sectors within the remanufacturing industry, within certain areas this process may be relatively simple (Clothing remanufacturers).

The WEEE Directive ensures that a significant portion of the market deals with Waste Electronic and Electrical Equipment, either through pure remanufacturing or through sanitisation and recycling (Kernbaum et al. 2009). Within the EEE sector there are questions regarding the necessity of dismantling core completely in order to conduct suitable inspection (Steinhilper 1994).

Non-disassembled assessment of electronic equipment can still show that all the relevant parts are present and functional, however, without a more detailed examination the core cannot be given remanufacturing standard and associated new warranty. Within the automotive side of the sector the process can be more firmly based on the physical visual examination of parts in order to ensure that they are both suitable and in appropriate condition but issues and areas of improvement still exist.

Focusing the range of literature at this stage to those most relevant to the developing question the next papers reviewed and deemed suitable for inclusion in this chapter were those that dealt most extensively with the various aspects of the typical inspection process; from addressing its overall structure as it occurs throughout the standard operations, to further investigation of methods that can be used to create a more economical process for the company in question. These papers were found to be of significant value during this research as they provided a clear basis from which to build assumptions and direction when conducting the latter stages of the investigation.

As stated in earlier sections, the work conducted by authors such as Lund, Steinhilper and Ijomah have helped shape the academic side of remanufacturing significantly. The overall remanufacturing process was given structure and definition by (Lund and Skeels 1983; Steinhilper 1998) in the early 1980's while Steinhilper's work showcased an overview and exploration of the entire remanufacturing concept. Providing the research which created his widely accepted role as one the key father of the remanufacturing industry (Charter and Gray 2008). More recently the work providing robust and rigorous definitions to the remanufacturing concepts conducted by Ijomah has provided a much more solid base for further academic work to build upon (Ijomah and Childe 2007;. Ijomah et al. 2007). The concept of a shared consensus with regards to the terms used within industry plays a vital part in ensuring that any information sharing or new developments introduced to the market can be widely understood and their implications realised by all members who share this consensus.

As stated by Steinhilper – " *A step of great importance in remanufacturing is to access the condition of the disassembled and cleaned parts as to their reusability or reconditionability."* (Steinhilper 1998)

This level of remanufacturing standard can only be given if sufficient inspection occurs. However for such a vital aspect of the process it has been a stage which until recently little work has directly addressed. The papers are more focused on the *processing* or *disassembly* stages touching on this aspect of remanufacturing without fully tackling it (Ketzenberg et al. 2003; Johnson and Wang 1998).

Automotive Remanufacturing is the selected area of the industry used for this research, this is due to several factors including the initial scope of the project as well as the sectors key place as one of the fastest developing areas of the industry within both academia and industry (Golinska and Kawa 2011).

An extensive study of the selected sector of industry (Hammond et al. 1998), conducted by Hammond, investigated the issues faced by those operating in the sector at that time. From that research a significant number of areas for improvement were identified, in particular 29% of those involved with the survey stated that a key issues that hindered the full success of their inspection operation was the knowledge of the operator in question. This is a significant percentage, and not only speaks to those involved with the survey but also those actually aware of the problems surrounding specialised knowledge or lack there of. Though in this case the level of knowledge present may be in comparison to others within the company the issue also extends to the level of knowledge present between operators at Independents and Contracts compared to OEMs. The level of knowledge present or lack there of can refer to both technical specification of the core/part/piece in question and the methods/tools available in order to assess such issues (Kapetanopoulou and Tagaras 2009).

The benefits of greater standards and structure across the remanufacturing industry is an easily understood concept. While OEM’s operate with much greater resources in terms of both technical information and technology in addition to greater staff and larger facilities a substantial segment of the automotive remanufacturing work is actually undertaken by the smaller companies (Kapetanopoulou and Tagaras 2009).

Public perception of remanufactured products has typically been very poor during the industry's history (R. Steinhilper 1998; Hazen et al. 2017; Watson 2008) due in part to the concept of 'new' is better that has been a staple part of the Capitalist cultural mindset that Western manufacturing has typically adhered to. As such all aftermarket activities, including remanufactured, second-hand, repaired, and refurbished products have all been viewed as inferior. This is despite the fact that remanufactured products are brought back to OEM standard (with new warranty) (Ijomah, et al. 2004) However with the case of remanufacturing, due in part to its recently defined terminology as well as its inherent aim to reduce the level of raw material consumption, the processed product does in fact meet with the OEM standards. As such it has a remanufactured warranty the same or greater than its OEM equivalent. In the cases of Reconditioned and Repaired products their warranties are less than OEM and can be dependant on factors such as the age of the part, the type, and the perceived level of damages that have been addressed during rework (King et al. 2006). In many cases due to the rigorous testing that takes place during the remanufacturing process the end product can be more reliable than the newly manufactured equivalent.

Recent awareness of the rapidly diminishing levels of our natural resources, as well as the increase in legislation and standards by governmental bodies (EU 2003; BSI 2010, 2014; Zero Waste Scotland 2015; Ellen MacArthur Foundation 2013) has led to a much more charitable view by other aspects of industry and members of the public.

New developments both in the manufacturing and remanufacturing process are being introduced each year, with companies aiming to ensure they remain relevant in this market on the rise. As such the number of academic papers focused on improving various aspects of the remanufacturing process have increased with several tackling the factors surrounding *inspection* (Errington 2009). It is noted that before these more recent papers (last decade or so), despite the issues identified in Hammond very little work had been carried out investigating the actual methods or procedures that occur during inspection. Instead the focus on design for remanufacture was given greater prominence as a potential solution to some of these problems.

2.4.1 Early Core Sorting Literature

One of the earlier papers that touched on this subject was (Aras et al. 2011) whose discussed the need for greater categorisation for incoming products as they entered the facility/process. This categorisation was aimed at the products once they have reached the facility in question as opposed to relying on supplier information. Incoming core to a facility organisation can be a highly variable situation. Depending on both the type of supplier and the level of reliability between supplier and company the condition of the incoming core may be known to the company or not. Further papers (Cai et al. 2014; Galbreth and Blackburn 2006, 2010) have extended and developed the need for core sorting and improved categorisation of incoming stock. In these papers the variability of incoming core conditions and the negative effects of poor inventory polices are discussed in detail. In addition, the stated condition may be different from the actual condition once delivered to the facility in question.

OEM based remanufactures typically place much larger orders for parts and core than the majority of contract or independent companies (on a individual case basis), and as such the suppliers in question are much more likely to ensure that the majority of ‘suitable’ core within the specified type and amount requested are those delivered to the larger company (Wei 2015; Ferguson and Souza 2016). With the increase in legislation and positive PR surrounding remanufacturing and sustainability, more and more OEM’s are bringing the aftermarket of their own products in-house and working more closely with suppliers than ever before (European Remanufacturing Network 2016). As such independent and contract companies have a higher chance of receiving core of a much more variable condition. Due in part to this situation then the remanufacturer has to conduct a suitable core assessment once the latest batch of core arrives at the facility (Hammond.et al.1998).

One of the key features of these papers is that the need for suitable categorisation of the core (Economical or non-economical) is addressed (Aras et al. 2011; Goodall et al. 2014). However categorisation of core can be a difficult task within the remanufacturing process (Konstantaras and Papachristos 2008).

2.4.2 Foundation literature – Errington & Ridley

The two key papers in recent years have been (Errington 2009) and (Ridley and Ijomah 2015) and in these papers the authors discuss the inherent ill-defined nature that exists across the inspection process. This *ill-definition* has led to various remanufacturing companies approaching this activity in different ways. This thesis investigated how the actual procedures occurred at an activity level.

As discussed in earlier sections the "Inspection" stage of the process is a critical component and is necessary to the successful remanufacture of any core/product. However, despite earlier work briefly investigating the basic assessment operation (the core is inspected before processing) it was Errington's work specifically that explored in detail how 'inspection' occurred across the spectrum of the remanufacturing industry. Based on both this and earlier work the inspection process can be stated to occur at several times throughout the remanufacturing process, from the point it reaches the facility till its end stage before shipping.

From this overview it can be observed that there are 4 key inspection stages that have been identified by both authors in their work; *Visual Inspection, Physical Inspection, Identification Inspection & Performance Inspection.* The factors were noted as the necessary steps involved to ensure that 'core' acceptance occurs within the company in question. At each stage of these four stages the core can be deemed unsuitable and is therefore redirected to an alternative avenue of waste disposal (i.e. Recycling, Part stripping or environmental disposal). Visual Inspection in this case is, a thorough visual examination of the piece which ensures that both the conditions specified by suppliers or pre-read paperwork are correct and also to observe any other issues or problems that may have occurred during the delivery process or been potentially overlooked during the initial paperwork (H. Wang et al. 2017). If the piece passes this point it is then directed to the Physical Inspection. Errington and Ridley state that this occurs as a relatively simple process in some cases of automotive remanufacture; sometimes only including two key factors, the rotation of parts that should move, to ensure that their expected range of movement is present and the 'scratch-sniff' test of smelling electrical components to detect any 'burnt' odour. Past this point the piece is then directed to Identification Inspection where the part and type of the core is recorded, partly in order to ensure that replacement parts are used as needed but also to gauge the rough value of the core in question. High value core is clearly much more useful to the remanufacturer than lower value, especially with independents whose supply of core has the greatest chance of variability in terms of type, make and model. The final stage proposed is Performance Inspection, where the post-processed core is tested for its functionality and performance on a purpose built rig, complying with industry standards and numerous criteria to ensure it can be given suitable new warranty (Liu Bo-hai et al. 2010). This last stage as suggested can also be referenced as the '*Testing'* stage within the remanufacturing process.

As of recent investigations into the area of automotive remanufacturing (in this case 2019) there does not appear to be a large amount of data freely available concerning the 'Inspection' stage of the typical remanufacturing process. As stated in earlier chapters the 'inspection' stage of the remanufacturing process is a vital aspect of the successful remanufacture of 'cores'. In fact considering that any type of 'Re-Process' (i.e. Remanufacture, recondition, repair etc.) requires a sufficiently detailed assessment of the products and parts in question, 'inspection' could be considered of primary value within the process.

Inspection as a remanufacturing activity still has a level of uncertainty with regard to the methods/tools used and the overall steps and stages of the process (BSI 2014; Govindan et al. 2016). Remanufacturing activities around the world are focused on numerous products and services, because of this the intricacies and details of how each stage is conducted varies considerably depending on the industry in question.

Although the generic remanufacturing process is used as a guide by each sector the various challenges and barriers that are faced in each area inevitably result in specific tasks, tools or methods that are best suited to the particular industry in question (Sundin 2004). Likewise attempts to improve the effectiveness and efficiency of remanufacturing activities, typically in relation to new technology or increasing competition can often result in greater variation to typical operations (Morgan and Gagnon 2013).

Regarding the earlier point of standards, the level of legislation and policy in remanufacturing has only taken hold with any great effect in the last decade or so (EU 2003; BSI 2009). Before this and to a certain extent even now many businesses will try and operate under the banner of 'remanufacturing' when in fact they do not possess the necessary skill, tools or knowledge to successfully remanufacture. This in turn can result in poor perception of remanufacturing and all re-processing techniques by the public and other areas of industry due to the mistaken belief that the poorer quality output of these establishments is the typical result of effective remanufacturing (Hazen et al. 2017; Watson 2008).

In an effort to reduce this kind of situation and to improve the public perception of sustainable manufacturing alternatives such as remanufacturing, more thorough and detailed standards have to be created with the purpose of building a basis of existing criteria that companies wishing to operate remanufacturing businesses can be held accountable to.

The sector of remanufacturing that is the focus of this research is the automotive remanufacturing sector, this is a significant aspect of the remanufacturing industry as a whole with several research papers estimating that it constitutes between 60-70% of (Golinska and Kawa 2011; Buxcey 2006) the overall remanufacturing market profits in both Europe and the US (Subramoniam et al. 2009). As such it is this area that poses a potential opportunity in the continuing aim of ensuring a more effective and successful remanufacturing process through detailed plans, frameworks, guides or legislation.

To that extent authors in recent years have understood this opportunity and a select number of works using 'inspection' as a focus for the academic research have emerged. Each of these works has examined inspection from a different perspective, but a business-based approach does often appear as a prominent theme in these studies. This will not be the basis for this author's academic work.

As noted the issues of 'what is inspection?' and 'how does it relate to the remanufacturing process as a whole?' are thoroughly discussed in (Errington 2009). However this wide-breadth of subject matter also means that the level of detail and in-depth analysis is only to a certain extent since the focus is across the entire spectrum of the remanufacturing industry.

As discussed earlier remanufacturing as a field of research or as a sector of industry is a highly broad and varied topic. The industry side covers a multitude of areas of life from clothing and cookware to electronics and automotive; each aspect has its own operational quirks and characteristics and these in turn affect the effectiveness and successes of the businesses involved (Parker et al 2015; Commission 2012; Lee et al 2010). A business situated within one of the remanufacturing industry ‘brackets’ utilises or adheres to legislation and policy depending on the country in question. Different areas of the world have stricter guidelines than others and some are more willing to allow larger corporations or more lucrative businesses a certain amount of leeway in terms of expected standards (Lewandowska 2018; Chaowanapong et al 2018).

Errington’s work closely examines ‘inspection’ across the remanufacturing industry, with a focus on inspection as a concept. This results in the activity of inspection being viewed in a very broad sense, as it relates to all the remanufacturing sectors rather than its methods and procedures within a specified area of interest.

Errington’s work provides two key outputs regarding remanufacturing inspection; the first is a series of proposed inspection strategies. An overview of each approach shows how different strategies are used to remanufacture items with different characteristics. The second is the first real attempt to identify what the inspection stage of the generic remanufacturing process actually involves.

The concept of models to detail the specifics of inspection activities in relation to the different remanufacturing sectors is a potentially vital tool to be used to identify where improvements could be made to the existing ‘modus operandi’. This could be achieved by clearly defining the different steps involved in the activity, as well as the purpose of each step. While both Errington and Ridley’s work does touch on this in an overarching manner the overall breadth and expansive nature of Errington’s research makes its applicability to industry difficult as it remains generic to cover the entire remanufacturing industry. Conversely Ridley's work goes into significant detail regarding her company's inspection practices and her methods to improve them however these improvements are so unique to the company in question that applicability across the automotive sector would be limited at best. Each research focus by these authors fills in a particular gap and brings greater focus to the area of inspection, by building my own research alongside their work the remaining gap of knowledge in this field should close even further.

Existing remanufacturing businesses by the very assumption of having operated for at least a reasonable period of time will have acquired some knowledge and experience from daily operations and problems/issues faced during early stages (Yang. et al 2016; Casper and Sundin 2018; Barquet et al. 2013; Fang et al. 2016). As discussed earlier in this chapter the inherent knowledge and skills that inspectors need to possess in order to successfully remanufacture can only be currently acquired through prolonged trial-and-error operations and real world application leading to these skills often being highly individual based and variation in opinion between inspectors can easily occur. The use of a model to aid in the definition of this stage can potentially be of use to existing companies, with those operating longer having greater resources (in terms of personal staff experience) to deal with the identification of areas for improvement or modifications to improve the overall effectiveness or efficiency of the remanufacturing process.

Any company wishing to start-up in remanufacturing could find it very difficult to apply the model effectively with so little primary experience to back it up. Some may argue that a start-up or newly developed company specialising in remanufacturing could always hire someone with extensive experience in this area (possibly from another remanufacturing company), however, this is not as simple as it first may appear (Roy et al. 2019; Wu and Zhou 2016; Steinhilper and Weiland 2015). Unless the new company was either a spin-off from an existing remanufacturer (possible specialising in a slightly different area) or a newly created subsidiary of a manufacturing corporation having the resources (in terms of financial or technological) to draw long-standing employees of other companies away may prove very difficult.

As remanufacturing businesses are not as plentiful across the industry sector as conventional manufacturing those involved in the business will have at least a peripheral connection or awareness of many other organisations undertaking similar work (European Remanufacturing Network 2016). Because of this any new company gaining employees from an existing one (to the older company's determent) can result in poor perception of the new addition to the market by the surrounding businesses.

Many employees of these companies may view their employment as a job-for-life scenario or else that remanufacturing may only be an area they wish to work in for a certain period of time. As such these employees can often feel a strong sense of loyalty to their current company and would require substantial incentive to leave. An alternative to this may be for operators of existing companies to work in a consulting capacity to the newer business, providing insight and knowledge to those without, though this option too poses its own problems. The problem in this case then becomes, how to effectively transfer the knowledge and experience to newer operators.

Knowledge can be very difficult to pass along in an effective manner, particularly when it comes to activities where experience based understanding is a key component of a successful output as is the case with much of remanufacturing (Calo 2008). While certain elements of that tacit knowledge can be explained as best as can be, the result can be that only parts are fully understood by those being informed and what is understood may be viewed slightly differently than what was intended. This is an issue which can affect many people trying to pass on information in effective manners and as such structured means to either pass on or obtain such knowledge are a necessary aspect which should be introduced into standard operations/set-up.

As stated earlier the specific sector of the remanufacturing industry that this work is concerned with is '**automotive inspection**'. Within remanufacturing as a whole and more particularly with any type of heavy machinery remanufacturing the ability to obtain knowledge and key information about products or 'cores' can be very difficult with opposition and barriers set in place by OEMs and corporations. Many OEMs guard the details about the design, processing and manufacturing of their products very strongly from the general public and more importantly other companies. This is with the purpose of stopping other companies stealing ideas or creating 'knock-off' versions of these products (i.e. vehicles, computers, machinery etc.) However, this 'wall of silence' can extend to remanufacturing businesses only interested in increasing their performance and quality of output as well. In the automotive sector having a comprehensive understanding about the vehicle and parts in question is of key importance and the more data that can be gathered the better.

Another thesis that has tackled the area of inspection is (Ridley and Ijomah 2015) which focuses extensively on an OEM remanufacturer and the operations that are conducted within the company. Aimed at improving the current inspection process within the typical operation, this paper had the unique situation of being fully involved with the OEM in question, since the author conducting the research was an employee of the company. As such with an unprecedented level of access the author was able to conduct highly detailed research on the procedures and methods in play. Ridley's work was very focused on improving the efficiency of complex parts through robots inspection of core within the specific company (in this case Caterpillar). The research detailed the current methods used when the company brought in its aftermarket core for remanufacture. The key aim of Ridley's work was identifying the most 'economical' level of inspection to occur at the initial receive stage of the process the research was extensively conducted across 2000 engines at the Caterpillar facility. Ridley stated that increased inspection at the beginning of the process lead to improved efficiency during parts inspection and processing during later stages but that the level of improvement within this efficiency was finite and that at a certain point the process became 'over-inspection', which cost time and energy without producing any results. As such rigorous experiments at the facility were conducted to more clearly understand the issue. The author states that the results of the research clearly showed that the level of appropriate inspection can be linked to the cost of the component or core.

Much like the earlier papers discussed in this section Ridley's recent addition to the field of academic knowledge has provided another valuable viewpoint on the issues and benefits of successful inspection within the remanufacturing sector. Improving the overall efficiency and effectiveness of the process is a vital goal and one that could be approached from numerous angles.

2.4.3 Literature examining Automotive Remanufacturing Operations

Remanufacturing operations can change significantly in terms of procedures and methods, often depending on the available levels of skill and resources at the company in question. As noted in earlier sections there is renewed interest and investment in the aftermarket sector. This is in part due to the legislation and polices that have come into play but also the awareness of the potential value to OEM's through remanufacturing activities (Golinska and Kawa 2011; Zero Waste Scotland 2015; Rolf Steinhilper and Weiland 2015). On a more global scale remanufacturing has resulted in increased profits and market share for many OEM's in western society (Guide et al. 2003; Daraba et al 2008). The available data for new companies moving into this sector is not always applicable. In the case of organizational structure the work conducted by (Lund and Skeels 1983) provided a significant amount of novel data for these types of new companies. However its focus was primarily aimed at OEM's wishing to move into this area of the market and due to the age of the research '1983' the applicability of some aspects of its data may no longer be as relevant. The remanufacturing operation itself can be roughly split into 7 key stages: According to Steinhilper (1998) and Sundin (2004) the activities composing a remanufacturing process can be divided into

- disassembly;
- inspection;
- sorting;
- cleaning;
- reprocessing;
- reassembly;
- checking and testing.

As part of the process all core has to be disassembled in order to return to full usage/condition. It is noted in this paper that the effects of disassembly operations impact a large number of areas, including production control, scheduling, shop floor control, and materials and resource planning. The disassembly and subsequent release of parts to the remanufacturing operations requires a high degree of coordination with reassembly to avoid high inventory levels or poor customer service. It is also noted that good design for assembly does not always signal the same result during disassembly procedures. During the process the core/product is disassembled to the part level and then assessed (though not noted in this paper this can constitute the beginning of true parts inspection), parts deemed unsuitable for remanufacture are then discarded or stored for later processing and replacement parts are used. This assessment procedure can occur independently from the more detailed Inspection stage that can occur post-disassembly. It is noted by Guide that some companies operating in the sector can utilise simple averages of internal records to record MMR's (the level of material recovery uncertainty) in order to try and observe the level of variability of incoming core.

Guide's article (Guide, 2000) concludes that from their study 38% of those interviewed stated that one of biggest threats facing the industry's successful growth is the lack of formal systems for activities and factors such as operations and internal paperwork and accounting. Another 28% viewing rapid technical changes becoming a growing issues (both in terms of the level of manufacturing technology and the required remanufacturing technology to remain relevant).

Goodall makes several interesting observations during his article (Goodall et al. 2014) relating to the decision-making tools available for companies wishing to operate within the sector of remanufacturing. Articles such as (Wu and Zhou 2016) have dealt with the evaluation of the quality of core through extensive use of programming tools, while another study (Jung et al. 2011) involving turbo-chargers and diesel engines puts forward the use of highly advanced sensors to aid in the evaluation process. The aim in these cases would be a highly developed cost-based model. Within any remanufacturing operation the use of the internal standard (either obtained from external sources or developed in-house) is the key for product assessment or pass//fail either in the processing, testing or inspection stages. Jung's work on the multi-objective evolutionary algorithm (MOEA) is primarily targeted at ensuring that the selection of 'routes' that a EoU can take (repair, recycle, recondition etc.) is the most cost effective to the company and has achieved this by breaking multiple levels of variable factors such as 'Product level – Part Level categories against factors such as test cost for each component as well as the degrees of tolerable quality within the part in question. This study provides a highly in-depth analysis of a mathematical viewpoint on the assessment process yet its feasibility in implementation or wide spread usage without access to such a volume of available data is difficult.

Investigating this issue from another perspective is (Kumar and Mahto 2013) the article in question approaches the issue of identifying decision-making factors for EoU products through the observation and characterisation of 'value flow'. The key assumption in this work is the value attributes used for the output models evaluation purposes i.e. that the last user in this case wants to maximise their economic gain (A relatively reasonable hypothesis in a business context) (Wang et al. 2017).

Many of these articles or papers attempt to target a particular facet of either the remanufacturing operations or the decision-making process regarding EoU products. However while there has been several authors examining the issue from a cost standpoint there are fewer papers that deal with the physical methods side of typical remanufacturing operations. Early work by Steinhilper and Lund provided a solid overview of the processes involved however since that point, there have been fewer studies examining any particular sectors typical operation in order to provide a real-world comprehensive overview.

Within the available literature there are several papers that explore facets such as strategies and tactics for success. Several authors have argued that current manufacturing technologies, practices and processes (traditional) have the potential for effective usage in a remanufacturing context (Wu and Zhou 2016; Steinhilper and Weiland 2015).This highlights the similarities in terms of goals between traditional manufacturing and the developing field of remanufacturing. These goals to success include quality, speed, flexibility and cost. Therefore, the transfer of relevant best practices from manufacturing to remanufacturing is an important concern of many managers.

Nenes work on inventory polices in remanufactured products (Nenes et al. n2010) discusses the factors relating to the suitable place on inspection within the remanufacturing process. The article mentions that due to high variability of condition in returned products the relevant inventory route (good as new, mildly damaged, heavily damaged etc.) can be difficult to ascertain. Inspection in this context is referred to as a near instantaneous process, however, the method of assessment is visual and again appears to rely on the experience and personal knowledge of the operator rather than any specific model or tool. In this case inspection activities at the company were carried out in two steps. The first being the initial visual inspection providing a general review and then a second later inspection during which detailed assessment takes place (like in the earlier operation this appears to be conducted primarily in a visual manner). His work in these areas relating to returned product assessment has so far examined this issue from a strategic perspective with examinations of both push and pull inventory polices used by companies in relation to meeting their demands (Van der Laan 2006; Hormozi 1997; Perry 1991).

A paper discussing inaccurate quality assessment procedures (Galbreth and Blackburn 2006) highlights one of the issues previously observed during this review, since it notes that a key issues with some remanufacturing assessment operations includes the need to suitably classify an aftermarket core (inspection) and to evaluate the quality and condition of the parts. However, achieving this in a timely manner while gaining a suitable classification system has proved difficult. As such current classification or assessment procedures can be subject to errors; i.e. good quality core being deemed inferior and vice versa.

Assessment procedures within remanufacturing operations and within automotive operations (Automotive parts remanufacture is most prevalent if not most profitable) are an essential stage of the successful process or bring an EoU product back to OEM standard. Based on several articles discussed above, while the operational side of some methods such as disassembly as well as the sorting of product once it reaches facility have been discussed, the hand-on stage of inspection during which the parts are analysed and deemed either suitable or unsuitable (with associated processing stages) has only been touched on from a costing perspective and through the use of very technical models. For such a key area this appears to have a significant gap in the available knowledge. Previous studies showed that the increasing level of technology combined with lack of formal standard breakdown for the operations are both real concerns to those in industry (DeLong et al. 2004; Ferrer and Whybark 2000).

As discussed during Steinhilper's work the disassembly process and the assessment of return core are two aspects of the typical remanufacturing operation that often go hand-in-hand. During the disassembly process the use of assessment practices to either dismiss or accept parts/core before later processing is a common occurrence. This can occur either as a decision made due to its outward appearance as the disassembly takes place or can be conducted post-cleaning at a later stage. As such academic work investigating disassembly has the potential to highlight issues relating to inspection as well as disassembly, Papers by (Johnson and Wang 1998; Ketzenberg et al. 2003) explores the economic factors affecting the disassembly end of use operations such as recycling, remanufacturing and reuse. Factors such as the volume of available data on assembly practices vs. disassembly practices is discussed. It notes that MRO (Material Recovery Operations) requires disassembly times to be minimised along with cost, while the value of the reclaimed part or product to be maximised. This can be achieved through suitable assessment methods; dismissing failed or non-economical parts while identifying high value parts more effectively. The ‘moving price’ or parts and methods in sectors such as the automotive sector also mean that evaluation of existing disassembly/assessment practices would aid in identifying those becoming unprofitable before significant losses are incurred. The mathematical model developed for this paper by Johnson aims to apply variables such was the potential value of the part against its disassembly costs with a numerical letter or value allowing for complex modelling to be conducted. The practicality of implementing this type of setup within the standard operation poses some issues; such as time taken to assign values calculate complex equations. However the use of such a model during the R&D stages using internal company data has merit.

Ayers paper (Ayres et al. 1997) is more targeted at the underlying imperatives driving the trend of remanufacturing and sustainability. Again the tasks of disassembly and the deification of key parts and their condition are touched upon. Ayers notes that disassembly can involve both skilled and unskilled workers but a certain level of knowledge is required in order to ascertain key core and components (high value) as well as differentiating between the condition of core in general and the most value or essential parts. This knowledge is gained through access to company data/training and can result from extended experience within the task. This paper again details the significance of personal knowledge to ascertain the condition and quality of remanufacturing parts (pre-processing). The fact that this knowledge is a vital aspect of the process is not disputed and has been confirmed from merely an assumption to a reality by multiple papers and later case studies. However the factor that is being investigated now is both the methods for obtaining that knowledge as well as the ability to remain impartial and unbiased in the actions.

A more focused case study examining the reuse of automotive engines is shown in Driesch's paper (Driesch et al. 2005), which targets the activities of Mercedes-Benz. Due to the high level of market share the company deals with (remanufactured about 60 of the above engines a day, selling14, 250 remanufactured engines in total, about 40% of the total world-wide market for remanufactured MB engines for cars and vans) the value of data from this source is likely high. Technical aspect such as the volume of components in a typical core (several hundred parts) and the need for manual disassembly as well as the difficulties faced by the increasing number of variant models of engine and parts which causes issue due to the necessary factor of matching suitable replacement parts with relevant core. In the case of operations this company bases the initial inspection on visual means for identifying components within the assembly. The core can then be moved to a specified group based on the number of components that can be identified during this task. Sorting of such engine groups is based on expected demand and the time taken to process the core for re-sale. In the case of this paper it is noted that the need to keep the core 'complete' does not apply and components once disassembled are than stored in separate containers for later use. This type of set-up allows for a more specialized assessment and inspection system to be set-up. The reliance on experience that has been noted based on data gathered from previous papers is not as detrimental due to the level of diversification in terms of components as opposed to core.

In this manner such a set-up using multiple operators each targeting a specific type of component would reduce the level of reliance on ‘complete core’ knowledge and reduce the level of potential variability if no single area is assessed by different inspectors, generating potentially subtle but noticeable differences.

Within the UK there are barriers and issues that can hinder successful remanufacturing and these factors are discussed by (Rahimifard et al. 2009). This article points out that product recovery and recycling has historically been under-developed within the UK, with typical resource consumption far outstripping that of material recycling, and therefore improving the existing remanufacturing and end-of-life activities will be a critical aspect of achieving a more sustainable industry of remanufacturing operations. Barriers to successful remanufacture include the need for more effective business models and strategies for achieving, distributing and design for EoU, however the technical expertise of the company in question is also brought up with the lack of available data present for independent start ups being a critical factor. China on the other hand has tackled the growth and development of ACR (Automotive Component Remanufacture) with the full force of many governmental and research bodies in an attempt to build up this aspect of the industry within their borders. The assessment of company operations in this area within China notes that one of the key features of independent automotive remanufacturers is a lack of key technical support and essential data (intellectual property details). The need for more specialized tools, methods and process in order to fully realize the success of remanufacturing products in this area is noted, especially when compared to traditional automotive manufacturing (from which any applicable methods are drawn from as opposed to the generation of specialized methods for this field) (Goodall et al. 2014).

The importance of technical experience and suitable tools for remanufacturing processes is discussed in (Chaowanapong et al 2018) where issues potentially facing the development of remanufacturing technology (including methods) are investigated. The paper notes that Technological issues are quite critical, as the remanufacturing process may become technologically infeasible due to lack in both the OEM manufacturing expertise and technical know-how. Hammond's 1998 paper regarding issues in the automotive sector includes the reliance on personal knowledge and skills of the operator as a vital aspect to successful remanufacturing and as a potential barrier to more impartial/widespread methods. Both papers agree with the role of skill and personal expertise within the remanufacturing workforce.

Despite aims towards automation (either in disassembly or cleaning processes) the majority of the standard remanufacturing operation remains labour-intensive, with a significant amount requiring specialized skills gained through extended experience in order to effectively deal with the variation in both type/model/core factors and the condition in which it may arrive at the facility in question. Therefore sufficient ability and expertise within the company is a requirement for successful remanufacturing operations. Within this structure of operations the areas where this type of expertise ad technical knowledge becomes most vital is during the assessment and inspection stages, since during this process as well as assessing the condition of core/parts the relevant processes required to bring all relevant pieces back to OEM standard are decided upon based on operator opinion and evaluation. (Wei 2015) also concludes that one of the major impacting issues of remanufacturing is in the difficulty of obtaining used products (cores) that are suitable for remanufacturing.

In (Ostlin 2005) the remanufacturing process is given an in-depth examination. Like Sundin's work building the generic overview of the typical remanufacturing operation this research uses the same steps established as a basis, however Ostlin also provides a new set of "phases" which breakdown the different activities less as single stages but rather a series of less defined periods from start to finish. These include the Pre-disassembly phase, Disassembly phase, Reprocessing phase, Reassembly phase & the Post-assembly phase. This was very interesting as "Inspection" is still classed as an activity that occurs post-disassembly in many remanufacturing set-ups. However from the examined literature it begins to look as though inspection occurs at different degrees across the entire remanufacturing operation.

Ostlin is keen to note that his work acts as an addition to the existing knowledge of the remanufacturing operation and does not contradict the previous model. During a more detailed elaboration of the phases a feature is noted as "Extended Core Information" and includes activities such as 'core identification core value & fault diagnosis'. These are activities that can traditionally fall under the overall purview of inspection procedures.

While the majority of factors that would be identified, as 'assessment activities' appear in phase 1 there are indications that multiple other inspection activities occur later in the remanufacturing operation.

Despite a more in-depth exploration in this paper of the different stages and activities of remanufacturing the area of 'inspection' still remains relatively untapped.

2.4.4 Discussion:

Despite no preconceived ideas regarding the final output of the thesis when the research began, there did exist a certain level of assumption that any tool or valuable addition to the existing knowledge would be directly tied to inspection. The initial stages of the literature review were designed to provide a comprehensive overview of available research, starting out with papers focused on remanufacturing as an industry and gradually becoming more focused until the most pertinent research on inspection was identified. A systematic literature review aided greatly in this activity, early review work clearly determined the knowledge gap to be found in core assessment practices. Each subsequent review Protocol allowed the literature to be narrowed down further as the key issues in inspection became apparent.

The work by Errington and Ridley act as cornerstones of this research and have provided a valuable example of the utilisation of existing or current academic work as a basis from which to build upon. This existing research is a highly valuable and distinct addition to the academic pool of knowledge and by using it as a foundation to build new and novel ideas/concepts the research can be shown to integrate well with existing work.

2.5 Perceived Issues with Automotive Remanufacturing

The literature presents a very interesting view of the current remanufacturing business landscape. Social awareness and new legislation from governing bodies is leading to greater prominence for sustainable manufacturing options. Increased recycling rates around the world and collection schemes to improve waste disposal have become features of everyday life. As such remanufacturing is gaining new ground in this landscape with academic institutions and research facilities now focusing on remanufacturing as a priority. In particular the creation of research centres like SIR (Scottish Institute for Remanufacture) in the UK and the ARTC (Advanced Remanufacturing and Technology Centre) in Singapore show a new level of engagement between academia and industry. As the automotive sector of remanufacturing constitutes between **65-75%** of the market this particular area is given special significance.

With potential benefits that could occur across the world as many developed/developing countries seek to become a more sustainable culture, any remaining issues or problems occurring in the automotive sector of remanufacturing have to be considered, identified and rectified. From the primary case studies and the data from the literature it appears that there are **3 main issues** currently occurring within the automotive remanufacturing process;

- Possible Over-Reliance of personal experience and opinions of inspectors.
- Lack of training in place to allow others to train up for inspections and assessment.
- Poor perception by public and lack of awareness by other areas of industry.

2.5 Summary Chapter 2

In this chapter the key literature regarding remanufacturing has been examined, papers regarding operations such as disassembly and core sorting have all been collected and compared in order to identify a potential knowledge gap. Papers by Hammond, Lund and Stienhilper have detailed the developments in early remanufacturing research as well as the importance of structure in operations. Ijomah and Sundin covered the vital necessity for consensus terminology and the importance of successful knowledge sharing within remanufacturing activities. The cornerstone research for inspection, Errington and Ridley have developed significant strides in this area with Errington providing the first basic generic overview for inspection across remanufacturing as a whole. Ridley on the other hand provided the first real look at the more hands on side of inspection she developed economic strategies for improved pre-processing inspection efficiency.

From this research its clear that a distinct knowledge gap exists;

- *What are the common inspection practices and procedures used by automotive remanufacturers?*
- *What issues currently affect inspection practices, as they remain ill defined?*
- *Can these issues be rectified with new knowledge or thesis output, specifically a structured guide to inspection for the entire automotive remanufacturing sector?*

CHAPTER 3 – RESEARCH METHODOLOGY

This chapter discusses the philosophical paradigm upon which the research design is based, as well as, explains the rationale for the choice of research methods and the research methodology. It also describes how the selected research methods were used as well as the measures taken to ensure the validity of research findings.

The two major paradigms that are the basis of research design are the qualitative and quantitative paradigms and these have their roots in the philosophical thinking of phenomenology and positivism respectively (Easterby-Smith et al. 1993 and Creswell, 1994). Gummesson (1993) proposes that phenomology and positivism have five distinguishing assumptions, (ontology, epistemology, axiology, rhetoric and methodology), that impact on research design.

3.1 Research philosophy:

Ensuring that a suitable research philosophy has been identified for a project is highly essential in order to maintain the quality of the research (Easterby-Smith et al. 2012). Philosophical stances aid the researcher in identifying suitable viewpoints, research methods and validation selection. A lack of a suitable philosophical standpoint can be inherently fatal to the project in question having a detrimental effect on the research quality as the project progresses (Easterby-Smith et al. 2015). In addition, understanding such stances can also aid in the creation of designs that are outside of the researcher's personal experience. Comparing and arguing opposing philosophical viewpoints is necessary to ensure they continue to evolve, however it is important not to elevate one in favour of another. As noted by (Smith-Thorpe-Jackson) it is important to understand both viewpoints in order to appreciate the benefits of the underlying methods.

The main key debate in this area is between the viewpoints within "Ontology" and "Epistemology", with the former focused on *'the nature of reality and existence'* while the latter expounds *'the best way of enquiring into the nature of the world'*. Those in the traditional sciences and those in the social sciences tend to choose opposing viewpoints in this area The debate of whether this is an active choice selected through informed opinion and balanced against the requirements of a specific project, or whether this occurs due to an ingrained tendency passed down from one generation to the next is frequently argued. Both stances consist of a wide range of options (Easterby-Smith et al. 2012).

Research Design Factor	Description
Ontology	Philosophical assumptions regarding the nature of reality.
Epistemology	A general set of assumptions regarding the best ways of enquiring into the nature of the world.
Methodology	A combination of techniques used to investigate and explore a specific situation.
Methods and Techniques	Individual techniques used for effective data collection & analysis.

Table 2 – Research Design Factors

Above can be seen the research design factors; from this it is easy to see that a researcher has a number of choices to make in these areas. It is not a straight '*black and white'* answer of correct or incorrect, but rather a selection of design factors that are both suitable for the research in question and appropriate to be used in combination. The aim of these tools is to provide the researcher with the most effective and potentially successful structure and approaches to the overall project.

3.1.1 Ontology

Ontology is the starting point of any philosophical investigation into the benefits of a more structured research design. As stated earlier in the chapter the ontological choice determines how the researcher chooses to view the world and analyses the data obtained through this viewpoint. Many of the types of ontological viewpoints can be divided by how they relate to two distinct aspects of reality, 'Truth' and 'Facts' (Easterby-Smith et al. 2012).

Realism/objectivism/rationalism

Realism exists in several versions, each with different beliefs in how they view the world. Realism states that 'reality' can be separated into two distinct categories; particulars and constants. Particulars are single objects or creations that can be 'grouped' together under the banner of certain constants, for example with fruit. In this scenario the particular is the distinctive object and the constant is the colour, taste and shape that it shares with other objects that fall under the banner of 'apples'). Constants on the other hand are typically much less tangible and more abstract in nature, with their uniting trait being their very nature (Easterby-Smith et al. 2012). Constants relating to emotion can be grouped together as they are abstract concepts that form the human spectrum of feeling.

Standard Realists believe that the world is external and fixed and that the perspective or belief of the researcher cannot affect the truth. In terms of scientific progress the realism belief follows that it can only occur if the researcher is investigating an area or subject that it directly tied to the phenomenon or "**Area of Interest**". This particular form of realism has been altered in recent years to reflect the still developing understanding of the laws of physics and nature, and as such a 'concrete' viewpoint has no way to adapt to these changes. The ‘softened’ viewpoint is labeled as **‘Transcendental Realism’** and states that ‘the ultimate objects of scientific inquiry exist and act (for the most part) quite independently of the scientists and their activity”.

Internal Realism

Internal Realism agrees that there does exist a single ‘fixed’ reality but disagrees that the phenomenon can be directly investigated through aspects directly tied to it. This belief finds that while a single ‘reality’ or ‘truth’ may exist it is impossible for the researcher to discover all the facts regarding it. The only way to gather evidence of the phenomenon is through physical processes that are ‘by-products’ of it. However this ontology does state that once observed ‘facts’ pertaining to the phenomenon are considered ‘fixed’ they are consistent and independent from further observations (Easterby-Smith et al. 2012).

3.1.2 Epistemology

Epistemology as noted earlier in the chapter is ‘*the best way of enquiring into the nature of the world*’. The differences in the selected methods for such enquiry forms the debate between its two key aspects; positivism & interpretivism (Creswell 2002; Easterby-Smith et al. 2012). Epistemology is the explanation of how we think. It is required in order to be able to determine the true from the false, by determining a proper method of evaluation. It includes our chosen methods for acquiring knowledge and provides suitable avenues and directions for research methods and tools that can be used to effectively collect and interpret data as the research continues. Without an effective epistemology the researcher would be unable to ascertain fact from error.

While Positivism and Interpretivism form the two extremes a number of newer epistemologies have developed in recent years including critical theory, critical realism, hermeneutics and postmodernism.

3.1.3 Epistemological Selection

Critical Realism:

Critical realists believe that the phenomenon does exist, and that only the actions of the researcher can identify it once sufficient investigation has been made. The main benefit of such a viewpoint is that it allows the researcher in question to better observe patterns or commonalties between various scenarios. As such Critical Realism can offer a greater chance of uncovering phenomena that the use of Positivism; This viewpoint also believes that many phenomena are context dependent and must be analyzed in order to determine any useable data, rather than solely viewed as the initially appear.

3.2 Research Methods:

Research methods refer to a set of techniques used for the collection of relevant data and its subsequent analysis. These techniques can often vary depending on the situation and partly due to the selected ontology (Easterby-Smith et al. 2012). This is due to each decision from the initial ontological selection having a subsequent ‘knock-on’ effect. Certain ontologies will draw the researcher towards certain epistemologies that will in turn suggest certain techniques as most suitable. The aim of this section of the thesis is to clearly explore and then identify the most likely suitable techniques to use for this research.

Case Study

Yin (Yin 1994) states that case study is ‘an empirical enquiry that investigates a contemporary phenomenon in depth and within a real-life context’. This method can allow the researcher to investigate phenomenon within the confines of its context allowing for additional variables and interactions to be observed and noted. As a technique, case study can be utilised across the different ontologies, including positivism, internalism and constructivism. When aiming to investigate a phenomenon that may be highly dependent on the variables of its situation and context such a form of data collection and examination is well suited (Frohlich et al. 2002).

3.2.1 Design of the Case Study Research:

The research design is the guide to how the research will be conducted during its subsequent stages, factors such as:

- What will be investigated?
- How will the investigation take place?
- What types of Data will be collected?
- How to interpret that Data?
-

In addition to this, the research guide will show how at each later stage the initial research questions were addressed and then validated or invalidated (Eisenhardt 1989).

3.2.2 Philosophical approach of the research:

Based on the previously discussed philosophical approaches the selected Ontology for the research is *Internal Realism*. This is primarily due to the belief that such a viewpoint is best suited for the work to be conducted. Inspection within the context of remanufacturing is a complex phenomenon and as such may involve multiple elements that cannot be quantified to any great extent. While this ontology is typically less subjective than others it does lend itself to the development of patterns and relationships between the phenomenon and its contexts, which can be applied to multiple branches of the automotive remanufacturing field. The data gathered will very likely include a significant amount of qualitative data. Based on both the observations and assumptions of the researcher, and the human based interaction of individuals, the more subjective ontologies did not lend themselves to the idea of an overarching solution. This was because they primarily appeared to solve issues present in a single scenario (1 company, 1 set-up) while the purpose of this research was to build inspection models for the entire automotive remanufacturing sector (including different set-ups, styles and approaches to inspection operations).

The selected Epistemology is *Critical Realism;* this is due to the key aim of the research to investigate the reasoning of why such a phenomenon exists and the contributing factors to it arising within the selected context of the investigation. This viewpoint is believed to be well suited to this research in that the researcher plays a separate but active role in the investigation. Users of this epistemology can tackle large amounts of qualitative data and have to help 'drive' the research, by devising new questions and directions as it progresses. When dealing with a human activity system (HAS) such systems are too complex to be studies by quantitative means alone hence the choice of qualitative research. I have selected the case study approach because it is an established method of undertaking industry based investigations into uncertain phenomenon (Frohlich et al. 2002; Yin 1994).Also case study is a proven approach when dealing with remanufacturing research (e.g. Hammond 1998, Kapetanopoulou and Tagaras 2009; Matsumoto 2009; Östlin, 2008; Sundin, 2004). Within case study research I have selected a multi-case approach as the data gathered has a greater generalisability across the remanufacturing sector and also a greater capacity for generating broader sector-wide theory than a single case study approach. In addition multiple case studies obtain more in-depth understanding in general than single case.

3.2.3 Methods for the research:

A Case Study method can be implemented under the assigned ontological and epistemological choices through the reasoning and thought process choices based on the works by Easterby-Smith and Yin (Easterby-Smith et al. 2012; Yin 2011). When investigating phenomena that rely on multiple interacting factors within a complex environment, much of which is outside the control of the researcher case based studies using a critical realistic approach can yield useable and effective data. When considering suitable methods during the early stages of this research, case study methods already appeared as a highly appropriate option. This was due to several factors including the likely interaction between multiple variables of the typical remanufacturing operation and the human-based aspect of the operation when in consideration with ‘Inspection’.

The *remanufacturing operation* has been established by multiple authors to follow the same core “stages” regardless of the sector, as such the area of investigation and the study of phenomenon is based on the investigation of the interactions and developments not yet noted. In particular how they change, develop and differ based on varying contexts and differences in interaction from a human aspect across multiple situations.

3.2.4 Replication Logic:

Replication Logic refers to the act of utilising similar conditions across multiple scenarios to investigate and compare the features and attributes of a phenomenon. Replication Logic follows that if the conditions of each situation are viewed by the researcher as suitable then the output from those cases may be considered representative of the conditions of the phenomenon present in the wider field.

3.2.5 Multiple Case Studies:

Case Studies are highly suitable when the selected phenomenon cannot be investigated separately from its context, this is ideal for investigations that detail the WHY and the HOW of a phenomenon in scenarios that the researcher has little to no control over (Yin 2011; Frohlich et al. 2002). This is essential when the aim of the research is the generation or development of a theory or model based approach. In the case of this research the literature review chapter has already identified that while some existing work does attempt to clarify and examine the nature of inspection within automotive remanufacturing processes there is still much that is left undefined and open to new theory-building. In particular, the nature of personal opinion and knowledge in the success and future development of visual inspection in remanufacturing.

The selection of multiple case studies for the purpose of this research was suited in that as opposed to single case studies which allow for greater depth but limit the scope of the research and lend themselves to constructivist ideals, the use of multiple cases allows for the perceived phenomenon to be observed across a greater variety of context thereby allowing for comparison and investigation into factors such as the human element and operational structure having a potential impact on the phenomenon being investigated. Multiple cases as suggested by (Yin 2011) allows for high generalisation and the applicability of the theory being built from the data. As the aim of the research is to propose a solution that may aid the automotive remanufacturing sector at large it is therefore essential to ensure that the selection of cases is suitably broad.

3.2.6 Selection of Cases:

The choice of the number of cases is debated by several authors as each method has its own validity and benefits; fewer cases can result in less applicability and generalisation but also provide greater depth, while a larger number of cases can increase the opportunity to conduct replication logic based analysis across more companies while at the same time rendering the cases more superficial and less likely to gauge truly valid observations from the companies in question (Voss 2010; Eisenhardt 1989; Stuart et al. 2002).

In (McCutcheon and Meredith 1993) states that between 2 and 8 cases is the optimum number for selection, while Eisenhardt prefers between 4 and 10. The debate between these two views stands that fewer than 4 cases being included in the research greatly lowers the applicability of the research output to the wider field and limits the level of generalisation that can be assumed or hypothesised from the case study results. Once over 10 cases however the sheer amount of data is either likely to become entirely too much to realistically compile and analyse within a reasonable time-frame, while if achievable then the depth of each study is likely greatly reduced.

The selection of the cases is also based on the characteristics of the companies themselves, as the most suitable attributes between selections allows for effective comparison as well as greater validity to the generalisations of data gathered from each case to the sector or field as a whole. This is also counterpointed by ensuring that certain attributes were highly dissimilar in order to more effectively gauge the results of each end of the case spectrum and provide a more realistic observation of the overall field (Voss 2010; McCutcheon and Meredith 1993).

3.2.7 Structure of the Selected Cases:

The structure of the selected cases chosen for the study are shown below, including features such as the size, type and product focus of each company.

Company:	Size	Type	Products	Status
Company A	Small - Medium	Independent	Gearboxes/Transmissions	Expanding Slowly
Company B	Small	Contract	Transmissions	Expanding Slowly
Company C	Medium - Large	OEM	Full Engine	Stable
Company D	Large	Independent	Full Engine	Stable
Company E	Large	OEM/Contract	Steering & Braking systems	Internal Re-developing

Table 3 – Selected Case Study Companies (A-E)

3.3 Qualitative vs. Quantitative:

An issue that has been discussed numerous times throughout the field of data gathering and analysis is “Which form of data is best?” or “Which type is the most useful and of value?” in short “Qualitative or Quantitative?” (Barratt et al. 2011; Creswell 2002).

Each type of data has its own positive and negative points, its own key benefits and limitations. Qualitative data has been known to provide key insights into human interaction and the thought processes than can occur during previously ill-defined or unknown areas. Whereas quantitative possesses the ability to provide solid, hard facts regarding situations and scenarios with structured ease. Qualitative data can be more fluid and adaptable, but as such can also require greater detail to gain valuable results from it and does not always provide a strong footing for outputs and solutions. Quantitative data is typically rigorous and allows for the data set to be approached in ways that illuminate obvious flaws and key insights. However, it can also be much more difficult to gain pure quantitative data from areas not extremely structured themselves.

When conducting data gathering it can often be best to utilise both methods in order to provide a more ‘comprehensive’ and ‘insightful’ overview to the problem at hand (Creswell 2002). The ‘slant’ between the level of focus on each approach can differ as the project requires. Though both qualitative and quantitative methods may be in play during the research investigation unless the question of the research requires a level and even approach by both sides of the research methods then a more profound leaning on a particular side of the methods is likely to occur.

This “shift” in methodological approaches is due primarily to the available types of data at hand in the ‘observable’ environment. The observable environment is the name given to the situation in which the research question or phenomenon inhabit..

Why Qualitative?

Qualitative research is a broad methodological approach that covers numerous routes of inquiry and methods of data gathering. Qualitative methods can be defined as the seeking of the Why and How of a decision or process rather than the more traditional What, Where, When and Who. Qualitative research is often associated with the more human based areas of academia such as sociological research and psychology. One of the key issues with this type of research is that it can be argued that the results of such data are always subjective, either in the responses given by those questioned or through the inherent bias of the observer/researcher. This is a significant point and is a highly potent reason why purely qualitative research cannot be taken only at face value. When conducting research in this manner it is important to try and ensure that the available data sources are coming from as many reliable sources as possible, allowing for extensive cross-referencing of relevant results to gain a more balanced and suitable viewpoint.

A key method in qualitative research is the use of “Case Studies” where the researcher utilises real-world instances to understand and explore the “question” or “phenomenon” that is the subject of the research. Some view qualitative research as only the “beginning” stage of true research with such data being used to form the initial hypothesis and then relying on more quantitative methods to gain the empirical results desired (Creswell 2002; Voss 2010).

Why Quantitative?

Quantitative research can be considered the systematic empirical investigation of a "question" or "phenomenon" through various math, computer or statistic based methods.

The main aim of such research is to create and utilise methods, tools and theories based on the investigation methods to fully analyse and observe the relevant 'object' of the research. As such Quantitative research is strongly associated with mathematical based areas of academia such as computer-programming, engineering and maths (Creswell 2002). However in order to conduct quantitative based research a situation will need to be made "quantifiable", all aspect broken down into numerical values or data in order to allow complex equations and mathematical analysis to take place. The clear benefit from such scenarios is the absolute level of precision and accuracy that can be achieved through the mathematical model. Manipulation in order to assess various outcomes of the situation deriving from differing variable inputs allows for numerous scenarios to be examined and investigated, all operating within scientifically plausible parameters due to the level of accuracy when constructing the mathematical model.

Unlike qualitative research this type of investigation remains largely objective and impartial due to the fact that it is built around mathematical models and as such cannot be subjective (Yin 2011; Creswell 2002). In these circumstances the equations should provide the accurate results dependent only on the suitable values being introduced at the start of the process. However like the sometimes subjective nature of qualitative data this type of investigation has its own issues. Effective mathematical models can only be created in this scenario if all aspects and variables regarding the "observable environment" have a numerical value or equation, allowing them to be suitably calculated or altered as the equation requires. However placing true value on actions based around human interaction, either in terms of operational technology or interactive data, can be a highly difficult task and can in some cases be one that is simply unsuitable for the research at hand (Pronin 2007; Nardi 1996).

Quantitative vs. Qualitative & Human Perception:

Earlier in this chapter the subject of inherent bias on the part of both the observed and the observer was highlighted (Pronin 2007; Barratt et al. 2011). During methods such as direct observation and discussion, the issue of bias has to be in the constant background of the researchers mind. Questioning their own questions and debating answers can be one of the tools used to ensure that the researcher remains as unbiased as possible, constantly aiming to be an impartial aspect of the 'observable' environment simply gathering knowledge and data.

3.4 Details of Data Collection

Company:	Method of Collection	Duration	Topic Addressed	Informants
Company A	Observation of Remanufacturing Processes	3 Days	• Remanufacturing Processes in general • Inspection activities • Testing activities	Process Operators
	Shadow Operators and conduct semi-structured Interviews	3 Days	• Remanufacturing Processes in general • Uncertainty of incoming Core condition • Difficulties faced by Operators conducting Inspection & Testing • Core Storage	Process Engineers/Operators
	Discussion of Observations and Interviews	1.5 Hours	• Issues and attributes of Inspection and remanufacturing practices	Head of Company & Process Engineers
Company B	Observation of Remanufacturing Processes	2 Days	• Remanufacturing Processes in general • Inspection activities • Testing activities • Core Storage	Process Operators
	Shadow Operators and conduct semi-structured Interviews	2 Days	• Remanufacturing Processes in general • Uncertainty of incoming Core condition • Difficulties faced by Operators conducting Inspection & Testing	Process Engineers
	Discussion of Observations and Interviews	1 Hour	• Issues and attributes of Inspection and remanufacturing practices	Head of Company & Process Engineers
Company C	Observation of Remanufacturing Processes	1 Day	• Remanufacturing Processes in general • Inspection activities • Testing activities	Process Operators
	Conduct semi-structured Interviews	2 Hours	• Remanufacturing Processes in general • Uncertainty of incoming Core condition • Core Storage • Difficulties faced by Operators conducting Inspection	Process Engineers/Operators
	Discussion of Observations and Interviews	1.5 Hours	• Issues and attributes of Inspection and remanufacturing practices	Head of Facility Operations
Company D	Observation of Remanufacturing Processes	1 Day	• Remanufacturing Processes in general • Inspection activities • Testing activities	Process Operators
	Conduct semi-structured Interviews	2 Hours	• Remanufacturing Processes in general • Uncertainty of incoming Core condition • Core Storage • Difficulties faced by Operators conducting Inspection	Process Engineers/Operators
	Discussion of Observations and Interviews	1 Hour	• Issues and attributes of Inspection and remanufacturing practices	Head of Facility Operations
Company E	Observation of Remanufacturing Processes	1 Day	• Remanufacturing Processes in general • Inspection activities • Testing activities	Process Engineers/Operators
	Conduct semi-structured Interviews	2 Hours	• Remanufacturing Processes in general • Uncertainty of incoming Core condition • Core Storage • Difficulties faced by Operators conducting Inspection	Process Engineers/Operators
	Discussion of Observations and Interviews	1 Hour	• Issues and attributes of Inspection and remanufacturing practices	Head of Company & Facility Operations, Process Engineers

Table 4 – Case Study Data Collection Details

3.4.1 Data Triangulation

Data from the cases studies was collected from multiple sources at each facility with the aim of ensuring that the data is relatively objective (Flick 2009); the inclusion of the term 'relatively' is used at this stage due to additional uncontrollable social factors such as company loyalty, inherent leaning towards strict professionalism during questioning and professional pride. These factors can result in some bias towards the 'inherent positive nature' of the current company set-up regardless of any issues or obstacles that may be observed or noted by multiple parties involved. This is not true of all or even most cases however it was an attitude that was prepared for due to the response and feedback observed from existing work in literature and among academia. As such sources included those at multiple levels of the company from the Process Operators at the very front line of the remanufacturing operation, the Process Engineers which took power positions and managerial roles on the work floor of many facilities, and those involved in Managerial positions such as Head of Facility Operations or Director of the Company in question. By investigating from multiple avenues the chances of corroborating or contrasting data was much higher leading to more effective analysis and identification of the 'truth'.

Triangulation allows for both increased robustness of the research but also a deeper and more nuanced understanding and content of the work put forward (Flick 2009; Wilson 2014). Such action ensures that bias on the part of the observer is not allowed to influence the studies themselves.

Triangulation Points of Data:

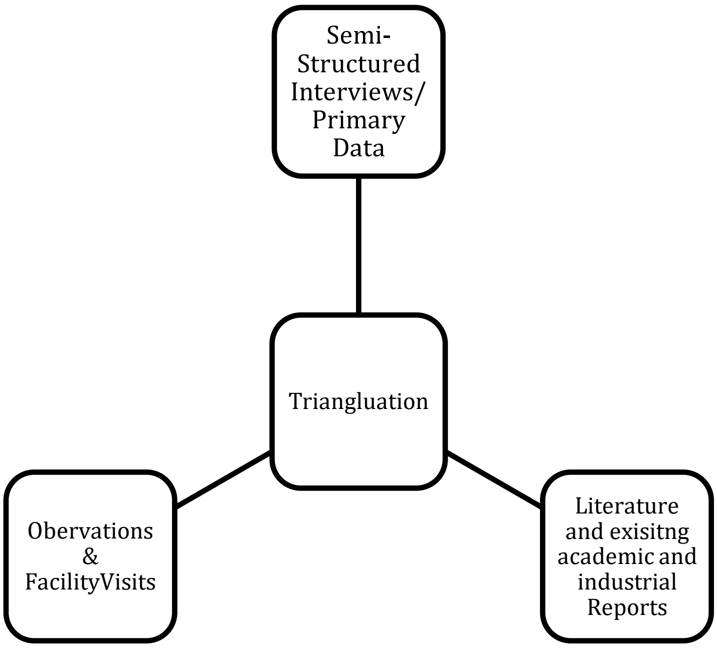

Figure 4 – Triangulation Model

3.4.2 Validation Procedures

Successful validation of the end result allows for justification of the entire project as a whole, while affirming the inherent value in outputs and deliverables of the research (Koro-Ljungberg 2008).

Validation of research can occur through various methods. The form of the results gathered through either analysis techniques or previous indicators of theory define the style of validation required in order to ensure that as unbiased a final result can be achieved (Pyett 2003; Noor 2008).

All data gathered during the Case Study stages was written up and then passed back to the subjects at the Company in question in order to ensure that it was an accurate summary of what was discussed and noted during interviews and observations.
As the interviews were of a semi-structured nature the key points noted from these interviews were noted as clear bullet points to accompany a more detailed summary of the data gathered. When the Case Study notes were returned any modification needed from the feedback was undertaken and then re-reviewed into order to ensure a true reflection of the real world conditions at the companies.

While experimental validation and other similar methods can be the most efficient way to ascertain the success of the research if the output being tested cannot be verified under such impartial conditions then alternative methods must be utilised. As such the type of validation selected for this research is "*Expert Validation*". This type of validation can be used when the subject area being investigated cannot be boxed into laboratory conditions and so is less suited to quantitative validation (Polit and Beck 2006; Koro-Ljungberg 2008). Due to the nature of the DATF model the only way to validate under real world conditions would be to utilise a number of companies across the remanufacturing sector; with each implementing these models to different levels and the researcher observing how the daily operations and business improve or change over a specified period of time (6 months).

This will be discussed in greater length and detail in Chapter 8.

3.5 Summary Chapter 3

In this chapter the details regarding the ontology, epistemology and methods of research that will be used to drive this body of work forward have been discussed. The selected viewpoints (Internal Realism and Critical Realism respectively) have been justified as well as the structure, number and style in which the selected cases used in this chosen methodology have been selected. The function of each aspect has been targeted at ensuring that the work is carried out in a manner that will both produce viable results from a data collection standpoint but also that any data or solutions derived from the investigation of the phenomenon will be robust and tested against the appropriate context.

With these research methodology finalized, the data collection methods were used as part of Case Study research to examine 5 separate automotive remanufacturers across the UK. Each case was selected to display a particular aspect of the automotive remanufacturing industry, and varied in size, component focus, company set-up (OEM, Contract, Independent) in order to gain a suitably accurate overview of the sector as a whole.

The Case Studies and the results are detailed in following chapter, while more in-depth descriptions of the findings at each Company are included as part of Appendix B.

CHAPTER 4 – CASE STUDIES

4.1 Introduction

The purpose of these studies is to examine in closer detail the typical operations of OEM, contract and independent automotive remanufacturers..These case studies will be focused on investigating all remanufacturing operations with an aim to identify which inspection activities take place. These activities will then be compared and contrasted in order to build a complete overview of the inspection stages that occur within automotive remanufacture. Semi-structured interview and observation at on-site facilities will be two of the main case study techniques used and all hypothesized issues surrounding inspection will be investigated to gauge their validity in real-world conditions and all relevant data surrounding the procedures and activities for Inspection will be recorded.

4.2 Methodology

The method used to identify and collect the data for this research was based in the investigative and exploratory techniques of Case Study (Eisenhardt 1989; McCutcheon and Meredith 1993). As noted in the previous chapter the companies were selected for a variety of reasons including factors such as level of financial and technological resources, size of facility, size of operation, product focus, longevity of company, and position within the UK market (Noor 2008; European Remanufacturing Network 2016).

Once the studies were approved by those at the facility, the methods for collecting the data were selected. First an understanding of the background and driving forces of the company would allow for a more in depth and effective assessment of the facility. Then a more thorough examination of the current operations and procedures in place was undertaken, This was then built upon by an investigation into specifically inspection stages and activities. Finally, questions regarding the future direction for the company were used to predict upcoming trends in the industrial landscape.

To achieve these semi-structured interviews involving question and answer sessions provided a very thorough and detailed background for the company including its initial formation, it's growth, recent changes in structure and methods and hopes and plans for the future. Semi-structured interviews and observations were the selected techniques to gather data during several case studies involving industry (Easterby-Smith et al. 2012; Patton and Appelbaum 2003; Yin 1994, 2011).

A thorough overview of the daily operations and typical duties of the operators would allow for an effective starting point to build on from this information with regard to exploring the practical side of the work. This was decided as the next form of data to be gathered at the facility. It was achieved through a guided walk-through of the facility, in this manner larger questions regarding operations could be addressed and discussed with those more aware of the larger scale implications of any changes or directions in the company and the more practical hands-on data gathered first hand as the actions and operations were performed.

4.3 Case Studies

4.3.1 Case Study Data gathering: Companies A - E

Below is the breakdown of the data collection points used to triangulate data within each Company that was the subject of the study:

1.

	Activities in Inspection	Inspection Layout	Obstacles to Inspection	Assessment Method	Process Adaptability
Observations	x	x	x	x	x
Process Mapping	x	x		x	
Operator Interview		x	x	x	x
Manager Interview			x	x	x
Other Methods	x				x

Table 5 – Company A Data Gathering

Name: Company A
Products: Automotive Products (Transmission/Gearboxes)
Collection Methods:

- Observation of Remanufacturing Processes
- Observations of Inspection Processes
- Interview with Operators
- Interview with Management
- Other Data (Company Data Records)

2.

	Activities in Inspection	Inspection Layout	Obstacles to Inspection	Assessment Method	Process Adaptability
Observations	x	x	x	x	x
Process Mapping	x	x	x	x	
Operator Interview	x	x	x	x	x
Manager Interview			x		x

Table 6 – Company B Data Gathering

Name: Company B
Products: Automotive Products (Transmission)
Collection Methods:

- Observation of Remanufacturing Processes
- Observations of Inspection Processes
- Interview with Operators
- Interview with Management

3.

	Activities in Inspection	Inspection Layout	Obstacles to Inspection	Assessment Method	Process Adaptability
Observations	x	x	x	x	x
Process Mapping	x	x		x	
Operator Interview	x		x	x	x
Manager Interview		x	x	x	x
Other Methods	x		x	x	x

Table 7 – Company C Data Gathering

Name: Company C
Products: Automotive Products (Full Engine)

Collection Methods:

- Observation of Remanufacturing Processes
- Observations of Inspection Processes
- Interview with Operators
- Interview with Management
- Other data (In house guide designed to aid inspection)

4.

	Activities in Inspection	Inspection Layout	Obstacles to Inspection	Assessment Method	Process Adaptability
Observations	x	x	x	x	x
Process Mapping	x	x		x	
Operator Interview		x	x	x	x
Manager Interview	x		x	x	x
Other Methods			x		x

Table 8 – Company D Data Gathering

Name: Company D

Products: Automotive Products (Full Engine)

Collection Methods:

- Observation of Remanufacturing Processes
- Observations of Inspection Processes
- Interview with Operators
- Interview with Management
- Other Data (Company in-house training activities)

5.

	Activities in Inspection	Inspection Layout	Obstacles to Inspection	Assessment Method	Process Adaptability
Observations	x	x	x	x	x
Process Mapping	x	x		x	x
Operator Interview	x	x	x	x	x
Manager Interview			x		
Other Methods	x				x

Table 9 – Company E Data Gathering

Name: Company E
Products: Automotive Products (Steering & Braking Systems)
Collection Methods:

- Observation of Remanufacturing Processes
- Observations of Inspection Processes
- Interview with Operators
- Interview with Management
- Other Data (Company Process Overhaul and record of new technology)

Each case study involved an extended visit to Company (A-E), a UK based automotive remanufacturing facility.. Each facility and company are considered a strong example of good quality output and a standard of remanufacturing that others in the sector can be held to. Certain selections for the study were made to compare companies of similar resources and size such as A and B, and C & D.

Each visit involved observation of the remanufacturing operation as a whole within each facility. Operators from various points of the process were interviewed to better understand how the inspection activities related to other aspects of the overall operation. Further interviews were conducted with inspector's to gain an in-depth understanding of their typical duties. Process Mapping was also used to build a complete layout of each feature of Inspection, allowing such data to be used as a training tool or reference point with new staff.

In addition to observations and interviews with those at the most hands-on stage of the automotive remanufacturing operation interviews were also held with management at each facility, this allowed for an additional perspective brining new information such as the direction of the company and its plans for future development.

The purpose of each case study was to examine how inspection is conducted across various UK automotive remanufacturers, the barriers it faces, the ways it could be improved. Utilizing carefully selected companies and comparing the data proved effective in investigating common points of concern and highlighting patterns in the various approaches to automotive parts inspection.

4.3.2 See APPENDIX – C (Case Studies A – E)

4.3.3 Review of Case Study results:

Case Studies A – E form the backbone of the data gathering exercise conducted for this research t. Each of these companies was selected due to the unique position they hold within the UK based automotive remanufacturing sector. Some of these companies are resource heavy contractors, while others are lean and adaptable independents and still others are large scale OEMs with all the technical resources and data available from the parent company. The purpose of each of these case studies was to gather both data regarding the inspection procedures and operations at work within the industry but also to more accurately ascertain the flow of knowledge and data between those operating in the sector as well as between the different areas of the company itself. The individual processes that occur within the typical remanufacturing operation have been separated into the six main stages. These stages though distinct can appear generic in their terminology and description due to the nature of detailing a potential process that can occur significantly differently from sector to sector. While some academic works have done much to provide in-depth and detailed accounts and investigations into the limitations and obstacles facing some processes within key sectors the literature review showcased quite clearly that an area yet be fully explored was the ‘Assessment’ stage of the operation.

As established during the literature review, the key papers selected that relate to the inspection process note that it is not yet fully detailed and that the current most in-depth exploration has generated a generic process outline based on the principles of all sectors. While this has been an invaluable basis to build from it also limits the applicability of the earlier outline to current practices within a certain sector. In order to more accurately assess the exact nature of inspection as it occurs within the automotive remanufacturing industry the case studies were conducted in a more operation and process heavy manner with key details of all processes being investigated. This allows the feedback to be later reviewed and the various stages and nature of any inspection and assessment stages to be catalogued for cross-reference and collation.

4.3.4 Results

Cross-Case Analysis was used to compare and contrast the findings from each Case Study, allowing common patterns to emerge and areas of concern to be highlighted. In particular 4 features of note became apparent during the analysis;

- Reliance on personal knowledge: Inspectors were found to rely extensively on personal knowledge and judgment during the part assessment process, deciding what needed to be done and if a part was pass/fail. The issue with this scenario is that such knowledge is by its very nature highly subjective and highly variable.
- Lack of Reference data regarding damage assessment: While Inspectors were noted to rely very heavily on their own personal knowledge and judgment it also became apparent that an additional negative factor was the lack of a suitable reference tool that could used to classify the level of damage present in a more impartial manner. Issues surrounding the subjective nature of the inspector's opinion could be mitigated by also adhering too less qualitative points of reference.
- Difficulties in Training: Passing on such unique knowledge to new staff proved to be a problem in these remanufacturers, while a "Watch and Learn" method was employed to some success any data communicated to new staff regarding the pass/fail judgment on core naturally varied from each staff member leading to new staff with the same imparted information reaching very different judgments on parts.
- Aging Workforce: Due to the difficulty in training up new staff the existing inspection staff at these companies primarily comprise of individuals

approaching retirement age. This is a serious issue and one the companies are starting to get suitably concerned over.

In addition to the patterns and issues noted during the case study analysis, the data was also able to used to construct an overview of the stages of Inspection that occur throughout the typical Remanufacturing Process, as shown below:

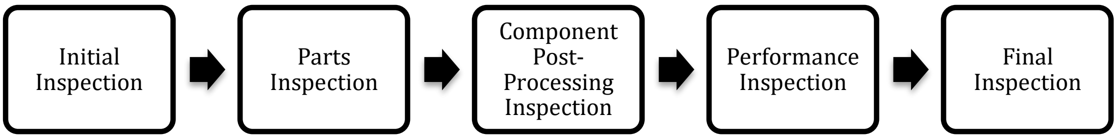

Figure 5 – Inspection stages

A full discussion of how these stages were created can be found in the Case Studies in Appendix C.

4.4 Case Study Protocol

A Case Study Protocol was designed for the purposes of following its criteria in terms of acquiring the most potentially relevant data from the company in question. This protocol was altered slightly between studies B & C and D & E as certain key assumptions and hypotheses were either confirmed or changed due to feedback and data from real world conditions. Semi-structured interview is the cornerstone of the feedback gathered from these case studies, due to the nature of ascertaining the benefits and the limitations of the method currently employed within a company, the ability to gain a result that is not the ‘standard company response’ (i.e. Everything is effective, I have no complaints). Despite gaining access to said company to examine their methods the likelihood for this response to occur during any discussion is quite high. However the less formal and more ‘discussion-like’ the interview the easier it becomes for the employee or operator in this case to feel much more free to talk. During this more relaxed situation it becomes much easier to gain meaningful feedback and to gently approach the subject of the areas of interest without causing any feeling of disloyalty to the company itself, when they discuss any process or operations failings or issues they have experienced.

As noted in earlier sections the range of companies selected for the case studies cover various aspects of the automotive remanufacturing sector. The aim with the selection of these companies was to ensure that any assumptions or data gathered through the experience of observing and questioning first hand data would reflect on this aspect of the industry as a whole as opposed to a single aspect of the sector. If the studies had been entirely focused on independent companies operating in the sector of automotive transmission remanufacture, for example, the results obtained may quite comprehensively reflect this particular niche aspect of the current industry. However, the applicability of such data to a wider range of the industrial sector would be doubtful and uncertain. Therefore each company represents a key distinctive aspect of the industrial landscape; including those dealing with automotive transmissions, torque converters, engender blocks and gearboxes as well as different structure and company set-ups from small-scale independents to large OEMS and contractors.

4.5 Summary of Chapter 4

During the case study chapter it can be observed that each study includes its own discussion and reflection on the data obtained, as well as any points or notes of interest. In particular across all the studies it became clear that there are a number of issues present in inspection activities, and that these issues are not solely contained within a single company. These issues include, over reliance on personal expertise, a need for more structured training methods for damage assessment, and an aging workforce with little idea of how to effectively transfer their vital knowledge. These issues were first identified in Company A, and so as each case study progressed each issue was compared to ascertain how it was mitigated by the company in question or whether it had been solved outright.

As the study went on the issues previously noted were integrated into the semi-structured interviews in order to identify if the company staff we aware of these problems, and if they saw them as detrimental to company activities. The responses varied but many had an idea that issues were present, some issues were unknown to them but after discussion were something that they realized the operations were affected by.

Finally all the key data findings were collected and discussed at the end of each case study, to ensure full understanding was had by both researcher and interviewees. This data was then analyzed using several techniques including regression, a weighted value system to assign which problems appeared most often, and cross-referencing between staff at different levels of the company hierarchy. At this stage the results were collated and hypotheses to the thesis solution started to form.

CHAPTER 5 – RESULTS & HYPOTHESES

5.1 Inspection factor results:

The factors and hypotheses of this chapter were derived from the data collected during the case studies as detailed during Chapter 4, in order to get these results Cross-Case Study Analysis was conducted. From the observations and interviews methods such as regression were used to summarize the data and isolate key features and phrases. Common concerns across companies A – E were noted and compared in order to determine if they occurred in the different facilities, and if so did a root cause exist.

5.1.1 Table of factors affecting inspection

In Chapter 4, the Case Studies for companies A- E have been detailed including the methodology used for data gathering and the findings discovered. From the discussion at the end of the previous chapter some of the key factors negatively affecting inspection activities (i.e. Knowledge of the Operator, Training Methods, Technology available) were stated. However in this chapter the full range of "Factors" will be laid out, including their effect on the remanufacturing operation and their root causes.

These "Factors" were identified from the primary data gathered during Case Studies A – E, using case study protocols to ensure the impartiality and rigor of the research. As can be seen below 6 variables were used to cross-case analyze, to determine the common issues facing inspection, to identify how inspection was conducted across the sector, and to account for causes of changes and differences between company approaches to assessment activities.

Observe each stage of the remanufacturing operation: Though Inspection is detailed to take place post disassembly and before further processing the assessment actions are likely to occur across multiple aspects of the later operation (though possibly to a lesser extent). Each stage is then examined and the data catalogued in order for later analysis to take place. Assessment procedures can occur throughout the typical process and can often become either overlooked (as simply part of the inherent process) or become grouped as a section of a later stage (Testing) as opposed to being included in the overall inspection action. In this scenario the 'assessment' actions can be referenced as part of multiple processes; in the case of 'performance inspection' of the rebuilt core it can fall as part of both 'Inspection' but also 'Testing' as the assessment procedures carried out to ascertain it functionality and performance at this stage also partly relate to the general inspection actions.

Conduct discussion with both managerial and operator level staff: In order to gain a more 'realistic' understanding of any potential issues or problems faced by the methods or procedures currently in play the semi-structured interviews used to gather data should be applied to both those at a managerial level (gaining an understanding of the more 'long-term' plans and developments of the company, as well as the operator level (gaining a true understanding of the actions involved).

Use of direct observation & Semi-structured Interviews: While examining operations and methods the use of direct observation to verify previously statements by staff allows for both a first hand experience of said process but also the benefit to perceive any aspects of interest previously undisclosed or unobserved by current staff. In addition the use of semi-structured interview allowed for a more relaxed and successful exchange of information between the researcher and staff at all levels. By conducting the data gathering in a less strict scenario the 'pressure' on staff that are highly aware of issues regarding confidentiality and IP as well as factors such as 'Company Image' is severely decreased allowing for a much easier flow of information. This set-up also allows for any potential deficits or problems faced by those operating at the most hands-on level of the operation to be discussed without causing issue to the operator in question. Staff in situations such as this will often follow 'the company line' during investigations into current methods or procedures, with limited data being communicated and clear statements that all operations are highly efficient and effective. While the aim of the research is to analyse and collect data regarding inspection methods, the link between assessment operations and the quality/success of the overall remanufacturing operation is undeniable. As such any investigation into existing issues or problems affecting factors such as 'lead times', 'process effectiveness' or general success may link back to missing or underutilised aspects of inspection.

Close Analysis of flow of knowledge: Within a functioning automotive remanufacturing facility it is highly valuable for the purposes of the research that the flow of information relating to 'assessment' is monitored and examined. Inspection procedures have already been identified as occurring at a relatively early stage of the overall operation, however the flow of information gathered by those involved at this stage forms a vital part in the on-going exploration of this previously undefined area.

This flow can be highly reliant on the operator/process interaction; does a single operator take a 'core' from Point A to Point Z following it through the entire remanufacturing operation or is a more 'stage based' scenario where operator A is only concerned with the disassembly of any core entering this particular section, which is later moved to Stage B where operator B takes over cleaning processes. The set-up in question can determine how the flow of information is distributed around the workforce; if it is a 'point A to point B' situation then it is likely that multiple operators are familiar with the initial inspection stage as well as any later assessment methods. Whereas if it is the 'Stage based' situation then it becomes a much more limited circle of knowledge.

Collection of Methods: A cornerstone of this research investigation is the development of a more comprehensive guide to the various aspects of the inspection stages. Part of that guide will comprise the suitable methods that can be used by the operator. However due to the level of 'red-tape' and sometimes 'bespoke' nature of the assessment tools in question there currently does not exist any catalogue or collection of possible methods and tools. In order to develop a suitable applicable guide to such features the methods in use at various companies will be collected and examined for their relevance and suitability. With the data from multiple sources collected the 'available methods' can be collated to ascertain which are actually available and suited to the tasks in question, including their benefits and limitations. This type of scenario would be ideally placed to aid companies operating with high volume output but low resources.

Verification of assumptions: Through the case study research certain hypotheses were developed. In order to verify the potential validity of these arguments the case analysis findings (the inspector factors seen below) were reviewed by those involved in the Case Studies.

Below can be seen a table with the relevant data collected stated clearly;

Inspection Factor	Effect	Cause
Company Knowledge of "Core"	Familiarity or Unfamiliarity can require the Company to reverse engineer product for OEM specifications, slowing down smaller IR operations.	New type of Core with no initial data. Needs to be obtained from OEM/3rd Party/Reverse Engineering
Knowledge of the Operator "Core"	Lack of familiarity with core type/make/model can require time for learning curve and understanding of main product failure points in aftermarket.	New Core type unfamiliar to the operator or the wider company.
Unstructured Training practices "Watch & Learn"	Bias and assumption passed on/variability in training and trainee knowledge	Lack of fully structured training methods and knowledge exchange.
Available Technology/Method	Utilisation of less effective technology can lead to increased lead times with newer core and difficulty in remanufacture.	Lack of available descriptor models to detail suitable technology/methods for different types of inspection.
Knowledge of the Operator "Method"	Utilisation of less effective method for core assessment can inaccurately assess core condition, wasting resources.	Lack of available training models to detail suitable use of technology/methods for different types of inspection.
Condition of Core "Contamination"	Previously valuable core now uneconomical to remanufacture	Poor storage or external storage leading to exposure to elements.
Difficulty in Knowledge Exchange	Key data limited to aging workforce.	Lack of available criteria and consensus terms outlining different types of inspection and assessment grading.

Table 10 – Identified Inspector Factors

The data in the above table lists the different “Factors” that can hinder inspection activities from being as successful as possible. As can been seen a common pattern emerges, with a lack of structure and the lack of availability of guidance in the area of inspection procedures which contribute to the cause.

In particular several of the “causes” for these detrimental factors could be alleviated through more accessible clear data regarding best practice for inspection activities in remanufacturing. Factors such as “*Company Knowledge of Core*” and “*Knowledge of the Operator – Core*” are features that many remanufacturers experience as part of their business development. When a remanufacturer is faced with new models or types of core it can be difficult to obtain the OEM specifications needed for remanufacture. Outsourcing this problem to technical consultancies, 3rd parties or in some cases reverse engineering in house can all become common practice. Likewise when an inspector is faced with new core this lack of familiarity with the new piece can create issues where new procedures or approaches are required in order to assess the core as effectively as possible.

By providing an overarching structure to inspection within automotive remanufacturing inspectors faced with this type of problem would have clearly laid strategies and routes to fall back upon. Similarly as seen with “*Knowledge of the Operator – Method*” and “*Available Technology*” the introduction of new methods to enhance current inspection activities can lead to uncertainty and inefficiency in this area. But before the technology can even be introduced into the company operation it is vital to ascertain what new methods *should* be introduced, in other words what new technologies are required to ensure the long term success of the company.

The need for new technologies among remanufacturers in order to keep up with the newer models of products being produced has likewise increased. While one of the noted activities for increase has been *disassembly* this need for new approaches has also carried over to *inspection*. In particular parts with ever increasing geometries and unique shapes require more effective and adaptable measuring techniques that traditional assessment struggles to keep up with. New material compositions and increasing high pressure during functional lifecycle have resulted in core with greater ‘wear’ and ‘cracking’ than previously observed. To counter this advanced manufacturing technology such as additive manufacture has begun to gain greater prominence as a more widespread option for remanufacturers. The main obstacle in these new methods is the difficulty that many companies face when identifying which are suitable for their own remanufacturing operation, as well as which may be useful in future work with more varying core.

The “Factors” affecting inspection have shown that there is a strong need for easily accessible information regarding inspection, and structure to aid in developing best practice for inspection activities. This type of structure would aid remanufacturers currently operating in the field who simply wish to streamline their activities or perhaps expand their operation, as well as companies wishing to set up in automotive remanufacturing and seeking guidance for successful inspection.

5.2 Hypotheses based on Case Study Data

From the literature review and early data gathered a number of hypotheses had been formed, each of these hypotheses was based on the predicted state of inspection activities within the automotive remanufacturing sector. This was a vital aspect of the research as the hard primary data of the case studies would either validate and further refine the initial thoughts of the researcher or force the research to adapt to real world data and form new more developed hypotheses.

The first hypothesis concerned the core inspection procedures. From the literature studies it was widely accepted that inspection practices were a vital feature of the remanufacturing operation. In fact in many cases it could be argued that it is the most vital to the core gaining remanufactured status and new warranty. The knowledge gap in the literature was the actual hands-on practices and procedures of inspection, what the inspectors themselves have to do and in what order, to achieve successful core assessment.

When undertaking the case studies the first hypothesis that the researcher held was that "*inspection assessment procedures are well documented but often unique to each company (due to in-house development in many cases). Therefore, the first stage to fill the knowledge gap is to identify the different structured formats each company uses*". However this initial hypothesis was proven wrong, since case study data at companies A & B showed that inspection assessment practices (particularly actual decision based assessment of parts) were conducted based on personal knowledge and expertise gained through long term experience. From literature on previous studies undertaken in the field it was understood that the inspectors knowledge and skill played a significant part towards the efficiency and effectiveness of the activity. However to find it relied upon to such an extent showed an even greater need for a more structured aid. Perhaps an even larger issue was that semi-structured interviews with staff revealed that within the same company different inspectors would have different views on the potential success of a core, based on their own tacit opinion. Further studies in companies C – E showed that despite the size and set up of the remanufacturer this issue was still present.

Likewise training practices at these companies displayed clear structure for remanufacturing activities such as disassembly, cleaning, and even the use of some key technology for inspection but could offer no substance on the area of decision making and product evaluation from a visual perspective. The use of a "Watch and Learn" approach to inspection decision-making led to the varying views held by inspectors at the same company.

The first hypothesis adapted to this new information to become "*a new approach for damage assessment, structured training and knowledge share is needed*". This formed the basis for the development of the **Damage Assessment Tracking Form Criteria** (DATF Criteria), which uses grading criteria and a weighted value system to more clearly differentiate the types of damage identified and to what extent they are present. Additionally the DATF Criteria gathers the data submitted by the user to allow for cross referencing, making trends in common damage or poor core storage much clearer to see. Its break down of the main forms of damage and their criteria based scale of "Bad" to "Good" acts as a reference tool for improved training practices within remanufacturing.

This new data regarding the inspection set up at the real world facilities factored into the **Remanufacturing and Process Inspection Database** (RaPID) model, which was developed to provide an outline of the possible paths the inspector can follow to successfully assess core. This is an extension of the revised hypothesis and the need for more effective knowledge sharing between inspectors. When undertaking the case studies it became apparent that each company knew which paths to follow to take core through its inspection stage but they had little knowledge of alternative routes out with their current set-up. Issues arose when new staff or new core models were introduced into the scenario with less experienced staff becoming very unsure when faced with different defects. Likewise experienced staff faced with new types of core found the learning curve to adapt a greater obstacle than expected.

The RaPID can showcase easy to follow routes for these inspectors to take, easily noting which issues they face and which suitable path leads to the necessary solution. This model works in conjunction with the DATF Criteria as a training tool for new staff.

The second hypothesis concerned the technology used by inspectors. From the available literature the technology and methods used to undertake core inspection were very dependent on the sector of remanufacturing in question and the type of core being tackled. This hypothesis was then "*new inspection technology is required for successful company growth and expansion. Therefore the question of* ***how*** *these companies identify suitable new methods is an essential aspect of inspection activities*."

This hypothesis was proven true with managers and engineers at all levels agreeing with the statement and in some cases providing examples of the introduction of new technology and the obstacles on integrating it into the existing setup. As speculated in the literature remanufacturers often develop their own ‘tools’ for tackling core in house and many of these are unique to the company and sometimes the inspector. Company C confirmed that in their case new technology to aid magnification for parts identification (a time issue for them) was introduced in recent years, only for it to be overlooked or disregarded by the more experienced staff that found this new method awkward, ineffective and time consuming. Companies A and E expressed similar examples.

So one barrier discovered to the implementation of any new technologies to improve inspection was the acceptance by the existing staff. During semi-structured interviews the reason for this lack of acceptance was narrowed down to the new method not being viewed as an actual improvement. The decision of “how” companies decide on which technology is suitable for them was found to depend on a number of factors such as the information available in the remanufacturing field, analysis of the current inspection technology in manufacturing, and educated guesswork on the pat of the remanufacturer.

These results gave rise to the **Pyramid of Methods** (PoM); a two-part model designed to provide inspectors and managers with a comprehensive view of available methods and a detailed layout to follow to identify which method is most suited for the company’s needs. Part one of the PoM is a visual pyramid structure that breaks down the major inspection technologies at use within the automotive field into a series of levels. The pyramid provides a base structure for basic visual inspection and then rises in complexity as the needs for advanced material analysis, magnification equipment, and computer aided measuring increases. The second part includes an extensive database that clearly labels the benefits and limitations of each method as well as its main suitability for different inspection practices, and then provides step-by-step instructions on the operation of each type of technology.

Due to the hesitation that companies may feel in adopting as extensive a new approach to inspection as the DATF Criteria, RaPID and PoM propose, the Internal Inspection Comparison Evaluation Analysis (IICEA) was designed to aid in this situation. The IICEA allows the company to first assess the effectiveness and efficiency of its current inspection practices and then compare the results of later assessments when using one or more features of the DATF models. This can be conducted in isolation from the rest of the remanufacturing activities, allowing for the daily operations to remain undisturbed. Managers can then contrast the results and observe whether any improvement in the overall inspection activities encourage full-scale uptake of the DATF.

5.3 Summary of Chapter 5

In this chapter the key factors observed to affect successful inspection and cause issue within the area of automotive remanufacturing were stated. These factors were derived from analysis and investigation of the case studies in chapter 4. These factors then either proved or disproved the researchers initial hypothesis. After adjusting the hypothesis where appropriate the researcher was then able to develop four models that can be used separately or in combination with each other in order to combat the identified inspection factors.

CHAPTER 6 – DEVELOPING THE DATF MODELS:

6.1 Introduction

This chapter is focused on the development of the Damage Assessment Tracking Form (DATF) models produced during this research. Many avenues of research and potential solutions were investigated, each area of research helping build the foundation for the DATF format and the communication of its data.

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As noted in Chapter 2 the knowledge gap identified primarily dealt with the methods and procedures of inspection and the need for greater structure. Further primary data from the case studies showed that the typical inspection activities were less defined than previously believed or indicated in existing literature (Errington 2009; Ridley and Ijomah 2015). Observational data and interviews with operators further highlighted a new issue; a reliance on personal experience and tacit knowledge of long-term inspectors had become a crutch. This problem was further explored across multiple case studies across the automotive remanufacturing sector in order to ascertain how widespread this issue had become. It was discovered that this existing set-up of reliance on such a small pool of knowledge was very prevalent, this scenario functions effectively enough for the current success of the company but it has no long-term viability as difficulties in knowledge share and an aging workforce become more dominant (Calo 2008; DeLong et al. 2004).

6.2 Modeling

This over-reliance on a small percentage of staff can have negative consequences for a remanufacturing organisation if suitably objective knowledge sharing methods are not in place to allow vital and relevant data to be communicated between experienced and inexperienced staff without inherent assumptions or bias.

In independent companies this form of bias can be carried over when the '*watch and learn'* method is used to train new staff to the operation, this can be a more common problem for sectors still operating at Industry 2.0 standards with a significant amount of unskilled labour as new staff (Piva, Santarelli, and Vivarelli 2005; Zwick 2006). With the awareness of this over-reliance on personal experience and the difficulties of communicating the key points of inspection to new staff, the idea of a more structured model incorporating objective communication and a more structured breakdown of all inspection options began to form.

That thought of utilising model(s) as the potential final output remained in the background as the research continued. After several case studies across the sector the initial assumptions about this lack of structure and overreliance on tacit experience had been corroborated and expanded upon. The availability of information regarding the varied activities of successful and effective inspection used during remanufacturing operations appeared to be the point from which many of the identified problems arose. Even within larger scale OEM companies with access to both the products original technical specifications and the manufacturing processes, identifying and disseminating the suitable inspection methods is a difficult task (Seitz and Wells 2006; Abdulrahman et al. 2015). As observed in the smaller remanufacturing organisations the task of actual parts inspection typically becomes the purview of a few skilled operators. However, the availability of more accurate inspection technology within these larger companies (OEM and Contract) do allow for operator knowledge to be counterpointed with the available data derived from these more quantifiable tools. The main obstacle lies in committing time and resources to ascertaining the more suitable set of methods for core inspection at the facility in question. Additionally, while this scenario can occur and allow the company to internally develop and refine their own inspection activities the wider sector remains isolated from this knowledge.

At this stage the concept of reviewing a particular subset of modeling methods, particularly maturity modeling, for use in this research took hold. Maturity modeling (MM) involves producing a model that can display the key characteristics and factors present in a company as it moves through its traditional life cycle (Underwood and Dillon 2004; de Bruin and Rosemann 2005). In terms of companies (either large or small) this type of lifecycle can be measured in decades. However, an effective maturity model can display each of the stages that a company may go through during that time as well as the level of significant factors that should be present within the company at that specific stage. This 'range' displaying the stage of the lifecycle that the company is at is referred to as a **Maturity range**; each specific stage shows a significant level of maturity and development that a company has either reached or that it could reach if the relevant criteria is detailed (Mani, Lyons, and Sriram 2010).

According to **Röglinger** there are 3 distinct types of maturity model or MM, these can treated as individual entities or as life stages of an evolving model (Röglinger et al.2012).

Descriptive: A model with the purpose of self-analysis allowing organisations to identify where they fall on a Maturity Range.

Prescriptive: A model providing paths allowing for improvement for said organisations.

Comparative: A maturity model serves a comparative purpose of use if it allows for internal or external benchmarking.

A descriptive model can be considered the most basic form of maturity modeling, it displays the maturity range as described above and allows for a company to self-analyse using the established criteria in order to determine where they fall on the range of maturity stages. The key benefit to this type of model is to allow a company to in effect 'rank' itself and gain greater self-awareness of the company presence within the sector. If a company was to find that they were not at a stage they desired then there is now greater incentive to aim higher and push themselves to reach the maturity stage desired. In addition it can also present suitable information for a company to realise that their position on the maturity range is potentially higher than where they are actually equipped to be, in terms of both resources and long-term planning.

Following this is the prescriptive model; acting in a similar vein to the previous section the prescriptive model builds upon the maturity range described and detailed within the descriptive aspect. Where the descriptive model details the specific maturity stages as well as their inherent characteristics the *prescriptive* side details the routes and paths that may be followed in order to move between the maturity stages. This can lead to improvements across overall company performance and aid in the removal of ineffective aspects that may yet be hindering greater success (Röglinger and Pöppelbuß 2011; de Bruin and Rosemann 2005). This model is of particular relevance to those using the descriptive model, since any desire to improve the company in terms of its place within the maturity range can only be successfully achieved through the use of a suitable prescriptive mutuality model.

Comparative modeling allows for companies to examine where they are within the maturity range and also in comparison to other companies existing within the sector. This model can be primarily used for both internal and external benchmarking.

At this stage in the research adapting a maturity model for the purposes of investigation was considered and further work towards this end took place as the project moved through its next stages.

However, as the research continued it became clear that the MM would not be as suitable for this work as first expected. Previous literature within the field has attempted to provide greater context regarding inspection operations within remanufacturing, however, much of this work has either occurred at a very generic level or has involved the approach of attempting to provide more economical routes for traditional assessment to follow (Errington 2009). This type of research when conducted has been highly focused on the experience of a single company and while the output may provide improvements to said company their applicability to the wiser sector remains an unknown quantity (Ridley and Ijomah 2015).

6.3 Development of overall Model:

In order to provide a true MM for the inspection greater detail would first be required within the sector itself. The main issue regarding gathering an overview of the inspection methods within remanufacturing companies, particularly the automotive sector, is the level of 'IP' or confidentiality used to maintain any existing edge they have within the market (Hartwell and Marco 2016). This type of scenario can greatly benefit the individual company but it does bring a level of detriment to the sector as a whole. With remanufacturing awareness on the rise, greater investment and new focus as the world culture attempts to shift to a more sustainable mind-set, new companies are entering the field at an increased rate (Zero Waste Scotland 2015; Guidat et al. 2015). Previously uninterested OEMs are now taking a more prominent role in the sector and new independents are starting out. (Ellen MacArthur Foundation 2013). Politically with issues such as core availability and parts availability due to Britain's exit from the European Union the longevity of these companies within the market may not be as stable as previously believed. Decreased access to necessary resources may lead to a much more competitive sector in the near future; independent companies and contractors especially may feel this increased competitiveness more directly. Despite increased awareness of the falsehoods that exist surrounding the poor perception of remanufactured products by the public the OEM brand is still trusted to a much higher extent than others (Watson 2008). Any potential variation in high quality output from the other company types may signal a decreased reputation and return to poor perception within the sector from associated companies due to the increased focus on maintaining relevance and profitability within a rapidly changing sector.

As such it was decided that the model out of this work would have to incorporate both the methods and procedures that may be used within assessment methods and provide a much clearer and more in depth structure to the types of damage that the assessment is targeting.

6.4 Development of DATF Model (Singular)

At this stage the as unformed model was given a set of 'factors' that it had to address through its usage within the industry. In order to build a successful and effective model the key points were kept at the forefront of the development.

These key points included;

1. Purpose: To provide a structured breakdown of Inspection activities
2. Training: Used in training to provide common points of reference for all inspectors.
3. Primary User: Staff dealing directly with Inspection
4. Efficiency: Model usage should be an easy process, since disruption of the remanufacturing process can lead to significant delays.

The model's main user in real-world scenarios would typically be at operator level; those staff working at the most hands-on area of the company operation. As such it had to be designed with this in mind, since the model could involve a deeper level of detail without substantial explanation of surrounding factors due to the familiarity of the user with the current operations of this area (assessment/inspection). Suggested methods or approaches by the model would be viewed with the benefit of basic foundation of experience and knowledge to draw on.

The model would be used more significantly in initial knowledge transfer and training purposes than during the typical day-to-day operation. The new knowledge/approaches presented by the model would involve a thorough 'run-through' of all model features in a form of 'training session' in order to familiarise the user with the proposed layout and practices of the new model. After this initial stage the daily operation would utilise the new approaches/methods in a much more subdued manner now that the core points of the data have already been understood.

The typical assessment/inspection operations like most of the remanufacturing process rely on effective operation within a reasonable time constraint. Speed is a very important factor due to the level of core and parts that move through a facility during a standard day (Guide 2000; Ketzenberg et al. 2003). With this relevant factor in mind the model would aim to be relatively easy-to-use with minimal time required for usage in daily operation. Post-training with the more detailed version of the full model the user should have sufficient information and data to utilise its key points with little need for further reference.

Relevant data and knowledge transfer between either experiences from the company itself or an external source such as the inherent model data is the prime purpose of the model. The purpose of the entire model is to provide a suitable solution to combat the issues discovered during the earlier sections of the research. As such the model will convey the most vital information in as straightforward a manner as possible, supplementary information regarding clarification of initial points or other relevant factors will be showcased for further reference for the user.

These factors defined a certain set of limitations and boundaries that the model could be built between, this was an important point due to the ease with which a research project of this kind can become so focused on the varying issues and counter issues affecting the field that in the aim to find a effective solution for all the proposed solution crumbles under its own weight. It is also important to note that while the proposed model aims to target several issues facing operators within the automotive assessment aspect of the field the initial assumptions and investigation chapters displayed the connection that these issues have to each other. Following this direction the proved model aims to combat the core issues from several angles (with these angles being the issues discussed).

The main justification for the DATF model being comprised of 4 parts was due to its overall evolution An clearly defined guide to 'damage conditions' for automotive parts and to act as a reference tool was the driving focus moving forward, however as this aspect developed it also became clear that it would be necessary to also lay out the stages involved in automotive parts inspection. Without such a step-by-step layout the DATF Criteria model would be of less use, this accompanying guide focused on providing each step of the various inspection stages and detailing the needed technology at each stage. However the model rapidly grew in size and complexity which necessitated its separation into two distinct parts;

- The RaPID to clearly display the stages of inspection and the various paths and steps that might be taken and in what order.
- The POM, which detailed all available technology and built a tiered system of progress for inexperienced inspectors to follow.

Once these 3 parts of the DATF models had developed the larger scale of the DATF information required an additional tool, in this case a form of self assessment to allow DATF users to evaluate their own inspection procedures and then compare and contrast with implantation of aspect of the DATF in order to determine increased efficiency or effectiveness.

6.4.1 DATF (Primary)

The proposed model now had key aspects to provide limitations and focus to the overall structure. The results of the case studies showing the real-world conditions faced by operators within the field at a variety of levels in terms of company structure, hierarchy and available resources.

The first stage in the model development involved identifying the 'core' issue that many of the others stemmed from. This issue was clarified as the suitable definition of part/core condition during varying stages of its lifecycle and aftermarket treatment. In other words a more quantifiable and structured record of the different states the parts could be in, providing an effective classification method other than remanufacturable or unremanufacturable. Following this the model core would then present the user with a more structured and less pure opinion based system for cataloguing the condition of incoming parts and core. This in turn would have a knock-on effect in terms of both training methods within the company structure but also the links between part condition and processing actions carried out before core rebuild. However, such a classification criteria when developed would have to be detailed enough to clearly differentiate each classification, but also leave enough room for some opinion to weigh in on the decision allowing for a much smaller range of classifications than might otherwise be required.

Time is a significant factor in a hands-on factory style based operation. Like many previous manufacturing operations the requirement of individuals to act as both process operators and transport between operational stages creates a distinct need for a highly organised and reliable workforce with lead times reduced to both a reasonably fast but also consistent speed. When considering the implementation of factors such as models (which may require interaction or paperwork) into daily operations, it is vital to anticipate how it may affect the operations activities. Questions such as "*Will it disrupt the operations lead times*?", "*Will it involve significant time to complete?*", and "*Will it be used at the end of every shift or each activity?*" needed to be addressed. In order to ensure these questions were suitably answered each version of the sub-models (DATF Criteria, RaPID, POM, IICEA) were simulated during typical. This allowed the researcher to gauge how their introduction into the existing processes could disrupt sequential remanufacturing task and add additional time constraints. This work was conducted alongside staff at the case study companies to ensure all theoretical scenarios matched up with real world remanufacturing conditions.

A desired feature of the DATF models was to reduce the time required to either consult or interact with them, allowing the user to be as quick as possible. The stage of the operation that DATF is mainly utilised (Parts inspection) is not one that is highly conductive to an extensive review of data or slow plodding through data heavy workbooks. Therefore if a model is to be effective in this aspect of the field it has be able to 'fit' into the rather ill defined operations that take place without significant disruption. In addition, if interaction is required then the leass intensive the interaction (extensive writing or paperwork) the more likely it will be adopted by those actively working in these areas.

With these relevant factors in mind the use of 'checklists' for the presentation of any comparison model developed was decided as the most effective means of data communication and interaction. Pre-defined criteria and sets of responses allow the user to either 'tick', 'circle' or 'block out' the relevant points in seconds so that a full and detailed response can be garnered with little excess time or effort on the users part.

6.4.2 DATF (Secondary) PART & CORE Comparison

An additional use for the DATF criteria involved the storage methods used on new core before it enters the remanufacturing operation. This has a direct impact on inspection, as any detrimental degrading of core occurring while in storage is a loss to the company. This is particularly true if stored core is then later deemed unfeasible or uneconomical to use during assessment stages. This issue was discussed with operators at facilities that utilised external storage methods (a typical norm for the industry due to the often highly variable level of incoming core) and it was noted that there does exist an awareness that this may be an existing issue. However, with no means to monitor or record the condition (in a swift and suitable manner) the problem has yet to be thoroughly investigated.

This factor was kept in mind as the DATF evolved and as the DATF criteria section was created, a slightly modified version of the 'grading sheet' was developed that allowed users to quickly and easily note the perceived condition of the core as it arrived from the suppliers. The company could then 're-assess' the same core after its storage period to record and observe any further damage.
This aspect was developed as a supplementary aspect of the standard DATF model and can easily be utilised independently of the rest of the DATF model itself and the associated sub-models.

6.5 Development of RaPID Model

In earlier sections of the thesis the literature was reviewed extensively to provide a comprehensive understanding of both the automotive remanufacturing field and the focus of inspection activities. A number of vital papers were identified which form the cornerstone of the existing consensus on inspection methods. One of these papers provided a generic overview of the inspection process, as it occurs across remanufacturing. While this particular output was a valuable addition to the existing knowledge its applicability at an operational level was somewhat lessened in part by its generic nature and lack of applicability at a more hands on level. The overview also only provided some of the key actions that should be taken rather than expanding further to display the truly 'hands-on' procedures that are more often at use within real world conditions.

During the early case study research the factors such as over-reliance on tacit opinion and personal experience was noted and further detailed. However while the focus of the models so far has been firmly routed in the methods and procedures involved in inspection activities and attempts to provide criteria the actual ‘routes’ that an operator may take during each inspection stage remained largely undocumented. This logically became the next key factor for further development in the DATF.

The RaPID (Remanufacturing and Processing Inspection Database) model was based off this concept; detailing the various inspection routes that can occur in the typical automotive remanufacturing process. The studies used to collect the data were conducted across 5 companies with comparisons to any existing academic data being used as cross-reference. This data analysis was used to firstly build the individual stages of inspection that occur within the remanufacturing operation, and then where they fall within the other processes. After this each stage was mapped out with the methods and decisions involved included (based on a YES/NO decision matrix). Depending on the level of technology and the advanced methods involved the routes of the process can alter, however, each path has been designed for the user to follow easily and visualize clearly. Clear colour coding showcasing the ‘Yes’ and ‘No’ decisions has been used and while the overall RaPID model can appear somewhat extensive by separating it into its component stages the processes become much easier to both visualise and understand. The aim of the RaPID is to be used primarily as a training tool providing new unskilled operators in the area with the understanding of the available route based paths that can be followed as well as a tool for those already working in the area if the overall operation is changed or altered by the implementation or adaptation of new technologies or methods.

6.6 Development of POM Model

The POM model (what does POM stand for?) forms a significant section of the overall DATF model(s) and from the outset of the development of both the DATF criteria and the RaPID it has remained a key factor. While the DATF provided categorisation and structure to the actually physical forms of damage that may be encountered by the operator the methods/procedures that can be used in order to assess such damage was as of yet undocumented or undetailed to any significant extent within the existing model. As such in order to provide a comprehensive model to all aspects of inspection within the remanufacturing process a suitable model had to be developed to target this area. Case studies A – E in addition to the data already gathered during the literature review phase had generated a significant range of varying methods and techniques at use within the automotive inspection operations. Some of these methods involved highly complex and expensive technology while others typically required very experienced staff (visual inspection). These methods from a technical standpoint utilised equipment ad tools that are applicable to a variety of other industrial sectors and their suitability for remanufacturing proposes originates more from the overlap in original manufacturing procedures than any specialised tool for the aftermarket operations.

The POM was designed to take these varying methods at work and display them in such a manner that a relative novice within the industry (with basic experience and understanding) would be able to utilise the data presented to assess the viability of a particular method for a core/part inspection procedure with little issue. The overall aim of this model was to provide a highly structured and fully developed breakdown of each possible inspection method, including factors such as the benefits and limitations of each method, its applicability in terms of materials or parts and the typical procedure steps in order to complete a successful operation. This was achieved through extensive review of each method selected, the relevant data was then collated from several sources and a relatively straightforward and simplified version of the data was then presented. In the cases of the more niche methods (such as those found in basic inspection) these were developed almost entirely through the analysis gathered in the case studies from real-world conditions.

At this stage the different inspection methods had to sorted into some suitable format, preferably with the most common and basic methods at the bottom and then rising in complexity. With this concept in mind the POM visual model was developed, which ranked the various methods within 5 levels, with each level becoming generally more complex and impartial as the user ascended through the model. A noted aspect during this development phase involved the lower levels more basic inspection methods also being some of the more opinion heavy and knowledge rover-reliant methods from those selected. The general trend of the POM Visual model (at this point with the Pyramid shape designed) then was decided with the level of reliance on personal experience and tacit knowledge being much more involved and essential at the bottom of the pyramid with the lower levels and as the user ascended the methods and techniques this reliance on personal opinion diminishes as the more complex methods and impartial data becomes available.

6.7 Development of IICEA Model

The development of the Internal Inspection Comparison Evaluation Analysis (IICEA) arose from the complexity and scale of the previous models. Each particular model aspect of the DATF Criteria, POM and RaPID has been designed to target a specific area of the assessment process that occurs in remanufacturing operations. From providing a more structured and less opinion based approach to the categorisation of perceived damage to the steps involved in the inspection process from start to finish.

While these models have been designed with the aim of improving both the efficiency and effectiveness of the processes involved no actual method had yet been detailed as to how the company utilising this knowledge would be able to observe its effects (apart from a potentially cumulative improvement on time or general efficiency). During the initial development stages the scale of data being communicated to the user was an unknown quantity and it was hoped that the use of highly visual mediums may yet become a predominant feature. However, as each model progressed it became apparent that while visual representations played a key part in understanding the model purposes in an effective manner, the core body would contain a significant amount of data. In particular the DATF and the POM utilise a much more data-heavy presentation than the RaPID.

Due to this aspect of the models becoming predominate as they developed the need for some form of specialised ‘self-assessment’ grew, with the aim of this model being the ability for companies utilising other aspects of the DATF model(s) to more accurately analyse and observe the results of any changes in terms of effectiveness and efficiency from the perspective of their own core/part assessment procedures (the other models target area). Using some of the same breakdown criteria as observed in the RaPID model the expected inspection stages/procedures were noted and those deemed most relevant to this area detailed for later use. The proposed model was then broken into 2 sections;

Section 1. – This first stage of the model was aimed at assessing the proposed effectiveness of the operator conducting the operation. To achieve this actions that would be necessary for successful inspection were noted, this allowed an external employee or 'observer' to assess which of the required actions had taken place, and to what degree of satisfaction.. In addition, the expected condition or 'characteristics' of the part/core post inspection were noted in order for the observer to detail that all aspects were present.

The reasoning behind this set-up was primarily related to simplicity, the more extensive and complicated the assessment procedure and marking criteria, the less likely that it can be easily utilised within the confines of the standard/expected remanufacturing operation with very little impact of its typical performance. As the self-assessment model is designed to be used by an external 'observer' who follows the operator in question while he/she conducts the inspection operations it is necessary to design it in such a way that the user can both visually observe and make notes very easily. As such the initial part of section 1 is broken into a highly simplistic grading which can be noted with the simple 'circling' or 'underlining' within a matter of seconds, while the second part is a straightforward Y/N mark against the specified characteristic.

This scenario allows the user to assess the *effectiveness* of the operator in question through the overall grading for each stage of the inspection process as well as ensuring that the core reaching the end of assessment meets the required expectations of successful inspection.

Section 2. – The second section details the efficiency assessment basis; as expected in traditional audit's or internal company assessments the efficiency of a company employee often involves the time criteria i.e. how long a specified action actually takes compared to the expected standard of the company. In a similar set-up this model breaks down key stages of the inspection process in order for the external 'observer' to note the time taken for each section of the process to be completed.

The IICEA form first displays the overall inspection stages in a more generic manner, with several of the basic inspection techniques (Visual, Handheld tools etc.) being combined into a single category. In a similar manner the more advanced inspection techniques are stated, with the observer easily noting any action taken to utilise them.

6.8 Summary of Chapter 6:

In conclusion it can be observed from the above chapter that the distinct models of the DATF were developed through considered analysis of the available data, the theoretical assumptions and available facts combined with the suitable identification and chosen direction of the output or solution, which involved what was most beneficial to industry (the key users). This thesis though primarily an academic work was developed with the close aid of industry, allowing for in depth case studies and expert validation when required. As such the development of these new DATF models has been designed to provide benefit to both sides of equation.

Each model has been developed with a target issues foremost in mind, each aspect specifically designed to address a factor within the typical inspection process. Together these models allow the user to apply as much structure and as quantifiable an approach to this operation as has ever been available to the industry at large. At each stage of development these models have been re-considered and re-evaluated to ensure that they match up to both the standards desired as part of the research but also the personal standards of the researcher to ensure both their inherent value and success but also their feasibility for further development post thesis.

CHAPTER 7: APPLICATION OF DATF

7.1 Introduction:

In previous chapters it has been noted that remanufacturing has gained more significant awareness and investment in recent years (European Remanufacturing Network 2016; Zero Waste Scotland 2015). With this increased growth and a cultural push for sustainability, now is the prime time to further refine sector wide guidelines on remanufacturing activities.

The key aspect of the remanufacturing process that is the focus of this thesis is 'inspection', the act of assessing core during remanufacture. Case studies conducted across the UK have yielded first hand data on the issues faced by those operating in this activity, and highlighting the burden on small-medium sized remanufacturers in particular. With the factors negatively affecting inspection identified the next stage in this thesis is the development of new approaches to reduce these problems.

The previous chapter detailed the thought processes and research possibilities explored, including 'Maturity Modeling' and 'Benchmarking' for inspection procedures, however the final output that developed was the DATF Models. These models are designed to reduce current issues and pave the way for further development of inspection procedures in future work.

7.1.1 Purpose of the model:

The purpose of the DATF (Damage Assessment Tracking Form) models is to aid automotive remanufacturing businesses in the further development of their inspection activities. As noted during the case studies A – E there are several issues affecting this stage of the remanufacturing operation (such as difficulty in knowledge sharing and training). The main source of these issues appears to be a lack of common understanding and guidance on the inspection procedures undertaken during the activity. The DATF combats this by providing a series of 4 models (DATF Criteria, RaPID, POM, IICEA) each with a specific role in promoting a more structured approach to inspection.

A visual overview of the DATF model and its parts can be seen below.

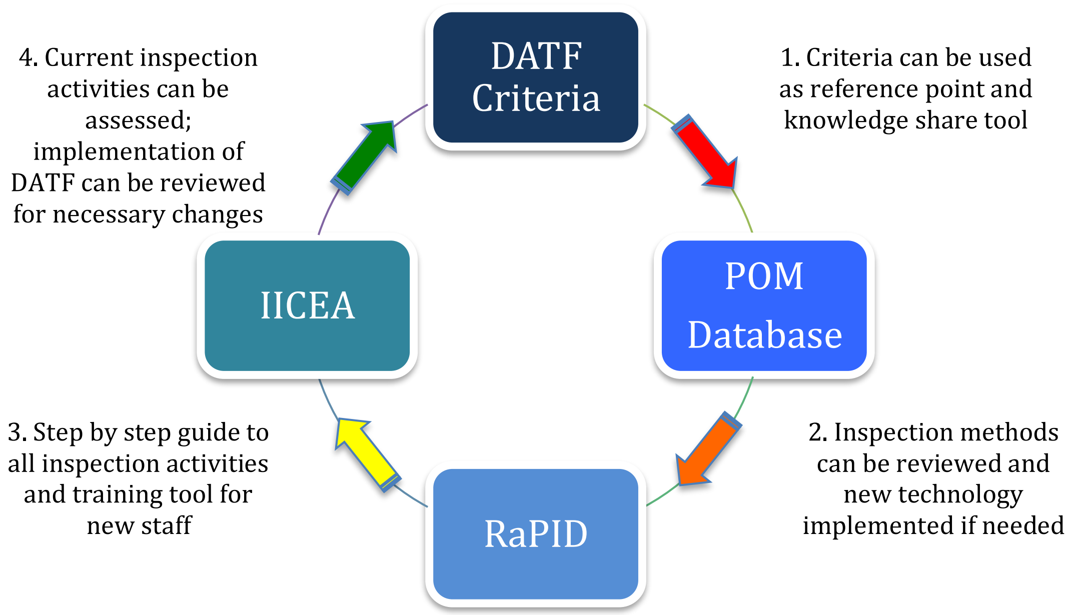


Figure 6 – DATF Overview

7.1.2 Model Damage Justification:

The level of damage present in End-of-Life core varies wildly from piece to piece, some core can end up at a remanufacturing facility with only minimal damage despite a long lifespan. Others can arrive in very poor condition, with a brief overview of the core indicating that serious rework and replacement parts will be needed. How that damage occurs is due to a number of factors, some can be attributed to the manufacturing processes and designs of the OEM, while others are due to the users treatment of the product while in service. Finally the last area of responsibility for the core’s condition is the aftermarket itself, how the suppliers handle and transport the core, and how it is treated once in the possession of the remanufacturer can have a significant effect on its final state.

Below are some of the key causes of damage:

1. First of all is the *age* of the core, depending on the time taken to bring it to the facility in question in addition to its time spent in storage before processing and the original life of the vehicle it was taken from, an incoming core’s age can be very erratic and difficult to judge. The longer it has been active and in use the greater the chance is of it acquiring multiple types of damage as the typical ‘*wear and tear’* of components in an active vehicle.

2. Secondly, is the type of components in question, this includes both the particular part and the manufacturer of said part. Certain components within a core are far more likely to be at risk of acquiring damage due to their proximity to highly active components (pistons, cylinder heads, torque

converters etc.). The increasingly higher pressured engines being designed and manufactured mean that these types of components are now at even greater risk of having a very short lifespan before significant damage than their predecessors. The manufacturers of the parts become relevant at this point as poorer manufacturing methods are typically analogous to poorer output in terms of component structure and reliability and therefore it can be expected that these types of components stand the greatest chance of failing or acquiring significant damage during their active lifetime.

3. The third reason can be the type of storage for the core employed by the company in question; since large quantities of core can be delivered within a short period of time to a remanufacturing facility it can often become the case that the amount of incoming input (core) outstrips the facilities typical processing capabilities within that time. As such the additional or excess core is stored (typically on-site) for what can be an extended period of time. Partly due to the physical size constraints of storing large quantities of core a noted trend observed across several companies is a tendency to store core externally. While this can save huge areas of space within the facility, needed for the daily operations, this method does leave the remaining core at the mercy of the climate.

   Extended periods of time (measured in weeks and months) outside cause the core to become highly vulnerable to degradation and contamination, requiring further rework or expense during core remanufacture that would have been previously unnecessary.

4. The fourth factor is the treatment of the core itself before it arrives at the facility. Since core can come from a variety of dealerships and outsourced companies in order to obtain it the treatment which it receives from these various factions can leave it in a much poorer condition that how it was found.

From the above factors we can see that the typical condition of core can be very difficult to predict, regardless of factors such as '*active lifespan'* or '*original manufacturer'*. The DATF criteria can be used to assess the type of damage found on parts and components and grade them on how severe each type of damage is. With this information the common types of damage may then be plotted to observe if there are common failure points in certain makes and models. This would allow remanufacturers to try and predict likely issues present in core before they reach the facility and also on whether new technologies may be needed in order to improve the current remanufacturing efficiency. (Cai et al. 2014; Teunter and Flapper 2011).

The condition of the core once taken for remanufacturing can be due to factors unrelated to the products previous lifespan and/or its manufacturer and model. However by recording the level of damage and state of core as it enters company hands the operators will be able to compare data with the cores condition post storage. If core condition deteriorates during company storage then the facility in question can make changes if required. The company can then re-examine the results after a period of time and observe whether the previously discovered storage issues have begun to decrease or even dissipate completely.

7.2 DATF Categories:

The reasoning behind the category and grading system at use in the DATF is an attempt to try and create structure and order out of the chaos of a highly qualitative and experience based aspect of the remanufacturing process. As discussed in other sections the inspection process within remanufacturing is a highly qualitative matter with personal experience and tacit knowledge becoming the key tools that are relied upon in these situations. While remanufacturing companies operating for longer have the benefit of practices that have been tested and refined over time, as well as often more experienced staff, newer remanufacturers lack such history to draw upon. As newer entries onto the business landscape of remanufacturing these companies may also be starting out with a very small staff. This can result in the '*personal knowledge'* issues discussed in earlier chapters. As the entire field of remanufacturing is currently experiencing several significant shifts and changes as it evolves it is the prime time to provide more structured guidelines to activities like *inspection* in order to aid these new entities starting out (Golinska and Kawa 2011).

The DATF form splits the damage/condition of the core and parts being assessed into **eight** key categories, these categories were developed based on the data gathered during case studies A-E. Noting the key features that inspectors look for several possible damage types were suggested by the research, these were then taken to each study company and reviewed by staff that then gave further clarification and contribution to the possible forms of damage that may be encountered during inspection. These categories were then further refined until the final 8 shown below became the final output;

- MATERIAL CRACKING: Material cracking is the term that describes the type of damage found in cores where it appears as physical ‘cracks’ and ‘fracturing’ of the surface of some of the core components. Typically found on some of the larger parts and the outer body sections of a core, material cracking can often result from rough handling of the components either during its functional lifespan or during its removal and storage post EoLU This type of damage can widely range in its level of intensity and as such can in some cases be very subtle and difficult to see with the naked eye while on other occasions the ‘cracking’ is highly obvious. The main negative consequence of ‘cracking’ is that this type of damage can signal a weakness in the very structure of the part in question. When damage such as this appears the chances of the same part fracturing or cracking further during testing or its second lifespan increases significantly. Therefore it is highly desirable that any damage such as this is identified easily and effectively, allowing operators to note any necessary rework or needed replacement parts.

- MATERIAL DEFORMATION: This term is used to describe parts or components that have acquired a misshapen or ill formed appearance in their structure. This can be seen as parts in which previously straight and level surfaces are now no longer this shape, or where more complex parts do not adhere to quite the same geometry as expected. This can occur due to high pressure placed upon parts during their functional lifecycle and is an issue that has been noted before in newer automotive designs that are improving the engines ability to increase and sustain high speed while lightening the overall engine weight. This combination has been noted by several operators at remanufacturing facilities as being a key contributing factor to this type of damage.

- MATERIAL WEAR: Wear in these cases is classed as the general reduction and breakdown of features and shapes within a part. In some cases this 'wear; can be as small as the sharp edges of two meeting planes becoming rounded and less defined over time and usage. In other cases it can be the gradual erosion of the material that makes a part until the mechanisms and key features that allow the part to function are no longer operating at peak efficiency. Wear can be considered perhaps the most common of all material damage in that simple general usage of automotive vehicles will often result in a core obtaining wear as it ages purely due to its operational lifespan. The key aim at this point however is to use the DATF to try and examine which parts/components appear more prone to significant wear in order for the operator to anticipate the likely components that require closer examination for this type of damage.

- STRUCTURAL DAMAGE: In addition to the concepts of material damage as described in earlier sections another significant issue is the *structural* integrity of the part in question. During part functional lifespan any component that utilises either fluid transference or pressurised air in its typical operation is at risk of structural damage occurring after prolonged periods. In the case of aftermarket core and part the condition of these components varies significantly due to issues such as transport, handling and storage in addition to the operational conditions. Like some forms of material damage structural issues aren't always readily apparent to pure visual inspection. In order to fully assess the condition of parts in this manner methods such as ‘pressure’ testing are typically required.

- MATERIAL DEGRADATION AND CONTAMINIATION: This type of damage can be a factor that is influenced not only by the core’s functional first life but also by the storage facilities used by the supplier or remanufacturer in question. Poor or open storage of cores can result in exposure to the elements and an increase in the level of contamination found (rust/dirt/growth) within the general core supply. Due to the variable size and quantity of the incoming and stored core at a facility it is known that external storage is an easier and often more inexpensive solution as opposed to internal storage within the facility itself or a purpose built location. The benefits of such a solution present themselves in the fact that they can utilise a wide area of space (externally) without the restrictions that can limit safe storage within a building, altering and modifying the layout as necessary and ensuring easy access to the relevant cores.

  Material degradation does not always pose a substantial problem as sand blasting and various other cleaning methods have proven very successful in the past at removing such impurities and contamination from the core. However it is the level of degradation that can cause the most problems. The longer a core remains contaminated the greater the chance that its structure can become weakened by the spread of such impurities (rust) which even when removed results in a core with weakened sections unsuitable for economical remanufacture.

- BURNT SECTIONS: This type of damage is very isolated and occurs in parts that contain motorised components, either through usage, handling or the cause of failure the motorised components are no longer functional, if this occurs it can be due to the motors themselves burning themselves out. The current and easiest test for inspecting such damage is to try and physically reach the motorised part, turning it and smelling the air, regardless of cleaning the burnt out section typically give off a highly noticeable acrid odour that clearly indicates that the part is no longer viable.

- PART 'MOBILITY': This category more directly addresses the potential 'functionality' of the part if a 'moveable' or 'rotational' section is involved. In these cases the operator can manually manipulate the part in order to both visually and tactilely assess the 'ROM' or Range of Movement present in the part. This action is then evaluated by the '*expected*' or '*specified*' range of movement covered within the technical information available or the knowledge of the operator. In this type of circumstance the component in question can relate to sub-assemblies, where one or more sizeable parts are connected or contain much smaller parts that cannot be removed through disassembly without causing damage to the overall component. In these cases where the purpose of sub-assembly is to allow a ROM between the different sections the ability to evaluate the 'mobility' of this set-up is a valuable stage of parts inspection.

- AESTHETIC: This category is not covered within the descriptive aspect of the grading criteria. Typically a very low priority factor during the treatment of a part or core pre-processing, the aesthetic in terms of the expected appearance of the piece in question only truly becomes relevant in the later stages of the typical remanufacturing process, in order to ensure it meets with the perceived value of the reassembly part in terms of appearance rather than functionality or intrinsic quality of the finished product. However the general appearance of the core or part is a valuable piece of information to be noted, particularly in situations where those with experience and skill may note the general appearance as an indicator of potential issues within. As such the DATF form allows for the user to complete this factor in an attempt to judge and provide any relevant data regarding the aesthetic so that suitable action may be taken at the relevant time (cleaning etc.).

7.2.1 See APPENDIX – D (DATF Criteria Grading Range):

The full criteria for the DATF Criteria Grading Range can be found in Appendix D. The criteria are extensive and cover each of the 8 Damage Categories previously described in 7.2. Each of these categories has a range of 1 – 5, this range can be used to note the severity of the type of damage encountered by the inspector. Use of colour coding of the grading range helps indicate the positive (Undamaged) and negative (Damaged) ends of the spectrum. Grade 1 denotes features that fall under the “Undamaged” section of the category in question, while Grade 5 indicates the

“Damaged” end of the grading. Parts with enough “5’s” across the damage categories are clearly uneconomical and in some cases unfeasible to remanufacture.

Due to the how many different parts, makes and types of ‘core’ that can be encountered across just the automotive sector itself, the decision of where the “uneconomical” line is for remanufacturers remains the purview of the inspector/company in question. Each criteria grade is accompanied with a descriptor; a short statement providing what an inspector may class as “Grade 1,2,3,4,5”. These descriptors aim to cover every possible type of damage a core may possess, and by providing the inspector with a clear cut grading system by which to class different forms of damage, more easily allow knowledge sharing between operators, management and external parties if required.

Training new staff in more experience based activities like inspection can be a difficult task, the DATF Criteria can aid in this task by allowing the more experienced inspector to utlise the Criteria as a reference tool for the different types of damage that the new employee will encounter. By clearly stating each possibility it then becomes a much easier task to detail which procedures or activities should be followed based on the now structured core assessment.

7.2.2 Visual Model Indicator (VMI):

In order to present this information relating to the part in a useful and easily understood manner (from a visual perspective) the design shown below is used. Each of the Damage categories is a point on the model with the different grading present as the levels radiating outward. In this manner the user can quickly and efficiently 'fill out' the model that can then be used for internal company records. In addition due to the highly visual nature of the model the user can then utilise past records for training purposes illustrating where potential parts fall on the category scale, displaying a more recognizable link between the theoretical and the practical than may have previously existed.

Linking to the 'Plot-graph' use of the data recorded from this stage the VMI may also have its data collected and collated to provide a single VMI showing the average score of a single part across 6 months' worth of data. This process can be repeated or modified in many different ways in order to re-assess and judge the changing types and prevalence of each type of damage over varying periods of time, providing indication of design issue or aftermarket handling/company handling etc.

7.2.3 Training Purposes:

While the DATF acts primarily as a method of examining and attempting to predict the level and types of damage found on incoming cores, it also provides a much more structured overview of the damage itself, when training new staff the inspector can utlise the data of the DATF Criteria as a reference tool. Many current remanufacturers have developed their own in-house training, and while it can be very rigorous and structured there is still room to improve. It has been stated during interviews with subjects of Case Studies A – E that experience and personal knowledge are still heavily used to explain and identify the type and levels of damage to the trainee.

Training within remanufacturing facilities can also vary substantially based on the size, setup and type of company. Larger OEM's are far more likely to bring over structure and training methods from the manufacturing side of the business, bringing in staff and trainers to facilitate a better overlap between the two aspects of the company. This can allow a free-flow of information resulting in a more streamlined training scheme to be implemented (lack of reverse engineering or technical alteration needed).

7.3 DATF Criteria Model

7.3.1 Part & Core

As discussed throughout this chapter the DATF Criteria Form functions as both a more structured approach of classifying the forms of damage encountered by the inspector, and also as a reliable record of that data for later use. The plot graph's capacity allowing users to 'map out' the recorded data aids in identifying trends (rising or falling) regarding prevalent forms of damage found across various core. Depending on the level of different products that remanufacturer in questions deals with this recorded data can then be separated out according to make and model. This would allow users to easily note observations, for example that '**2004 Model J Torque Converters**' manufactured by Ford are the type of core in which there is 68% chance of '*wear'* damage to closest inner surface.

DATF SHEET (PART)	DATE:
PART No.	
Part Name:	
Manufacturer:	
Model:	

PART CONDITION CATAGORIES	GRADING – (1 2 3 4 5) +
Material Damage:	
Material Deformation:	
Material Wear:	
Structural Damage:	
Material Degradation & Contamination:	
Burn Damage:	
Part Mobility:	
Aesthetic:	
PASS/FAIL	
ACTION TAKEN	

Table 11 – DATF Criteria Sheet (PART)

From this example the remanufacturer would then know to pay close attention to wear damage in incoming core of this type allowing for streamlining of the inspection activity.

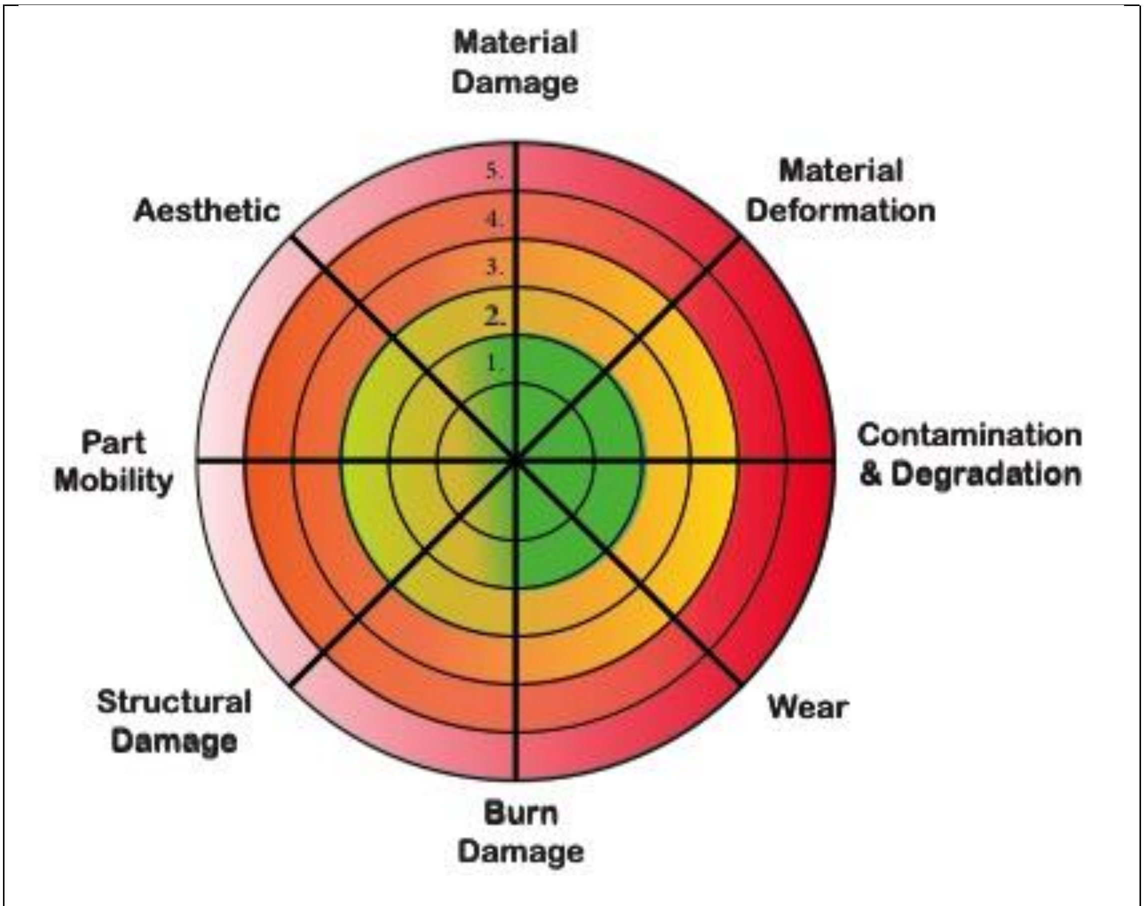


Figure 7 - DATF Criteria Visual Models

An additional aspect of the DATF data being plotted is that it can also be used to assess the condition of core both pre and post company storage. The issue of how much deterioration that occurs during external storage (a norm for remanufacturers due to core volume and available space) is one that is still unknown. With external storage a near necessity for companies with a large turnover this knowledge could prove key in identifying factors such as the maximum time core can be exposed to the elements without suffering significant material degradation. Issues such as the effects of climate, seasons and levels of protective wrapping could all be addressed and given more definitive answers.

The solution to this particular problem is the DATF (CORE), which can be seen below:

DATF SHEET (CORE)	DATE:
CORE No.	
Assembly Name:	
Manufacturer:	
Model:	
PART CONDITION CATAGORIES (EXTERNAL)	GRADING – (1 2 3 4 5) +
Material Damage:	
Material Deformation:	
Material Wear:	
Material Degradation & Contamination:	
Burn Damage:	
Aesthetic:	
ACTION TAKEN (STORAGE)	

Table 12 – DATF Criteria Sheet (CORE)

This details a much smaller set of damage factors and is aimed at these being assessed solely from an external visual standpoint. The aim of this particular format is to provide relevant data that can be cross-referenced at later stages in order to assess how much damage in terms of factors such as 'Contamination & Degradation' occur during the storing of the core at the facility site (damage typically caused through external storage exposed to elements). In this manner the brief but detailed records regarding the condition of core post-storage can be quickly evaluated. Even if the damage caused through extended external storage is small if the records indicate that this is occurring across the board then the potential value saved through internal storage may exceed the cost of creating said storage, in the long term.

7.3.2 Plot-Graph

As discussed during section 7.1 and 7.2.1 the DATF Criteria Grading can be used to assign value to each particular type of damage found in a core. The plot graph is the visual approach used to 'plot' the data recorded from the grading to observe any noticeable trends. The two main aims of the plot graph is to allow users to identify common failure points in certain parts or models, as well as noting any additional deterioration to core during company storage.

At key points of the year (Monthly, Bi-Annually etc.) this data is examined by the management of the company in question in order to observe any identifiable trends in the type of damage found as it relates to common parts and manufacturers. This is the point of the Plot Graphs, they act both as a frame of reference regarding observable trends in core damage, and also allow the inspector to use this information to make a more informed decision of which new technology or methods might be required to maintain effective inspection despite these changing trends. An example of the Plot Graph is use can be seen below:

Example 1:

The below section details an overview of data utilised from the collection of DATF criteria recorded. The example shows the detailed "Grades" for a series of 10 parts of identical make and model that have been recorded during typical inspection processes. This data has now been collated below in order to observe any noticeable trends of commonalities in the condition of incoming core/parts. The data has also been plotted onto a line graph to better observe the results.

DAMAGE/GRADING	PART 0001	PART 0002	PART 003	PART 004	PART 005	PART 006	PART 007	PART 008	PART 009	PART 010
A -DAMAGE: "WEAR"	4	3	2	1	5	2	2	1	5	2
B - DAMAGE: "MATERIAL DEFORMATION"	2	4	4	5	4	1	2	2	4	5
C - DAMAGE: "MATERIAL DAMAGE"	3	1	5	2	4	2	3	2	1	1
D - DAMAGE: "STRUCTURAL DAMAGE"	3	1	4	4	3	3	1	2	4	4
E - DAMAGE: "BURN DAMAGE"	4	2	3	4	1	4	4	5	5	4
F - DAMAGE: "CONTAMINATION"	2	4	2	3	1	2	2	1	2	1
G - DAMAGE: "PART MOBILITY"	2	2	2	1	2	4	5	5	4	3
H - DAMAGE: "AESTHETIC"	2	3	2	3	5	3	2	2	1	2

Table 13 - DATF Criteria Example Data (Grading)

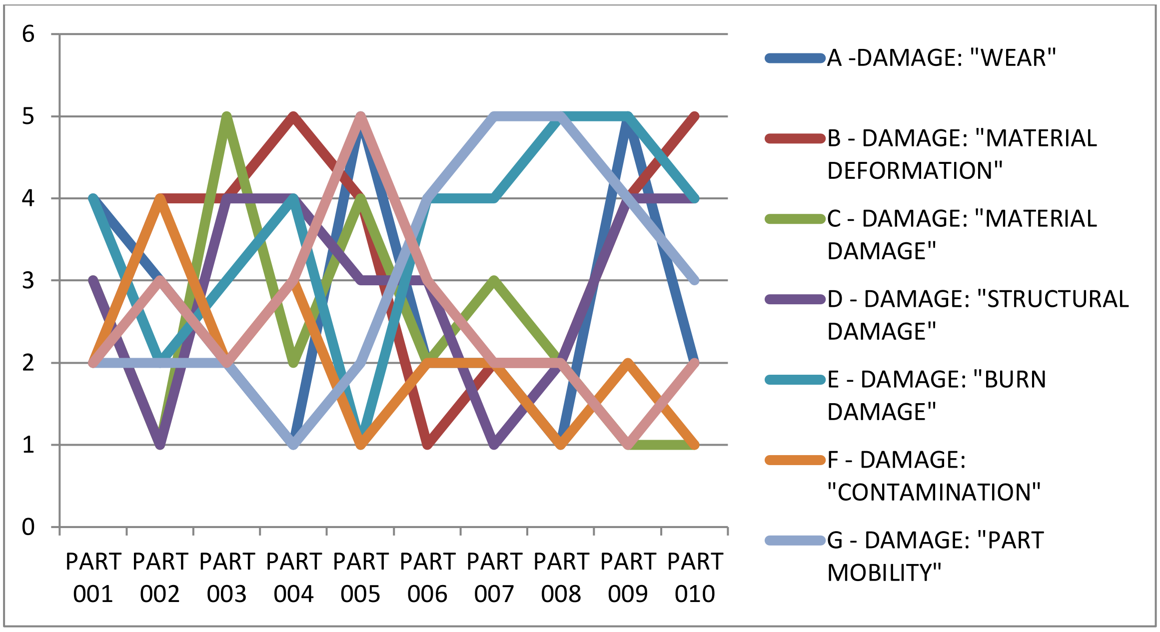


Figure 8 - DATF Criteria Example Data (Plot-Graph)

When presented in plot form the collected information can be very difficult to discern. However when stripped to single factors, as shown below the data is much more easily read:

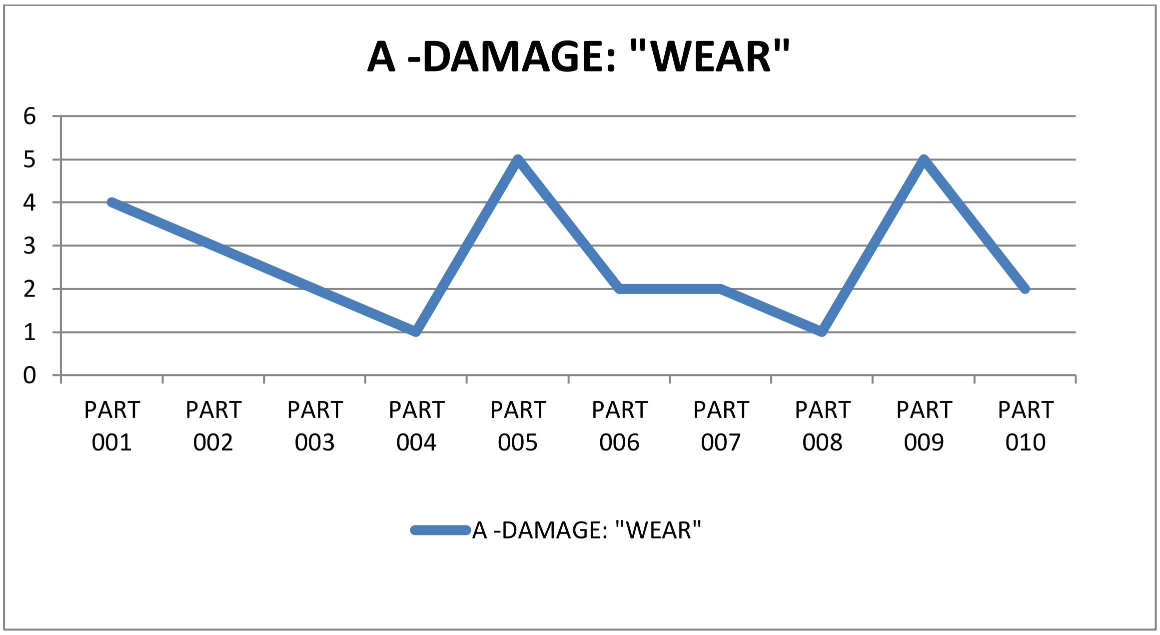


Figure 9 - DATF Criteria Example (Wear)

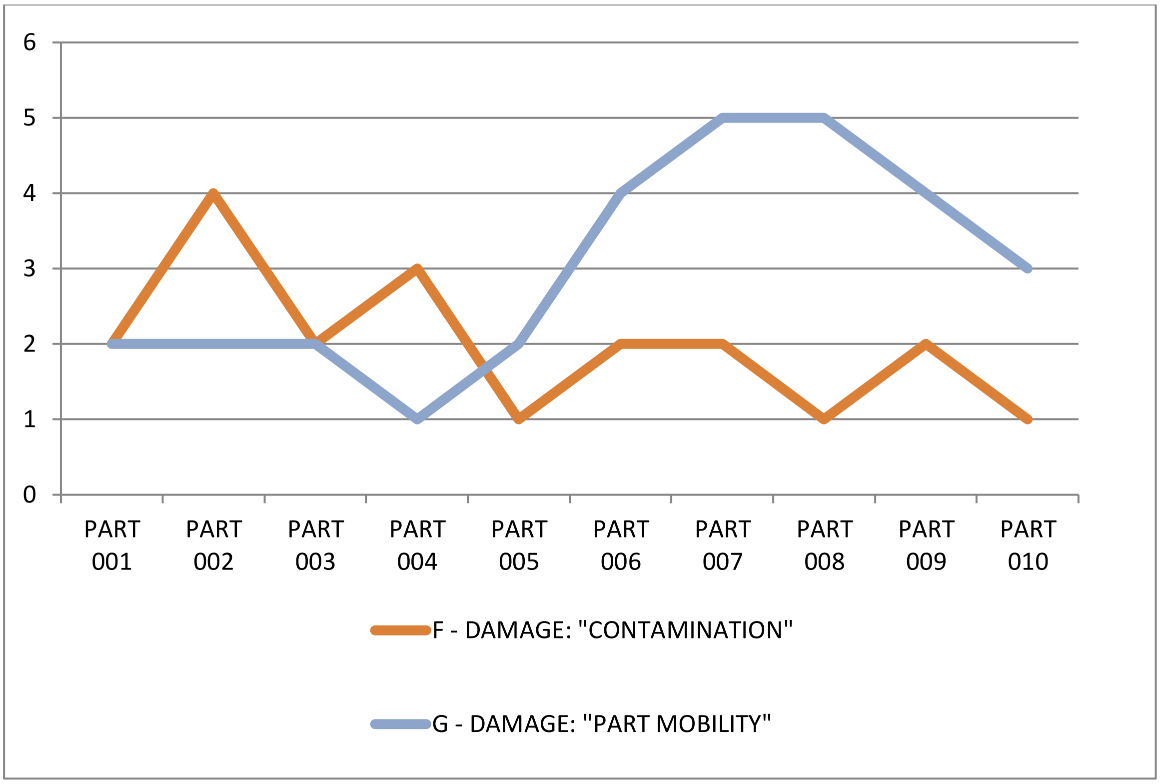


Figure 10 - DATF Criteria Example (Noticeable Trends)

In the above graphic the 'trends' shown are two types of damage selected from those recorded in the first visual. In both of those depicted the beginnings of a potentially observable trend can be seen, with the level of contamination dropping successively as the graph continues. In the context of this work the grade of '1' signifies positive values, in these circumstances then the condition in terms of contamination of the part has reduced and the part had been in very good condition regarding this factor.

Of course this graphic is used merely to display how the DATF data may be used. In real world scenarios the level of data required before noticeable trends in the condition of incoming core would be significantly more substantial. As detailed in the chapter itself it has been suggested that a review conducted every 3 – 4 months would allow for a significant enough range of data to be collected for noticeable trends to be identified.

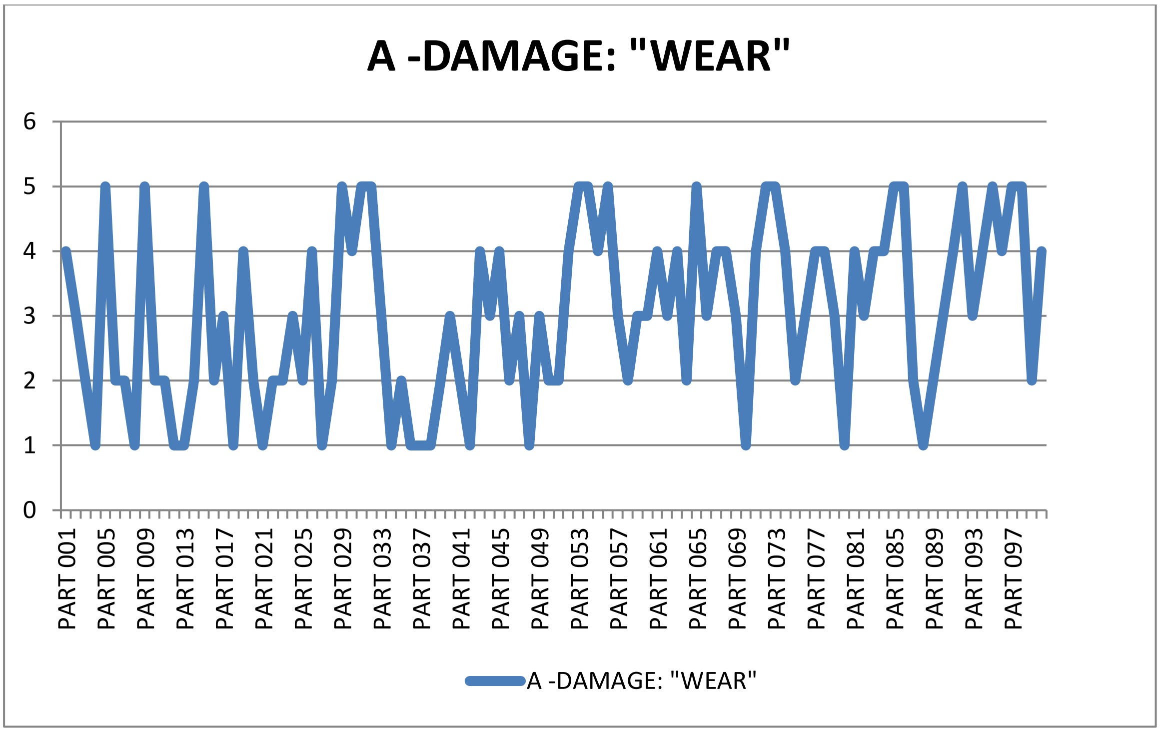


Figure 11 - DATF Criteria Example (Wear - Multiple parts)

This graph depicts a more accurate representation of the data visually displayed, as it would be in real-world conditions. On this scenario the damage category "Wear" has been detailed across a data set of 100 versions of the same part as recorded during daily remanufacturing operations. It can be observed that there is a much higher number of grading's in the 4 & 5 value range as the graph continues over time in comparisons to the beginning. This can signify that in the case of this particular part the likelihood of wear is increasing and that any inspection procedure may want to target this particular form of damage slightly more during assessment stages.

In terms of CORE PLOT GRAPH:

DAMAGE/GRADING (EXTERNAL)	Core 001 (Pre Storage)	Core 001 (Post Storage)	Core 002 (Pre Storage)	Core 002 (Post Storage)
A -DAMAGE: "WEAR"	3	3	2	2
B - DAMAGE: "MATERIAL DEFORMATION"	2	3	4	4
C - DAMAGE: "MATERIAL DAMAGE"	2	2	5	5
E - DAMAGE: "BURN DAMAGE"	1	1	2	2
F - DAMAGE: "CONTAMINATION"	2	4	3	5
H - DAMAGE: "AESTHETIC"	2	3	3	4

Table 14 - DATF Criteria Example (Core pre and post storage grading)

As can be seen above both Core 1 & 2 show slight changes between pre and post storage, most noticeably with damage factors such as contamination and aesthetic most affected. This can be due to the external storage conditions of the core, and its potentially long storage period. This allows weather and environment to add additional pressure and damage to the core during its storage period. These results are also shown on the line graphs below.

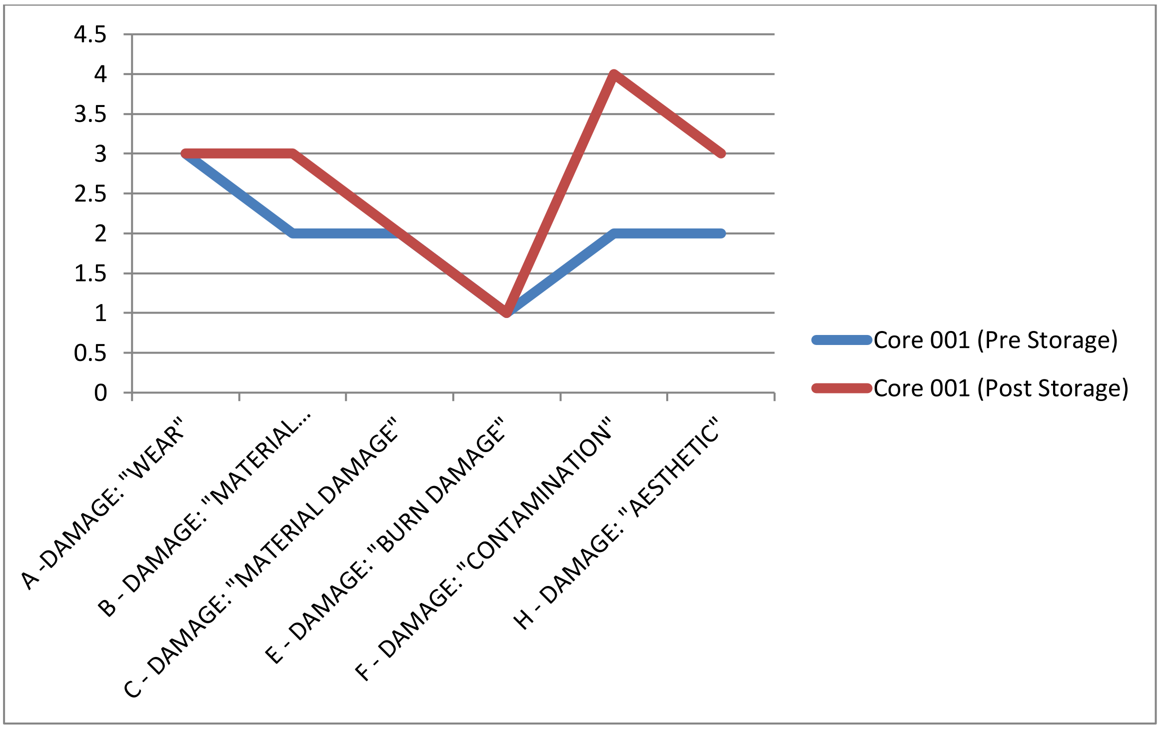


Figure 12 -DATF Criteria Example (Core 001 comparison data)

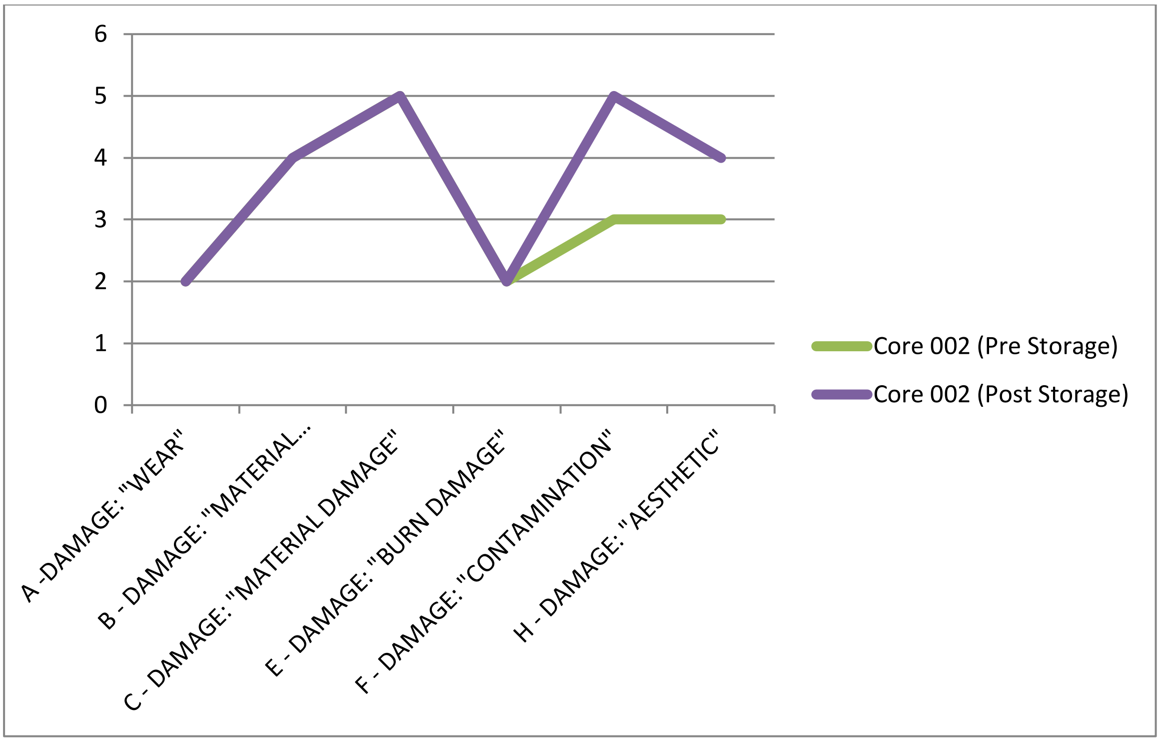


Figure 13- DATF Criteria Example (Core 002 comparison data)

7.3.3 Plot-Trend Analysis – DATF

Discussed in earlier sections of this overall chapter the idea of using the levels of damage identified during the inspection process to try and predict the condition of incoming parts/core is a key aspect of the DATF model. The core idea of the DATF is the concept that by gathering data from parts as they are assessed by company personnel can be used to analyse and estimate what condition they may be in when they arrive at the facility. The main assumed benefit of such a set-up is that if a reasonable percentage of the incoming core adheres to the predictions then the operators at said facility will have an advantage over those without such knowledge, leading them to become more efficient at their inspection operations as they already have a probable idea as the main issues of failure that need to be addressed.

This concept operates on an assumption this is true, however this assumption is based on reasonable hypothesis and observable fact; within the remanufacturing sector it has been stated at many points that ‘core is king’ as any company operating within the field requires sizeable, frequent and suitable input to function (Wei 2015; Krupp 1992). However a more apt term especially among smaller remanufacturing organisations would be that ‘*knowledge is king’*. Without suitable knowledge of the core then successful remanufacture cannot be achieved, without all relevant technical data sub-standard output will be produced, damaging the reputation of the company in question and the sector as a whole (Hammond et al. 1998).

5 possible reasons for damage found; OEM manufacturing process, Functional Lifecycle, Repair work, Aftermarket Handling, Company Storage.

OEM Manufacturing Process: In most cases OEM products are designed to preform as expected for their first functional lifecycle. After this point their disposal or reuse is beyond the purview of the typical manufacturing mindset. However this has begun to change in recent years, now that Remanufacturing is becoming more prevalent the concept of Design for Remanufacture is starting to take hold too. Unfortunately this is still early days and many products produced by OEM’s for the automotive industry are not designed to aid remanufacturing activities. In particular activities such as disassembly can cause serious damage to the product/core without specialized equipment. Newer more effective manufacturing processes have reduced tolerances and improved the accuracy of the original ‘Assembly’ processes for automotive core, as such it has become steadily more difficult to break down newer product for remanufacturing purposes in recent years.

Functional lifecycle: The typical functional lifecycle of a product is expected to begin to 'wear down' its physical features and capabilities as it comes to the end of its lifecycle. Many products survive and can function effectively long past their typical failure point however from this situation it can be expected that any product reaching remanufacturing (second-life cycle) will have a certain level of 'real-world exposure' due to its time being physically interacted with (either by users directly or other parts by the users) resulting in accumulated damage that can be very difficult to predict (Galbreth and Blackburn 2010; Mashhadi and Behdad 2014).

Repair work: For some areas of the remanufacturing sector, particularly automotive previous 'repair work' carried out to the core during its functional life-cycle can be a serious issue in terms of successful remanufacture. Unlike many current remanufactures who now have to abide by agreed definitions into order to promote themselves as remanufacturers and not simply 'repairers' or 'refurbisher' companies that conduct simply automotive repair have not pressure to ensure that any work they do takes the potential remanufacturing route of the parts into consideration. As the term suggests 'repair', classed as an act which restores a level of suitable functionality to a product does not ensure that it reaches the same standard as an OEM equivalent. As such repair work undertaken by these types of companies can result in parts which are highly unsuitable for remanufacture and in turn can cause damage to other nearby parts within the assembly due to the repair work conducted and the now altered part(s).

In some situations the condition of parts once they reach the remanufacturing stage can be the result of a combination of factors, if certain parts either through design or manufacturing are prone to fail under certain conditions than similar repair work may be conducted by multiple companies on the same type of part. As such any damage/modification caused by these companies is only a by-product of the OEM itself.

Aftermarket Handling: The treatment of core and parts post first life-cycle can be vary significantly between the companies handling the collection and sorting of such parts/products for future use further down the remanufacturing route. Complying with EoU legislation and policies the treatment of post-life "waste" has changed drastically over the last decade or so allowing for a greater number of cores to be acquired by remanufacturing organisations (EU 2003; Gerrard and Kandlikar 2007; Zhou and Ma 2019).

Previously with End-Of-Life Vehicles being seen purely as waste the level of scrutiny and investigation into the disposal and tracking of vehicle parts or as a whole was given very little thought, however with a renewed focus on sustainability and the increased awareness of the damage that "waste" vehicles can do to the environment the urge to ensure that appropriate action is taken. With the value of EoU vehicles and parts now observed by a greater segment of the market there exists many aftermarket handlers who supply parts and cores to the relevant facilities. As such the acquiring of core and parts and their treatment before the reach the facility in question can vary significantly between the different companies and handlers. Though the understood value of the cores can be seen as strong motivation to ensure that they are kept in suitable and appropriate condition the transport and acquirement methods used can occasionally unintentionally cause issue to the valued parts.

Company Storage: The suitable storage of core once it reaches a remanufacturing facility can be a very 'rough' process with the expected durability of the core allowing for a certain level of rough handling ensuring that it is acceptably stored in a form that makes it easily accessible and cheap to store. As such the storage for some companies can be very reliant of external storage where exposure to elements and impurities can occur with ease (depending on the period of storage). The variable level of core that arrives at the facility can necessitate the need for a readily adaptable system for core storage (Teunter and Flapper 2011).

7.4 RaPID Model Visual – SEE APPENDIX C for full Model:

7.4.1 RaPID Model & Inspection stage overview

The RaPID or Remanufacturing and Processing Inspection Database is the "Guide" aspect of the DATF Models. Whereas the DATF Criteria provided a new format in which to identify and class different forms of damage, the RaPID displays the different activity routes that an inspector may follow while undertaking core assessment.

It may seem like a fairly straightforward process - the inspector receives the core post disassembly and then examines each part for damage, noting their findings and moving the parts onto the next logical stage (replacement, disposal, rework etc.). However the actual routes that an inspector can follow can vary depending on a variety of circumstances that can be encountered.

Firstly the RaPID model provides a complete breakdown of the 6 separate inspection stages that occur across the remanufacturing operation, these stages have been identified and listed below;

- **Overview of Core**
- **Initial inspection**
- **Parts Inspection**
- **Component Post-Processing Inspection**
- **Performance Inspection**
- **Final Inspection**

Each of these stages involves at least a basic level of inspection. In the case of "**Overview of Core**" it is typically a visual inspection, assessing that the core is the right product in question and it doesn't appear to be unfeasible to begin remanufacturing (i.e. missing parts of the core, extreme damage deforming the entire structure etc.).

"**Initial Inspection**" occurs when the core begins the remanufacturing operation. This stage is very surface level, and is aimed at identifying significant defects that make further remanufacture uneconomical/unfeasible. This includes easily observed issues such as significant material deformation where external surfaces have been distorted out of shape (possibly through high speed impact), or extreme corrosion, weakening the material strength. Another issue noted at this stage is the value of the core (make and model), if the core has become obsolete during its time in storage then there may be no economical reason to remanufacture. In this case the obsolete core is broken down for valuable parts and the rest disposed or recycled.

With stages such as "**Parts Inspection**" the number of procedures and level of detail is much greater, technologies such as "Pressure Testing" and "Computer Monitored Measurement" can be utilized depending on the type of core. In each of these scenarios' the RaPID visual aid showcases the various routes and paths that the inspector might take. The hope is that this model can be used to help staff operating with new core or new inspection technologies to understand exactly what to do in any situation that might arise. Like the DATF Criteria the RaPID is also designed to be used as a teaching tool, allowing more experienced staff members to easily note the appropriate routes to take based on the inspectors actions. The purpose of the "Parts Inspection" stage is for the inspector to fully assess all parts of the core (post-disassembly and cleaning) turning and examining it from several angles to gauge any specific issues or damages that can be seen externally. These include blackened or burnt areas, mild to medium material deformation or cracking and broken or corroded parts. These types of damage are some of the most noticeable and can indicate higher levels of financial resources needed later in the process in order to return the core to remanufacturing standard and new warranty.

The inspector then decides whether any of the damage found at this point justifies declaring the core unsuitable to remanufacture (technically unless there is complete significant material damage to almost all parts any core is remanufacturable, the point that it is deemed "unsuitable for remanufacture" is at the stage when the cost of returning the core to standard begins to approach that of any potential price the company could find for it after the process is complete.

With “**Component Post Processing Inspection**” the activity is very similar to the overall assessment of the core when it first reaches the remanufacturing plant, a very broad examination of its state with the additional use of the remanufactured cores functional testing to rely upon as an aid to gauging that it has reached OEM standards again and therefore be given suitable warranty by the remanufacturing company is question. This stage occurs after the part has been "reworked" which refers to the techniques and methods used to bring the part back to OEM standards from a technical point of view.

This type of inspection can be very basic with a purely visual assessment being made on the part from the perspective of the operator, however during initial rebuild of reworked components some additional inspection is undertaken for ‘moving’ parts/structural seals on complex parts requiring manual manipulation and minor testing. The aim of this assessment is primarily to ensure that no previously non-identified issues have occurred or further developed during the 'treatment' or ‘rework’ of the part and that it is now suitable for full rebuild and reassembly.

“**Performance Inspection**” is part of "Testing" one of the final phases of the remanufacturing process, where the rebuilt core is tested thoroughly, often on a purpose built rig designed to simulate real-world conditions for the core or assembly. In these terms performance inspection is the process of observing the results of the 'Testing" phase and ensuring that the results are all suitable for the now rebuilt product to be give remanufactured standard and new warranty. Within the inspection sub-stages this segment can be viewed to be one of the most critical after parts inspection.

“**Final Inspection**” involves detailed visual assessment. The aim of this stage is to ensure that any core leaving the facility is in the suitable and appropriate condition all that all paperwork ensures that the relevant technical notes (Model/age/number etc.) have been matched with the right core. It is also a chance to ensure that the aesthetic of the core is as desired, while not a functional factor the appearance of a remanufactured part remains highly important. Though this stage may seem like a triviality it is an important factor in the aim to ensure that the output of a remanufacturing facility is to the highest standard it can be.

7.4.2 RaPID Model – Example

The entire RaPID model can be observed in Appendix C, however the first stage “Overview of Core” can be observed below;

OVERVIEW OF CORE

This process occurs as follows:

Start: Facility ready to receive core

Has shipment been received? Y/N

Is Core present? Y/N

Is there any accompanying paperwork (external)? Y/N

Does core condition match paperwork (external)? Y/N

Does Core appear to be roughly intact (Anything short of Unfeasible is accepted)?

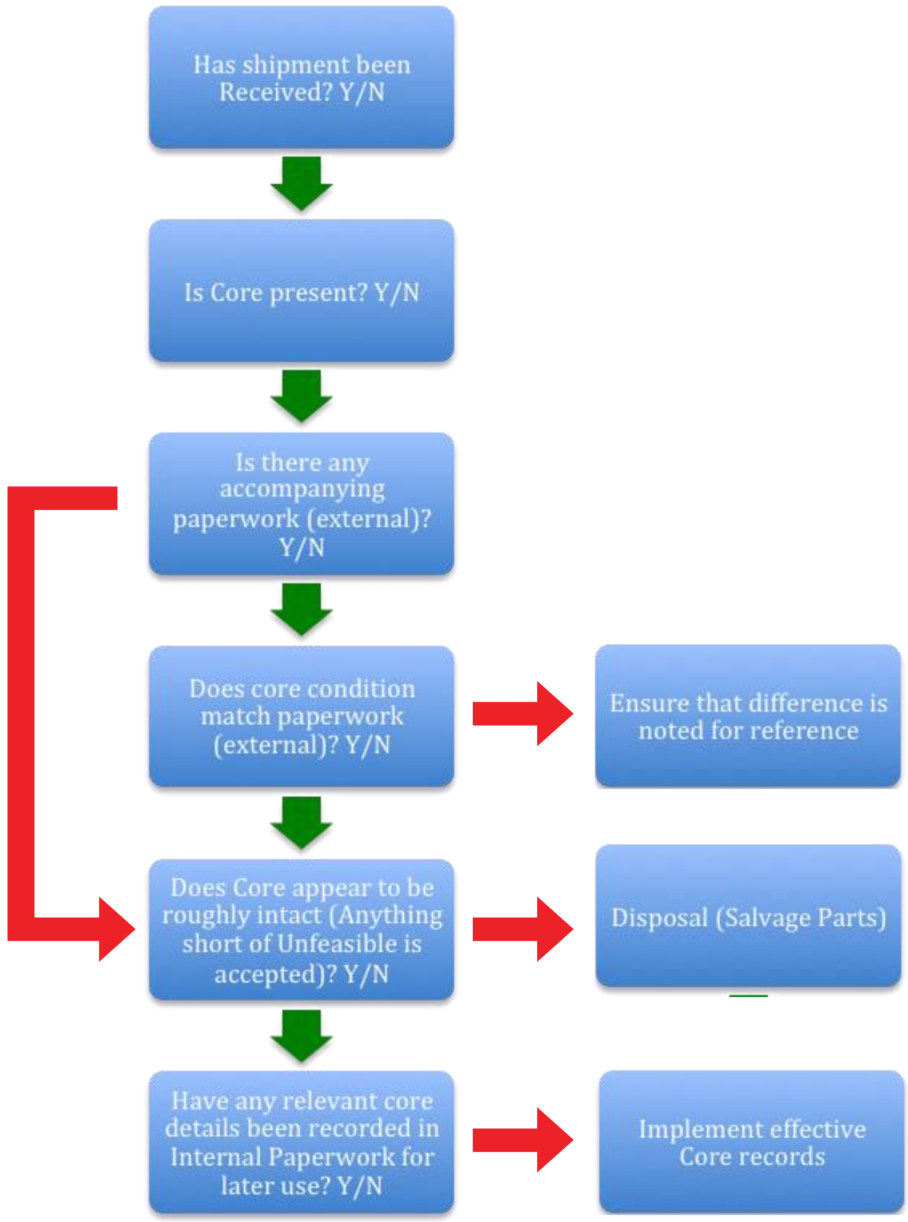
Y/N

Have any relevant core details been recorded in Internal Paperwork for later use? Y/N

End: Core is passed to Storage

Visual:

Start: Facility ready to receive core



End: Core is passed to Storage

Figure 14 - RaPID Model – Overview of Core

See APPENDIX – C (RaPID Model Visual) for full data:

7.5 POM Database, Model

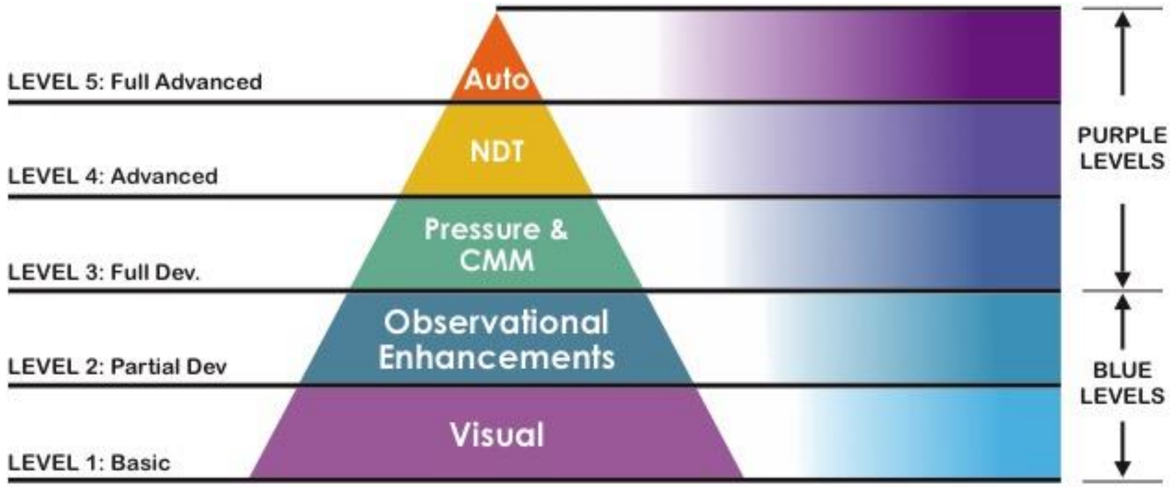


Figure 15 - POM Pyramid Model

7.5.1 Introduction to POM Method database

The POM database is the detailing and breakdown of the individual methods observed in operation throughout the industry relating to the inspection/assessment of automotive components within the remanufacturing process. These methods have been separated into Levels as observed within the 'Visual model POM', the POM is designed to showcase the potential methods/technologies available to the user (inspector/operator) in a comprehensive manner. Levels have been separated and stacked according to the relative complexity of the method, specifically in terms of user knowledge and technological requirements. Methods towards the top of the pyramid involve expensive machinery and strong technical ability in order to implement them.

An overview of the POM Level methods:

- Level 1: Visual - This is the base level from which all inspectors can work from. This levels details the actual steps involved in visual inspection, including identifying part number, examining material surface for defects, and checking for contamination. The discussion of each step allows for all users to have a common ground of understanding from which to now build up from. Each new method introduced in the PoM is discussed in terms of their application in aiding and enhancing basic inspection.

- Level 2: Partial Developed – This second level details the necessary technology needed for thorough visual inspection; the methods discussed do not utlise complex or costly equipment. Specifically this level details techniques such as 'Borescopic Examination', "Magnification Tools", and "The Smell Test". Borescopes and Endoscopic tools are used to examine parts with complex geometry that make traditional visual examination impossible. Magnification equipment allows inspectors to assess intricate parts and pieces with very features. The 'Smell Test' is the loose term used to describe a very simple and common method of assessing the functionality of mototrised parts without having to power them up.

- Level 3: Fully Developed – This level deals primarily with advanced measuring processes and pressure testing technologies. With more geometrically unique designs appearing across the manufacturing industry it can be difficult now to accurately measure core parts using only traditional means. As such CMM (Coordinate Measurement Machine) can be used to more quickly and effectively measure all aspects of the part. This is particularly useful with assemblies that require much tighter tolerances than usual. Hydrostatic and Pneumatic testing methods cover the more advanced tools inspectors can use to assess the structural conditions of core, this is a vital action when inspecting parts that inject or store fluid during functional lifespan.

- Level 4: Advanced Processes - Non-Destructive Testing (NDT) is the main focus of this level of the POM, these are techniques used to assess the condition of the material and internal surfaces of the core without having to break the piece down past a useable point. MPI (Magnetic Particle Inspection) is a rising favourite for remanufacturing inspection, a relatively straightforward process that allows the inspector to use fluorescent magnetic particles to identify near surface cracking in material surfaces. Other methods detailed at this level include ECT and Ultrasonic testing.

- Level 5: Fully Advanced – The top of the POM is reserved for automatic inspection practices for remanufacturing. At the moment this is a theory rather than a widespread practice, inspection in the case of aftermarket core is a process that involves such a variety of unknown variables and potential part conditions that automating the process is still quite far off. This section discusses the possibilities within the area of automation and what likely direction the research may take as well as its clear benefits to inspection activities.

Unlike other pyramid based model the POM user does not automatically move through the levels step by step, but rather views the model as a whole with the knowledge of how the levels are broken up and then assess which methods may be most suitable/feasible within their own operation.

7.5.2 See APPENDIX – D: POM Database

The full breakdown of the database, including the steps required to successful undertake each method of inspection can be found in Appendix D. Within the appendix the tiered system described in section 7.4.1 can be examined in its entirety; each 'level' presents the user with the form of technology that will be discussed, its use in inspection activities as well as its benefits and limitations. Following this each 'methods' application is noted and the user presented with clear step-by-step instructions on how to successfully complete each procedure; additional reading and notable standards are also included for further examination by the user.

7.5.3 BLUE & PURPLE Levels

A new company only starting out in remanufacturing can focus its attention to Level 1, which primarily deals with visual inspection in order to gain a secure footing in the basics required. Such understanding can aid in easier uptake of the more complex technologies required in advanced inspection methods. Utilising the POM the inspectors can then review their staffs capabilities, understanding and application of the level 1 descriptions and methods before moving on to Level 2.

From Level 3 onwards the tiers shift in colour dramatically, this is to clearly display that the lower two levels are different in category from the upper. These lower levels can be considered the “BLUE” tier, a category of methods and tools used primarily by small low resource remanufacturing organisations, although as discussed in more detailed sections of the POM the tiered approach ‘builds’ upon the previous level as a understanding of the methods and procedures from the lower levels. It is perhaps more suited to state that the BLUE levels comprise the core methods of inspection that are used by all remanufacturing companies across the spectrum of experience and resources but that those much smaller companies must rely upon such methods almost primarily as their main source of assessment criteria.

The upper levels, the “PURPLE” levels comprise the stages at which remanufacturing companies begin to invest time, training and expense into their assessment approaches to incoming parts and core. The methods and processes discussed during the Purple Levels comprise a much more stringent and extensive set of assessment tools and technology than those typically found in small-medium scale remanufacturers. Complex high-end technology is utilised in these levels, with processes such as Magnetic Particle Inspection and Computer Monitored Measurement becoming intrinsic parts of the daily inspection operation.

Like the lower levels the users (Management or Operators themselves) build upon each level in terms of knowledge and understanding allowing them to more effectively identify which processes are suitable for the parts/core at hand. However unlike the lower levels there are some aspects of the more developed methods that can be overlooked or declared N/A (Not Applicable) to the user in question. Some of the procedures discussed in the upper levels involve tools and technology that are unnecessary to user operating with very specific parts or cores, tools targeted at assessing the material damage found ferrous parts are only applicable to those parts comprised of ferrous metals otherwise the process becomes useless. Likewise measurement technology that aims to assess the tolerance accuracy and shape of parts with a large number of two-dimensional circular planes are no longer helpful when examining the issues of parts that are comprised of primarily flat, rectangular shapes. Advanced assessment technology is required when the inspector wishes to assess the non-visual aspects of the part. While visual and measurement inspection can provide significant information on the exterior condition use of technology such as Magnetic Particle Inspection is needed in order to observe any near surface defects that may comprise the piece in question.

7.6 IICEA Model 4

7.6.1 Internal Inspection Comparative Evaluation Analysis

This model forms a sub-segment of the DATF Inspection tool, utilising a structured approach to self-analysis from an internal company perspective in order to allow employees at various levels of the organisational hierarchy to critically review their effectiveness and efficiency of their daily inspection operations.

The IICEA breaks down the typical operations required during inspection at all areas of the remanufacturing process, with the obvious emphasis on "Parts Inspection". These 'steps' are similar to those discussed in the RaPID Model and further detailed in Appendix C, but in this context are used as a more structured border of where each operation begins and ends. As such the IICEA can build a comparative analysis model that allows users to review the twin critical factors (Effectiveness & Efficiency) side by side at each stage of the process by placing numerical values regarding each of these factors against a particular individual. This then allows the company to evaluate the differences in both factors across the employee board identifying where operators are falling behind or potentially require re-training or aid in order to bring them up to higher levels. In addition to this fact the use of such a rating system of “Most E&E” allows for a competitive nature to be fostered within the employee ranks. The benefits of such a nature with company structure is that a friendly rivalry can induce staff at the stated facility to attempt to ensure that their work is always at the best level in a much more complimentary manner than simply stating that work being conducted does not meet the required standard.

As stated above the aim of such a system is to promote “desired” excellence on the part of the employee as opposed to “required excellence” which can produce results but also fosters low morale and unhappy mindsets during work hours, which can in turn have a cumulative effect of organisational efficiency and daily operation. However the free statement of all results in a system like this can allow for those ranking in the bottom areas to feel persecuted and unhappy (generating the same ill-will that the system was designed to avoid), as such the IICEA results would only show the top 10% of the staff being reviewed.

The structure of the IICEA is very similar to a spreadsheet, with the aim of making the model highly user-friendly and simplifying it to a point where it can be utilised and filled out without undue stress or complexity on the employee part. In addition to the simplicity of the design for the purposes of ease of use the concept also includes allowing the use of the IICEA to be tailored to the company in question, increasing its effectiveness and turning a generic improvement model into a more bespoke valued tool through repeated use and modification by the company in question.

The terms of efficiency and effectiveness can be defined in several ways and are often dependent on the situation or scenario at hand, within the section regarding the IICEA and the overall scope of the entire research project the terms can be defined as thus;

Efficiency: The speed with which an act or operation is carried out within a particular time frame. "How quick was it done?"

Effectiveness: The level to which the act was conducted properly. "How well was it done?"

These two factors are critical components in many actions and interactions in life. They can also become very dependent on each other The speed of the action can often occur at the expense of the level of effectiveness; likewise the high level of effectiveness taken with the action can have a detrimental effect of the level of efficiency involved.

This is not an '*absolute*' however and both critical factors can be achieved to a very acceptable level without detriment to the other. However such balance can typically be best achieved through examination of the "action' taking place, as well as any surrounding variables regarding the human-interaction element as this can be the most suitable aspects to modify in order to achieved successful balance in this type of equation. The suitable balance of these two factors is even more crucial when considering them within the context of 'Remanufacturing' and with the action being 'Parts Inspection', a highly qualitative and human-interaction based system itself.

7.6.2 Measuring E&E

The assessment tools only require the external presence of one assessor during the examination of an operator, the assessment itself can be carried out within a very short time and can be conducted by any member of staff, provided they have appropriate experience within the process. In order to reduce the level of disruption of conducting external examination a potential solution is to 'stagger' the assessments. Potentially only conducting them for one day a week, during the review period; depending on the size of the company and the availability of examiners, two or three assessments could be conducted in a day. The aim would be to cause as little disruption to the daily routine of the staff and processes as possible.

The results of this could then be collated and a suitable time scheduled for the next assessment (conducted every 3 months) allowing management to compare the level of staff improvement every quarter.

7.6.3 Measuring Effectiveness

In order to suitably measure the 'effectiveness' of the action being taken the operator's work is observed during operation and the output examined. This observation and examination is conducted by an additional operator or employee well versed in the procedures themselves. A check-sheet noting the key operations and characteristics of a successfully inspected product are then measured against the output of the work.

7.6.4 Effectiveness Check-Sheet

The effectiveness check sheet was developed in conjunction with industry contribution from case study companies, common features of successful inspection were discussed at length and a final set of ‘factors’ were decided upon. The final design of the check sheet factors was re-examined during the industry review post model development, some minor alterations to better phrase the questions asked were required but overall this feature of the DATF models was met with positive views. Part 1 of the check sheet which focuses on the various effectiveness factors can be seen below.

Part 1 – Methods Operation:

METHOD FACTORS	RATING
Have the parts been given a thorough and in-depth visual examination by the operator in question?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Have all forms of visual damage been recorded by the operator for later reference during processing?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Have the parts been suitably measured by the operator to ensure they remain within desired tolerances?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Have all moveable parts been manually manipulated to ensure that an appropriate level of 'mobility' is present?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Have all areas where material deformation or damage compromising part shape or measurement been recorded by the operator for later reference during processing?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Have the parts been subjected to more detailed investigation methods to assess damage (i.e. CMM, MPI, Borescopic examination etc.)?	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor
Has any relevant additional data been recorded by the operator for use in later processing or in general parts/damage assessment.	Y/N Excellent Highly Satisfactory Satisfactory Unsatisfactory Poor

Table 15 - IICEA Effectiveness

Part 2 – Characteristics of completed assessed product (action taken post inspection & cleaning stages but before reassembly:

CHARACTERISTICS OF COMPLETED ASSESSMENT	
All parts are devoid of rust/contamination that could obscure existing damage.	✓ ✗
There are no parts clearly unfeasible (No longer economical to remanufacture) to process still remaining in the core tray.	✓ ✗
Suitable replacement parts for any unsuitable components (Damaged or altered) have been introduced into the part collection ready for re-assembly after later processing.	✓ ✗
All signs of damage adhering to the 8 critical inspection factors have been noted in earlier stages and appropriate action regarding these factors has been undertaken.	✓ ✗
All prominent and clear signs of damage match those found in the recorded data form.	✓ ✗
(Optional) Use of the DATF models if implemented or referred to are utilized in a manner improving the overall success of the operation.	✓ ✗

Table 16 - IICEA Success Characteristics

The above check-sheet is relatively simplistic in nature however this is one of its advantages, by breaking the key operation and post-inspection aspects into a number of short points those investigating the effectiveness of the operator in question can do so in a straightforward and timely manner. Unlike the efficiency side which relates to the speed of the operation, successfully judging the effectiveness of such an operation can be a very difficult matter and can easily result in the majority of those assessed being marked to the same or similar standard.

This is an unfortunate side effect of an area where human-based interaction is based on internal processes and judgments and it can therefore be difficult to note tangible areas of examination without more detailed structures in place. As such the effectiveness side of the IICEA becomes less of a detailed assessment tool and more of a base standard that can be used to ensure that staff undertake the required procedures in a suitable fashion,

7.6.5 Measuring Efficiency

In order to measure the efficiency of the operator undertaking inspection activities, each stage of the operation has been broken down into a short statement and then given a numerical value based on the time taken to complete it. This type of data can be very useful when identifying either areas where an operator may require assistance or where the stage itself requires modification or improvement on the part of the company. As the inspection activities can be assessed independently the reviewer can observe if the there are specific stages where operators are taking longer than expected but making up the time in other stages instead.

7.6.6 Efficiency Check-Sheet (All Levels)

Inspection Procedures	Time taken for each process:		
Basic Inspection:	Operator 1	Operator 2	Operator 3
Visual Assessment			
Magnification Assessment			
Borescopic Examination			
Scratch-Sniff Test			
Developed Inspection:			
Pressure Testing			
Pneumatic Testing			
CMM (Measurement)			
Advanced Inspection:			
MPI (magnetic Particle inspection)			
ECT (Eddy Current Testing)			
UT (Ultrasonic Testing)			
TOTAL:			

Table 17 - IICEA Efficiency Check Sheet

7.6.7 Efficiency Check-Sheet (Basic Inspection – Detailed)

Inspection Procedures	Time taken for each process:	
Basic Inspection:	Operator 1	Operator 2
Visual Assessment		
Identify Part (Make, Model, Type etc.)		
Contamination & Degradation Examination		
Wear Examination		
Material Damage Examination		
Mobility Examination		
Paperwork noting relevant data		
TOTAL:		

Table 18 - IICEA Efficiency Check Sheet (Detailed)

7.6.8 Efficiency Check-Sheet (Example)

Inspection Procedures	Time taken for each process:		
Basic Inspection:	Operator 1	Operator 2	Operator 3
Visual Assessment	3.43	4.20	3.54
Magnification Assessment	2.45	3.51	4.25
Borescopic Examination	1.51	1.30	2.41
Scratch-Sniff Test	1.01	2.00	1.46
Developed Inspection:			
Pressure Testing	4.53	5.04	5.55
Pneumatic Testing	6.22	4.32	6.45
CMM (Measurement)	5.16	5.11	6.01
Advanced Inspection:			
MPI (magnetic Particle inspection)	4.05	4.10	4.45
ECT (Eddy Current Testing)	7.23	5.53	6.54
UT (Ultrasonic Testing)	5.34	3.42	8.48
TOTAL:	42.53 m/s	40.13 m/s	51.54 m/s

Table 19 - IICEA Efficiency Check Sheet (Example)

As can be seen in the above example Operator 3's total time is significantly longer than both Operator's 1 & 2. When observing the breakdown it appears that it is stages such as 'Borescopic examination', 'CMM' & 'UT' that slow the overall time taken for the complete task. Using this data the company can then analyse and determine at what point the time taken for the process becomes uneconomical and has to be addressed. In this manner the operator in question can be questioned in order to ascertain where the 'hold' in terms of operation, takes place and why.

7.6.9 DATF Model

DATF MODELS	Time taken for each process:	
DATF Model assessment:	Operator 1	Operator 2
DATF - Training		
DATF Paperwork (p/p)		
RaPID - Training		
RaPID - Reference & Application		
POM - Training		
POM – Reference & Application		
IICA – Usage & Review		
TOTAL:		

Table 20 - IICEA Check Sheet (DATF)

7.7 In conjunction with other sub-models

As stated from the beginning of this chapter this sub-model is designed to be used both separately and in conjunction with the rest of the DATF. However the IICEA is more likely to achieve quicker widespread usage and display than its more comprehensive brethren due to its applicability to current inspection practices. In addition to this there is also the hope that usage of the IICEA aiding small-medium sized companies may spark increased interest in the entire DATF itself and in turn promote the trust and belief that companies place in it.

When used in conjunction with the larger DATF it is hoped that the user finds even greater use from the IICEA and its associate sub-models. The structure and criteria provided can be highly useful when looking to isolate areas for improvement within Inspection. The POM containing the 'tiered approach to the various methods, tools and technology available during this stage can be used to ascertain the most suitable and relevant "improvement" or "modification" required in any problem area.

7.8 Inspection as Human based Physical Interaction

Physical interaction within the manufacturing and remanufacturing industry is a significant factor. Inspection (with a focus on parts inspection) is a critical factor within the typical remanufacturing operation,. In Case Studies A - E the emphasis on human perception during the visual interpretation of information (visual inspection) was noted. It is the base level from which all directions regarding core assessment and treatment are decided upon.

There exists an intrinsic human need to physically touch an object to ensure that it is "real"; while this concept may sometimes appear ludicrous in reference to operations such as remanufacturing the concept of "realness" within this context does not always refer to the belief that the object exists but that the assumptions and ideas regarding the object (in terms of colour, composition, texture etc.) generated by the viewer within the mind, do in fact match up with the reality.

This concept can appear laborious and an individual may discount the fact that they do in actuality utilise this concept on a daily basis both personal and professional, however this factor is such an in-built aspect of typical life that it is rarely viewed objectively. The reason that this facet of human nature is so significant relates to the existing operation of remanufacturing inspection procedures. As it stands the research in this thesis has displayed a marked prevalence towards heavy-reliance on the tacit knowledge and personal assumptions/opinions of operator across the automotive remanufacturing sector. Following from this relevance the level of human interaction not only to observe and gather data from parts/core but also to utilise said data to assess the condition of the part can be deemed an instrumental and integral facet of this operation.

As Inspection procedures as discussed in this thesis rely so heavily on human perception and physical interaction (Touching the parts, moving them to gain more effective or differing perspective on features or potential damage) the concept of shifting such a process to a computer based automated procedure becomes a highly complex one that requires considerable development. As stated earlier typical automated manufacturing operates so effectively because the parts used for assembly and construction are created from the same material and manufactured in the same manner. As such when they arrive at assembly operations all parts are arriving in the expected condition (within expected and stated tolerances) whereas within the remanufacturing operations these tools would have to be able to effectively assess the varying condition of parts delivered.

This is not to suggest that automating parts of the inspection process would be an insurmountable task, simply one that is still in the stages of infancy compared to more established and less cost intensive methods.

7.9 DATF models

As described in several sections throughout this chapter the DATF model as a whole is made up of a number of sub-models and tools that act as both an integrated and comprehensive review and analysis system for parts inspection methods and also as singular aspects that can be used in isolation from each other as best suits the company in question. This section will outline and discuss a brief overview of each sub-model and how these segments of the DATF are planned to 'fold' into each other to form a complete system as well as how they may be utilised separately.

DATF (Standard, +, -): The DATF can be considered the "core" factor of the overall model and details the grading and criteria that can be applied to the types and forms of damage found within incoming cores to an automotive remanufacturing facility. The + and – forms this model are structurally virtually identical with only the criteria regarding the damage being altered to focus on both "significant damage grading" and "lower damage grading".

RaPID: The RaPID system comprises a step-by-step direction of procedures for the operator or trainee to follow as they progress through the levels of complexity and detail required to utilise and learn the more technologically advanced and detailed forms of inspection. As such this model links quite closely with the POM which deals with the increasing levels of technological complexity within the pyramid of inspection methods.

POM: The Pyramid of Methods comprises a visual model displaying a tiered approach to inspection technology and its implementation. As well as a database of all stated methods and a step-by-step guide to their successful usage in enhancing inspection activities.

IICEA: The IICEA acts in a more separate capacity than the rest of the models with the purpose of this tool not acting as a way of improving the typical inspection process from the operator point of view but in fact acting as a self-analysis method that can be used by the company themselves to analyse the effectiveness and efficiency with which those using the previous 3 DATF models have successful implemented those strategies and procedures that were detailed there.

The DATF models are designed to operate within the automotive parts sector of remanufacturing; in particular the models have been developed with the target parts being mechanical in nature. Automotive components such as Camshafts, Transmissions, Torque Converters, Engine Blocks are the main focus, however there has been discussion of using the models when remanufacturing automotive braking and safety systems, in this content however the remanufacturers already typically have very tight tolerances and existing strict safety standards in place, as such the addition of the DATF may only be of limited value without additional refinement.

7.9.1 Limitations of the DATF models

The DATF models are designed to effectively function at the inspection activity stages of automotive part remanufacturing, however they are also limited in their usage. The DATF models target key operational stages within the remanufacturing process, specifically the ‘inspection’ stage of automotive parts remanufacture, and are primarily created to be used during the assessment of mechanical automotive parts. As such the criteria and value of the models is directly tied to this particular area of the remanufacturing sector. The DATF models are built to act as supplementary material to an automotive parts remanufacturers’ own existing set-up. The data and structure of the models allows for greater impartiality, clear reference material and a guide to the typical stages and routes of successful inspection. An existing remanufacturer already operating in the automotive area of the industry and tackling mechanical parts/core can use the DATF models to aid their approaches to inspection.

While this does set limits on the applicability of the DATF Models to the wider remanufacturing industry it does not negate them acting as a basis for the development of additional versions of the DATF specifically targeting areas of the sector (i.e. Automotive Electronic parts, Aerospace Parts, Heavy Duty Off Road HDOR Parts etc.).

7.9.2 Interest from Industry

Those in industry have already positively responded to the DATF Models; during the review stages automotive remanufacturers examined the models to assess any needed changes to better reflect real world scenarios. At this time significant interest was expressed, in particular when the completed model data would be available to external companies, and if bespoke versions could be created. Case Study companies B, C & E all made requests to be notified when the DATF became available to them and Company E stated that if possible they would be keen to further refine the DATF effectiveness through extended in-house use.

More recently at a 2019 sustainability research event three companies involved in remanufacturing left contact information and requests for discussion regarding implementing the DATF models when they became available for industry usage.

7.10 Summary of Chapter 7

In this chapter the DATF models developed to combat and mitigate the issues identified from the earlier case studies and literature research and present in industry have been detailed and showcased. The function and practical benefit to the inspection activities that occur across automotive remanufacturing have been noted, with particular focus giving to the positive factor of introducing the grading system and method database as acting as a mid-way point between the pure qualitative judgment based actions that can occur and the more robust and data heavy quantitative based methods that are a desired part of a developed aspect of industry. Finally the need and impact that these models may have upon industry as well as providing a foundation for future research has been stated.

CHAPTER 8 – VALIDATION:

8.1 Introduction

A defining end point in the research is the validation of any output devised during the work of study. Successful validation of the end result allows for justification of the entire project as a whole as well as affirming the inherent value in outputs and deliverables of the research (Koro-Ljungberg 2008).

Validation of research can occur through various methods. The form of the results gathered through either analysis techniques or previous indicators of theory define the style of validation required in order to ensure that as unbiased a final result as possible can be achieved (Pyett 2003; Noor 2008).

8.1.1 Value of Validation:

The value of the validation process is as the confirmation of both the inherent value and the robustness of the research, and how accurately the theoretical meets the practical. Traditional *experimental* validation uses the scenario of a closed system with a limited number of variables that can be adjusted as needed to observe and record the results (Yin 2011; Cash, Stanković, and Štorga 2016). The main benefit of such a set up is that the results can then be duplicated multiple times with the exact same conditions. This is a highly efficient form of validation as hypothesis can be tested and proven/disproven under objective conditions. Unfortunately while experimental validation is one of the most robust types it also relies on the conceit that all variables and conditions of the scenario in question can be carefully controlled. Ensuring that the final output of the research (i.e. model, theory, solution etc.) can be validated and checked in a rigorous and unbiased manner allows for the author to confirm that their own ideas and concepts are both correct and suitable for dissemination as a piece of successful academic work.

Biased or unsuitable validation can be just as detrimental to the content of the research also as it may provide outputs that signify negative aspects of the research when in reality the content remains sound (Koro-Ljungberg 2008). Unsuitable validation relates to methods that can rely extensively on a single viewpoint elevating that point of opinion to a degree that is unrealistic and unsuitable for a research project of this size and detail.

8.1.2 Validation Methods:

While experimental validation and other similar methods can be the most efficient way to ascertain the success of the research, if the output being tested cannot be verified under such impartial conditions then alternative methods must be utilised. As such the type of validation selected for this research is "*Expert Validation*". This type of validation can be used when the subject area being investigated cannot be boxed into laboratory conditions and so is less suited to quantitative validation (Polit and Beck 2006; Koro-Ljungberg 2008). Due to the nature of the DATF model the only way to validate under real world conditions would be to utilise a number of companies across the remanufacturing sector; with each implementing these models to different levels and the researcher observing how the daily operations and business improve or change over a specified period of time (6 months).

Since such an undertaking would require massive resources and financial recompense to those involved regardless of outcome, this type of validation is clearly unfeasible for use at student level. As such the next suitable form of validation is "*expert opinion"* in this case involving experienced operators/mangers from across the automotive remanufacturing field. In the selected set-up these individuals evaluate the DATF models using purpose designed assessment forms to ensure that all relevant areas of the work are addressed. These individuals would then evaluate the research using both their individual and combined experience over a specified period (3-5 days) creating as rigorous and detailed an assessment as possible (Gorard 2013).

The aim of this type of validation is to utilise the long-term experience of those operating at the top of their field to examine the solution (DATF) and then given that experience make a decision of whether such work is of value to the industry and academia. To reduce bias of a single operator several individuals have been selected and their personal assessments have been cross-referenced with each others as well as group assessment values. As such the hope is that a succinct and successful evaluation can be carried out, with the aim of a positive result from the assessment desired.

8.1.3 Verification Methods:

However while the selected validation method has been tailored to ensure that as little personal bias as possible influences the expert opinion the addition of a separate company within the same field to evaluate the research at a slightly later date has been introduced as a method of verifying the initial validation gained from the first company of experts.

Using the same method of evaluation as the first company the verification experts perform the same type of assessment on the research to validate it. The data resulting from this assessment is cross-referenced with the data results of the first company. If both data sets, are predominately positive in key areas then the research can be deemed a success with the opportunity to put forward potential model modifications for future improvements (Pyett 2003; Gorard 2013).

8.1.4 Redundancy reworking:

If during the initial validation stage the results from the expert opinion proved that the output of the research (the DATF models) were seen as predominately negative then further discussion and identification of failure sections would have been carried out with experts allowing for clear issues to be conveyed. *"Reworking*" of these negative sections of the models/research would have then been done over a necessary period before returning the modified research to the evaluation of the initial experts. The models would have been re-reviewed to see if the results were now positive and if not then further reworking would be carried out till suitable.

8.2 Review and Modification of the DATF Models

8.2.1 Review Workshops

The validation workshop utilised the DATF evaluation form to provide both a grading and commentary on numerous aspects of the DATF models and their component parts. Each of the statements made in the evaluation form is designed in the method of a statement that can be agreed with or disagreed on the grading scale. The level of agreement can be taken within this context as the value of that particular aspect of the model due to the working of the individual statements (Kirk and Miller 1985).

The final score given through grading methods in this case is provided through a consensus grading, with those gathered at that particular workshop being used provide an average. This average is then evaluated through the pass/fail constraints discussed below.

In order to conduct an effective validation workshop the data gathered has to be analysed in order to determine what constitutes a pass/fail of the model aspects. The evaluation sheet provides a grading of 1-6 in terms of how much the user feels they agree with the statement provided. As this grading has been classed as the 'value' of that particular aspect the grading of a 3 given to a statement is the lowest form of pass rate for that section. Grades 1 & 2 are immediate fails of the statement while 3 can be considered a 'grey' grade; any statement given this grade will be re-evaluated in order to ascertain exactly where the statement went wrong. A 3 grade will be addressed at the workshop after all data has been gathered and discussions will be conducted in order to ascertain where the particular statement falls short. Within these conditions there is a chance that the information may be solid but that its presentation has not shown the statements intent in the most suitable method (Emam, Quintin, and Madhavji 1996; Beecham et al. 2005).

After such post-discussion the workshop may be asked to grade the modified statements in order to ascertain whether it too falls on the same grade. If a statement falls on a 3 grade twice then more detailed review of the model aspect and its presentation is required and is conducted outside of workshop conditions.

Any grading given through workshop consensus that is a 4 or higher is an immediate pass and those statements achieving a 6 will be reviewed in order to identify the most valuable points in order to showcase the model benefits more effectively in later stages.

Each workshop is treated as a separate entity in order to ascertain whether different routes of users (academic, industrial etc.) and different levels of users within a group (management, work floor etc.) view different model aspects with different values.

Outliers & Discussion:

As stated above the chance for high variation in grading values placed upon statements by the collection of individuals at the workshops is very strong due to differing opinion and understanding. One of the main assumptions however for the purposes of the workshop evaluation activities is that those operating at the same level within the company will have some common ground in terms of their perceived value of the model aspect in question. With this in mind after the consensus value for a statement has been collected and generated from the data provided in the workshop any significant outliers (in terms of value) have to be identified. ‘Outliers’ in this case refer to those values that are substantially different from the common value and are relatively alone in terms of the number of individuals assigning that value to the statement.

For example if the common value placed upon a statement is found to be 4 the outlier in this case may be an individual value of 2 given to the statement by either a single individual or very small percentage of those collected for the workshop. When this type of action occurs the next steps involve the discussion with the individual regarding the assigned value. This is conducted in an effort to remove any misunderstandings or misconceptions regarding the aim and point of the statement. This action is not to suggest that those taken part within the workshops are unfamiliar with the concepts being discussed, particularly in relation to remanufacturing and the inspection processes, but rather that the information conveyed within the evaluation form (though aimed to be clear and easy to understand) may not be as easily accessible to a particular individual. The hope with this set-up is that any discrepancy may be easily identified and the statement given a new value post-discussion (as mentioned earlier in this section) however this will in no way aim to pressure the individual(s) to change their value for the purposes of the workshop and only to more adequately elaborate on the details of the statement or model if required (Beecham et al. 2005).

Likewise any positive outliers occurring, common value is 3 and an outlier is 6, will also involve discussion and elaboration of the statement to avoid assigning any additional positive value to the model aspect that was not inherently present.

Failure Statements:

When the consensus value is lower than 3 within the workshop scenario then the statement will be considered a failure. This is a situation that is not desired however any failing on the model aspects from expert analysis is a vital part of the research in order to ensure that the final output is as valuable and useful an original contribution to both academia and industry. When this type of failure occurs the next stage involves a detailed review of the commentary provided by those grading the failed statement within the workshop conditions. This review of commentary to better understand the reasoning for low score occurs during the 'outlier' stage as well, however in this case the review is conducted in much stricter and detailed circumstances in order to fully pinpoint the key features that caused the statement to fail.

The aim at this stage is to discover exactly how the statement failed so that the inherent information provided by all models and generated as part of this research can be potentially remodelled into a more effective statement or model aspect (Pyett 2003). This would allow the model to remain functional for its purposes but modified to combat the perceived issues identified by those operating within the field.

In a similar manner significant discrepancy between the assigned consensus value for models or statement between workshops requires further investigation.. In this situation ‘significant discrepancy’ can be classed as a value difference of 3 or more points (e.g. 2 & 5, 3 & 6 etc.) though if less discrepancy exists it may be explored at the researchers discretion. The aim of this second stage analysis is to identify any areas where the differing groups involved with workshop (academics, industrials) and those at various levels within these groups (floor-shop worker, managers, long-term academics etc.) disagree over the perceived value. However the aim of this analysis is not to solely try and ‘marry’ the two differing opinion into a single coherent value but rather to understand why the difference itself has taken place. Where this differing opinion can be understood to have legitimate justification then the value will be left to stand, in this fashion the final ‘validation & verification’ sections of the research will display the final values from these workshops (indicating the inherent value of the model) but also the reasoning behind multiple values for key aspects of the models in question. In this manner the reader will be aided in identifying areas that are of greater interest to the practicing industrialist and those that are perceived as more valuable to the academic and research side of the equation.

8.2.2 See APPENDIX – E (Review Panel Form Example):

8.2.3 Case Study Validation

As previously discussed in Chapters 4 and 5 the case study data was gathered from several sources using the triangulation methodology. One of these sources of data included semi-structured interviews with staff at each selected automotive parts remanufacturer. The results of these interviews were vital in furthering the research and ensuring that the data received was accurate and a true representation of the interviews was a key aspect of validation. To this end after each case study the results of the interviews were written up and the most pertinent points highlighted, these write ups were then reviewed by the staff at the company in question to ensure it was a valid representation of the original responses given and that the assumptions made were sound. The following format was used to ensure rigour and robust validation;

- Interview responses sent back to staff for review.
- Any changes required noted and added to interview results.
- Any significant changes in interview responses examined to identify why discrepancy exists.
- Key points regarding company set-up and operations reviewed by multiple members of staff to ensure true representation.
- Patterns and assumptions derived from Cross-Case Analysis reviewed by case study staff to ascertain level of agreement or disagreement.
- All previous factors critically examined before moving forward.

8.2.4 Results & Discussion

Within this body of research the value and critical nature of 'inspection' has been heavily discussed and at several stages justified with both primary data collected on site at various remanufacturing facilities as well as through existing academic material. The purpose of the DATF models developed through observation, analysis and review by industry is to aid the 'inspection' process across multiple levels. With its main attributes involving the detailed breakdown of the various aspects typically involved in the process allowing the models to be utilized in a similar manner as prescriptive maturity models, clearly displaying the possible routes and expected procedures involved at each stage.

In order to ensure that the DATF models are as effective and valuable to industry as possible it has remained a key factor as this research has progressed to periodically "re-assess' the overall structure and content of each model. This has proved highly useful in allowing for gradual 'modification' of the models as new data either derived through subsequent research or case study analysis is introduced or utilized to refine the model aspects for maximum effect. As well as the content it is also key that the application of the models, their 'interaction' with the user, is as streamlined as possible.

Despite the continual refinement of the DATF model aspects the most essential 'modification' stages occurred during the 'review' period involving both industry and academia. In order to provide some veracity and justification of the ideas and concepts stated in the DATF model with reference to the automotive remanufacturing practices, external review of the research output by reliable and suitably expert sources was required. For this review stage two external industrial remanufacturers specializing in the automotive sector were selected (Company 1 & 2). Their task was to use grading systems and commentary to provide valuable feedback in response to the DATF models. The different features of the DATF models were presented as a series of statements that the reviewers could then assign a rating (how much they agreed or not) and give reasoning.

The academic side of the review was conducted through a similar process but involved a ‘workshop’ style scenario with a group of researchers and post doctoral experts all familiar with the remanufacturing field both from an academic and more primary hands-on perspective.

Post this initial review the feedback and data gathered was collected and studied in order to determine the most suitable modifications, if necessary, required to bring the DATF models to the desired standard and ensure that they were of greatest benefit to those operating in the field. The results of the reviews were highly informative, both sides of the review stage (Academic Workshop, Industrial expert review) produced significant feedback, which aided in both the further development of the individual DATF models but also helped showcase the need for the concept as a whole. Individual points of feedback and the changes that occurred therein are addressed in a later section of this chapter, at the moment the points of interest that were noted were those connected to the ‘need’ for the models and the hypotheses that generated them. From early case study work conducted for this research the concept of a ‘need’ for a more defined structure to inspection within the remanufacturing process was identified (Errington 2009; Ridley and Ijomah 2015). Though formed through exposure to the industrial remanufacturing operation this specified ‘issue’ although deemed vital by the researcher was difficult to validate in an empirical manner across the sector. Based on the academic data and with the benefit of initial primary experience this concept was developed through multiple case studies and further research (Yin 2011). The output of this body of work, the DATF models are a direct response to this initially perceived problem. While greater data collection from companies operating in the sector lends some level of legitimacy to the ideas presented, only a more thorough review by those operating at the top of the filed and of sufficient size as an operation could begin to clearly mark the beginning of true validation.

In the case of the industrial reviews both companies selected responded with highly positive feedback, giving full credence to the initial claims put forward by the researcher that inspection as a process within the automotive remanufacturing sector has become over-reliant on the personal opinion and tacit knowledge of long term operators who base their actions and procedures on the benefit of long experience. While this type of reliance within the operation may lead to general success across the sector it does lead into several problems that are then spawned from the acceptance and identification of this initial concept. Most specifically is the level of 'bias' that is likely present in the opinions and assumptions of the specified operators. In the type of activity that requires any form of external judgment the aim of the observer should be to make such decisions with as little assumption or skewed bias as possible (Piva, Santarelli, and Vivarelli 2005). In other operations outside of remanufacturing these types of activities are typically accompanied by some form of data that is based on impartial and objective evidence and can be and should be used in conjunction with the observers judgment. In the case of remanufacturing, the creation of such a document or concept has not occurred to any discernable level most likely in response to the level of confidentially and IP that covers a significant amount of the internal operations and specialized technology often developed in house to aid with remanufacturing operation such as disassembly and inspection (Majumder and Groenevelt 2001).

In such a competitive field any advantage gained through successfully developed highly specialized inspection technology remains a closely guarded secret to the company in question. With the relevant knowledge in question being limited to a small selection of individuals within the company the next issues that arises is one of an increasingly aging workforce (DeLong et al. 2004). While as a sector remanufacturing has been growing as cultural and social awareness of the need for sustainability has increased, drawing individuals to the more manual and physical labor aspect of the operations has been difficult in recent years. Many of those operating within companies at the top of the filed in the UK lean towards the older end of the age spectrum with the likelihood of retirement within several years being a strong possibility.

While the actual choices involved for these types of decisions are based on a variety of factors the realization that the if the individual is no longer available and as such no longer there to provide the experience and tacit knowledge is a significant threat to the continued success of the remanufacturing operation. Transferring this knowledge in way or method more direct than merely ‘watch and learn’ is of invaluable aid in this area (Calo 2008). New staff have to be provided with some form of data access in which they are no longer as heavily reliant on their own opinions, or of the transferred subjective assumptions from training..

The next issue from this point is then the communication of the information gathered through the experience of the operator in question. Feedback from the reviews showed that the suggested methods of the Damage Forms for evaluating the condition of newly arrived core based on descriptive grading made for excellent points of understanding between those already operating at the facility in question.

8.3 Results:

This section details the feedback and data provided through review sessions of the DATF models with those operating in the industrial sector as well as the benefit of the remanufacturing research group within Strathclyde University. Firstly the industrial feedback will be discussed with the areas of concerns of interest noted in the feedback gaining the most focus. The results of the academic review will then be detailed including the areas where the purposes and key features of the models was communicated most effectively to the proposed audience.

8.3.1 Industrial Review Responses:

Rating – (1 2 3 4 5) +			
Question	**R1**	**R2**	**Average Value**
1. Do the DATF damage categories sufficiently cover the key forms of damage that may be encountered by the operator?	**3**	**5**	**4**
2. Does the grading system used to assess these categories cover a suitable range of the potential levels of damage encountered?	**4**	**5**	**4.5**
3. Do you believe that the DATF damage categories/grading provide a useful method of conveying important and valuable information within a straightforward approach to the operator in question?	**5**	**5**	**5**
4. Does the POM (Pyramid of Methods) Model present potentially relevant and useful information on the available type of inspection technology to the user?	**5**	**6**	**5.5**
5. Does the POM (Pyramid of Methods) model present the information it contains in an effective and suitable manner?	**6**	**5**	**5.5**
6. Does the structure of the POM convey the differences in the various inspection "Levels" in a clear and concise format?	**3**	**6**	**4.5**
7. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that the level of qualitative impact on the final assessment decision decreases?	**5**	**5**	**5**
8. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that the level of quantitative data available to the user that may impact on the final assessment decision increases?	**2**	**6**	**4**
9. Do you find that the POM Database (which details the various methods described in the visual model level) conveys appropriate and suitable information to the user?	**5**	**6**	**5.5**
10. Does the RaPID guide present a potentially useful and valuable tool to less developed Remanufacturing Companies?	**5**	**6**	**5.5**
11. Do the RaPID guide steps to successful "Inspection" cover the key factors and provide a suitably comprehensive overview of the requirements of this process?	**6**	**6**	**6**
12. Do you believe that the RaPID model in conjunction with the criteria discussed in the DATF model & POM could be used as a valuable training tool in turning unskilled labour into more skilled labour?	**5**	**5**	**5**
13. Does the IICAE (Internal Inspection Comparison Assessment Evaluation) present a potentially valuable tool allowing for the company in question to self-assess the efficacy of its operators in this area?	**3**	**5**	**4**
14. Do the methods stated within the IICAE to assess the operator allow for a relatively unbiased and objective result?	**5**	**6**	**5.5**
15. Do you find that each Model may be used independently or in conjunction to the benefit of the user?	**5**	**6**	**5.5**

Table 21 – Validation Review (Industrial)

Company 1:

The 4 DATF models were reviewed externally by Company 1, which is an independent automotive remanufacturer in the UK. This company had previously been the subject of a case study and so was ideally placed to provide review on the assumptions and output of the research that generated the DATF models for inspection and assessment. Each model was abridged into its key features and relevant data, the full model sections are significantly extensive and a full review of each would be an extended undertaking that would make it unlikely that industrial companies would take time to review them for the purposes of this thesis. However each ‘cut-down’ version still maintained the core of its usage and the data that accompanied it allowing for a suitable review of each model and its aspects by those operating in real world conditions and the befit of extended experience.

The review was conducted across a period of time to allow for full review and consideration to be given by the company and the results of the review were very positive. Several modifications and additions were suggested by the company and key points were discussed in detail, however, the overall response was that of a company who believed in the value that the DATF and its component sub-models present to the industrial sector.

Several key points included the construction and paths used to build the RaPID model for inspection procedures. This model was viewed positively by the company however there were certain path routes that they stated could be altered or modified to better fit the model and/or better represent their own experience of the remanufacturing process. These suggested changes were noted for later modification of the DATF models based on the feedback (this review and modification of the models would not occur until after all external reviewers feedback was gathered).

The POM model was reviewed in terms of both the methods stated as well as their inherent hierarchy within the pyramid levels. Feedback regarding these factors allowed the researcher to re-assess the assigned structure within the model, since some methods though selected for middle levels were viewed by the external company as more difficult to utilise and implement for the majority of remanufacturing organisations due to the availability and expense of the technology involved. As such the inherent difficulty faced by the user in terms of both adaptation and the sufficient level that they should be at before advancing to this method were deemed to be higher than previously assigned. The terminology of some points of the POM were also addressed with key terms being unknown to the external company or known by different names. This factor was rectified by the understanding that while many companies may have different terminology for similar actions/procedures, those used in conjunction with the Model(s) can be considered defining terms in relation to the overall research.

In addition the IICEA model being as an internal company audit of the efficacy of the current inspection methods and procedures was noted as positive idea, with both structure and criteria gaining approval from Company 1. The DATF data sheet was reviewed well although clarification on the part of the researcher was required, since in its current state the data sheet is generic and the associated information led to the assumption that it was to be used by the user (operator) in the assessment of every component of a core, an action that would highly inefficient and require extended periods of time. The researcher addressed this worry by suggesting that the data sheet be used primarily with the most high value parts of the core, reducing the amount of time needed to fill out the information.

Company 2:

Company 2’s feedback has the benefit of being recorded by two key operators within the operation. This allows for two sets of the same evaluation form to be used as comparison within the company experience/expert opinion. Feedback included key constructive criticism, with suggestions regarding the potential improvement or refinement of the models developed.

In particular the applicability of the DATF damage categories to some aspects of the market were discussed during the feedback from Company 2. The point of issue was in relation automotive safety components (such as brake systems etc.) where the use of a grading or scaling system may not be as directly viable as it would be with regard to ‘core’ products such as transmissions or gearboxes. In regard to such cases the idea of providing a simple YES/NO system based on tight tolerances adhering to safety standards is a valuable idea, however in order to develop such a system the newly designed model would have to be very highly tailored to the needs and requirements of the company remanufacturing said safety equipment in order to provide a valuable addition to their existing set-up.

Generating such a model (acting as a partly generic but detailed/tailored model for applicable use by all automotive safety equipment remanufacturers) would require extensive review and co-operation with at least several companies operating in this area in order to produce a viable model (Röglinger et al.2012). While this could be possible, the time requirement would have limited the development of the other models while providing an output with unique value only to a single subset within the overall market. The purpose of the DATF models is to provide value and a solid basis for improvement for as wide a range of companies operating within the automotive remanufacturing sector as possible, as discussed during earlier sections of this thesis **(Chapter 1, 2 & 6).**

With regard to future research the hope is to use the DATF models as a foundation from which to build more detailed and targeted process aids for those operating within the sector. This future research may very well include a more structured YES/NO system as discussed, however, it is not a feasible avenue at this point. Those companies operating within the automotive safety equipment remanufacturing sector may not gain quite as much use from the existing DATF criteria as others in the field however the remaining models should still present a valuable resource for their usage if desired.

In the case of independent remanufacturing organisation the remanufacturing standard and associated technical data used to bring the product or part back to OEM level is developed internally through reverse engineering (Freiberger, Albrecht, and Käufl 2011).

Another key point discussed during feedback was in relation to the viability of the RaPID, POM and DATF criteria being used to turn unskilled labour into a more skilled workforce. Company 2’s feedback illustrated that while they felt that it may not turn a completely unskilled labour force into highly skilled operators it did present a highly effective method for improving the overall effectiveness of the assessment processes, streamlining the existing operation and more easily allowing for the identification of scrap waste and parts uneconomical to remanufacture.

Discussion:

This feedback has been invaluable in both confirming the assumed potential value of the DATF models to industry and also for highlighting where they rise and fall in regard to their direct applicability. Issues such as the stated terminology, the value of the scaling grading system for damage assessment and the structuring of the POM methods have all been discussed during the feedback sessions. From the results of the debate some modification of the existing models incorporating suggested changes or new knowledge have taken place.

The final validation of the models involved a workshop, in which engineers and managers operating within the highest end of automotive remanufacturing provided feedback, generating validation through expert opinion. The initial review sessions allowed for potential issues to be identified ahead of the final validation workshop and all necessary modifications made and justifications noted.. This ensured that the DATF models were as fully developed and rigorously tested as possible (in both academic and industrial circles).

Academic Workshop:

As previously stated the DATF models were assessed in an early workshops in preparation for the industrial review, the feedback from those sessions was very useful in determining where (from an academic perspective) the models appeared positive or negative. In particular the benefit of the opinion of those experienced in the same field but with a different perspective provided numerous alternative viewpoints that may otherwise have been overlooked.

8.4 DATF academic validation workshop

This section will focus on the validation stages that were undertaken as part of the rigorous testing of the thesis output, in this case the DATF model and associated sub-models. This validation could not feasibly be carried out in the desired industrial conditions (implementing the DATF into Company A, B, C and observing the results after 6 months) due to the level of expense in terms of structural change in both operations and internal company routine as well as the likely financial risk associated with this scenario. Ideally the concept of using a small company with this chosen field (automotive remanufacturing) as the basis of the validation was considered; working with them to adopt the DATF model into their general operation and then recording the result over the course of several weeks or months. However as became apparent when given thorough consideration, this scenario would necessitate the increased risk to the partner company and as such strict financial recompense would have to be established so that no significant loss may be observed by the partner company during the validation period (introduction of new structure plus training workshops would likely incur several days of lost profits and extend lead times at minimum).

As stated earlier in this chapter the final selection from true assessment for the DATF model focuses on validation through expert opinion. This scenario involves multiple individuals from both 'hands-on' and manager level from a variety of companies operating within this field to provide opinion and evaluation of the DATF properties including their perceived potential value to both themselves and the industry as a whole. As these validation workshops pull the experience from several companies the received data gathered for evaluation purposes can be cross-referred to give a much more accurate and robust review of the DATF models potential than any single company. In addition to this the use of academic workshops also allows for those operating at a research level to provide their open feedback and expert opinion on the model properties.

This first workshop was academically based and used the Strathclyde remanufacturing research group as its focus. This group is comprised of several notable academics within the field of remanufacturing as well as PHD students in various stages of their degrees and all have a focus on the remanufacturing sector. The purpose of this workshop was to evaluate both the DATF model itself but also the method and presentation style in which the information was communicated to the audience. Conducted as a several hour session within university grounds the workshop was structured as an interactive presentation with the audience being presented information on each model and encouraged to question and debate with the presenter as well as a set time for additional questions at the end of each section. The use of purpose designed evaluation sheets with which to 'grade' the potential value of the models through a series of 20 key points including commentary for explanation of assigned grade allowed for a detailed understanding of the perceived 'pros' and 'cons' of each model during this presentation as well as an external viewpoint on the successful communication of the concepts, a highly beneficial aspect in the route for effective and successful presentation of ideas during later industrial workshops.

8.4.1 Academic Review Responses:

Rating – (1 2 3 4 5) +			
Question	**R1**	**R2**	**Average Value**
1. Does the Inspection Process Overview Model constructed for use in this Model Application Review present a suitable overview of the various stages of Inspection that occur during the typical Automotive Remanufacturing Process?	**6**	**5**	**5.5**
2. Do the DATF damage categories sufficiently cover the key forms of damage that may be encountered by the operator?	**5**	**3**	**4**
3. Does the grading system used to assess these categories cover a suitable range of the potential levels of damage encountered?	**6**	**6**	**6**
4. Do you believe that the DATF damage categories/grading provide a useful method of conveying important and valuable information within a straightforward approach to the operator in question?	**6**	**5**	**5.5**
5. Does the POM (Pyramid of Methods) Model present potentially relevant and useful information on the available type of inspection technology to the user?	**6**	**5**	**5.5**
6. Does the POM (Pyramid of Methods) model present the information it contains in an effective and suitable manner?	**6**	**3**	**4.5**
7. Does the structure of the POM convey the differences in the various inspection "Levels" in a clear and concise format?	**6**	**6**	**6**
8. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that the level of personal judgement on the final assessment decision decreases due to the benefit of additional more objective data?	**6**	**1**	**3.5**
9. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that this level of additional data (gained through various methods beyond visual inspection and judgement) can only produce a positive impact on the final pass/fail decision for the part/core in question?	**6**	**6**	**6**
10. Do you find that the POM Database (which details the various methods described in the visual model level) conveys appropriate and suitable information to the user?	**3**	**4**	**3.5**
11. Do you agree that the 'Steps' detailing the actions to be taken in each method of the POM Database provide a detailed and comprehensive breakdown of the necessary steps for the user to follow?	**6**	**6**	**6**
12. Does the RaPID guide present a potentially useful and valuable tool to less developed Remanufacturing Companies?	**5**	**5**	**5**
13. Do the RaPID guide steps to successful "Inspection" cover the key factors and provide a suitably comprehensive overview of the requirements of this process?	**6**	**6**	**6**
14. Do you believe that the RaPID model in conjunction with the criteria discussed in the DATF model & POM could be used as a valuable training tool in turning unskilled labour into more skilled labour?	**4**	**5**	**4.5**
15. Does the IICAE (Internal Inspection Comparison Assessment Evaluation) present a potentially valuable tool allowing for the company in question to self-assess the efficacy of its operators in this area?	**5**	**6**	**5.5**
16. Do the methods stated within the IICAE to assess the operator allow for a relatively unbiased and objective result?	**5**	**6**	**5.5**
17. Do you find that each Model may be used independently or in conjunction to the benefit of the user?	**6**	**6**	**6**
18. Do you agree with the placement of the DATF models within the inspection overview as described in the initial point?	**5**	**6**	**5.5**

Table 22 – Validation Review (Academic)

Key aspects noted during workshop:

Terminology:

Previous to this workshop the assigned terminology at use prevalently throughout the thesis involved many terms to which a certain degree of uncertainty still existed. Within the remanufacturing field there are a number of terms either detailing key processes or conditions which are known by multiple variations. During this workshop the specified names used to provide categorisation to factors such as the damage catagories and those provided for structuring the inspection stages were called into question due to their potentially non-specific or less accurate nature. Discussion with academics at this stage of the workshop revealed that several of these terms did not in fact reflect the information or concepts behind them in the most efficient or effective manner. A review of these terms with new and more accurate terms in place was conducted at a later date.

Categorisation:

The categories selected to cover the varying forms of damage that can be encountered during inspection procedures were reviewed during this workshop. The terminology used as part of these categories was noted for changes to reflect a more accurate description however the categories themselves were found to be highly suitable and provide a valuable breakdown of the possible conditions of incoming parts. The categorisation itself was also reworked to include a ‘top level’ and ‘lower level’ separation of categories with those deemed most vital to the success of a part placed at the topmost points.

Visual models:

The Visual aspect of the models is an essential part of their overall effectiveness. While the majority of the 'key detail' of these models can be found in the information they convey the visual style in which it is presented remains a highly valid factor. During the academic workshop the visual presentation of model aspects such as the DATF criteria web, the DATF predictive core condition and the RaPID process stages were all reviewed to ensure that the data was presented in the most effective manner. Feedback from the academics highlighted the fact that the visual representation used for the POM data showcased clearly the varying levels of methods that could be used for inspection purposes as well as breaking them down into a series of gradually increasing levels in terms of accuracy and less reliance on personal opinion. However it also highlighted the fact that the visual model clearly shows the method categories but was not as clear at displaying the main method groups in each category. . A more detailed visual representation of the POM including the methods that form each category was then devised as a supplementary addition.

Intended user base:

From the outset of the thesis the output has always been targeted primarily as a tool designed for industry. To be of use to those working at the most 'hands-on' level of the remanufacturing operation, during discussion and feedback from the presentation of the DATF model the academics involved with the workshop noted the level of detail and discussion of complex concepts unique to the niche area in question. This is in part an unavoidable factor due to the highly involved nature of this area and the surrounding factors. In order to effectively discuss the benefits and limitations offered by the DATF models a relatively high level of understanding is expected so as to conduct the workshop within a reasonable time frame without the need for additional explanation.

From the thesis standpoint the data can be more extensively expanded upon and given full background through its length and the ability to go back and reread sections for further clarification if required. In terms of delivering the data in a presentation manner where it has to understood and relevant enough to hold the attention of the audience though the question of how much data should be delivered and what manner is the area for further investigation.

Applicability to other sectors:

During discussion with this workshop the viability of the 'structure' and 'methods' used to build the DATF being applied to other sectors of remanufacturing inspection was brought up. Academics involved with this discussion noted that the overall approach displayed by the model of the DATF while focused at the automotive sector could provide a very solid basis from which to adapt from other areas such as Aerospace or EEE.

Potential future research:

Feedback from the presentation included a discussion on the level of 'personal tailoring' that the DATF models could reach for potential users. The categorisation of expected or recorded damage, in turn providing both training foundation and common standard, is structured in such a fashion that suitable and more accurate data can be reduced however it still exhibits a certain level of 'generic' quality in terms of available data and suitability of its approach to all relevant company structures. The concept was further detailed as an avenue of future research that would build upon the outputs of this thesis. Post thesis acceptance future work would utilise the DATF model output as a foundation from which to build more specified and 'tailored' model approaches for an individual company, in consultancy with this author the specified users data would be utilised to generate such a 'reviewed and modified' set of models for maximum effect and user satisfaction.

The use of this research as a basis from which to eventually build an industry standard in terms of part/core damage condition was discussed during post model debate where the potential 'endpoint' of the overall research was given consideration. Ideally the output of the thesis would be developed post-graduate.

Level of data communicated successfully:

As a whole the presentation workshop was found to be highly valuable providing vital feedback and new perspective on the research outputs. The aim and structure of the models gained an overall appreciation and positive review by those at the workshop, while the level of effectiveness in the communication of these concepts was less positive. A more refined and developed presentation which communicated the key points of each model was developed based on the feedback so that more efficient communication would be in place during the industrial workshops. During feedback discussion the aspect of the level of information and 'new data' that is presented to the potential user during the workshop scenario was deemed to be too excessive.. Each DATF model has several unique defining points that contribute to the inherent novelty in the overall output and the value of the thesis, as such these points should be presented as clear and distinct 'highlights', showcasing their value ahead of any additional data dump of the more mundane aspects that detail the development and use of each model.

8.5 Addendum to DATF Damage criteria:

The following section details some key points that have become more relevant post-review and initial validation. While these features may have been touched upon within the main chapter this sector provides a more comprehensive and detailed discussion and investigation into stated areas of interest.

The DATF grading system (utilising the specified damage categories and grading them based on a grading criteria) has been purposely designed to aid inspection and assessment procurers within remanufacturing organisations. Targeted at the automotive sector in order to provide a more specialised and valuable model to a significant sector as opposed to a more widely applicable but generic solution, its key features involve providing a more structured and quantifiable approach to the process of parts/core assessment, reducing the inherent reliance on personal experience and knowledge and instead allowing for the more impartial training of new staff. Within more developed companies these aims may not be required and instead the models benefits would include the data provided aiding those in internally streamlining the overall operation.

The applicability of this criteria to all aspects of the automotive sector and to the overall industry is a factor worth discussing in greater detail. The potential applicability of the criteria and the overall model to the sector is highly reliant on the type of Core in question. The 8 damage categories highlighted in the model have been designed to cover as wide a range of potential issues (faced by a variety of automotive parts) as possible. Therefore not all categories will be immediately applicable or useful to the company in question; "Burn Damage" a category typically associated with motorised components will be "n/a" to a remanufacturer of Camshafts or Torque converters. Likewise "Part Mobility" will not be a factor relevant to a remanufacturer of engine blocks or core bodies. The selection of suitable categories for a company undertaking the usage of the DATF models is a factor that is down to the discretion of those within the company. Further development of the DATF models may involve a consultancy situation between the researcher and the company however at this stage the DATF models are designed to operate individually or in parallel and outside the adjustment or modification by the researcher.

In terms of the suitability of a 'grading scale' form of assessment to record and differentiate the levels of potential damage found during inspection; core and parts can very significantly in terms of geometry, purpose, material, longevity and functional requirements. In order to produce a system that would allow for each factor that may be found to be addressed the model would have to be substantially larger and would likely be to the detriment of the user as such a large volume of material to work through each time would make efficient assessment an unfeasible task. Therefore through investigation and analysis the most relevant and widely used categories were identified, including the main key forms of damage likely to be encountered. Any additional categories, perhaps those more niche due to the nature of the core in question could potentially be introduced into the model by the company using the structure and approach as a basis from which to tailor the model more accurately to their needs.

Remanufacturers of automotive safety equipment (i.e. braking systems) would likely wish to utlise the DATF criteria in conjunction with their own highly developed safety standards. It is completely understood that the OEM standard in these cases is often an industry standard of safety on the part/product and has much tighter and more developed tolerances than may be found in other parts. However there does still exist room for the DATF damage categories to be applied and aid in the assessment process, where applicable the standards defined by industry or an external body (safety compliance etc.) remain.

While it is desirable for the DATF models to become the main form of damage assessment criteria, in order to be further developed in this manner this model would be required to be much more sector specific (only being viable to a select faction of the overall industry). It would also likely require full access to many companies own bespoke assessment methods in order to much more accurately focus the criteria.

This information is typically very highly guarded and confidential and is therefore very difficult to acquire and more likely unpublishable. One of the reasons that the research from this thesis is viable is due to the fact that while it is the product of extensive investigation of both the industrial field and the procedures and methods in play it does not specify the unique or bespoke features of any individual company. Rather it utilises the data gathered and through the output provided (the DATF models) allows companies utilising this approach to build their own more internalised bespoke systems using this as a foundation. By providing this slightly more generic basis many companies currently underdeveloped in this area have something to develop in conjunction with their own ideas or direction as opposed to the majority of data remaining unavailable due to red tape and confidentiality. In addition the bespoke methods for one company may not be viable or applicable to another.

As such the ‘grading’ model suggested and detailed by the DATF is the more viable solution in the eyes of this researcher. Its approach allows for each aspect to be self-assessed by the company in question in order for them to select which factors are relevant to their own operation. The use of the other models provides significant data with regard to the undertaking of the operation with this data as well as the ability to self-audit and assess the efficacy of those involved.

From the general feedback the outcome of the academic workshop was very positive. All academics involved found value in the inherent ideas and concepts of the DATF models, providing further peer-reviewed justification of the basic assumptions and foundation that the research has been built upon. In particular the DATF criteria grading system was met with positive reception; discussion and debate concerning the applicability of the ‘damage’ categories and the grading system itself to single company use as both a training tool and the beginning of a potential industry standard was highly valuable.

8.6 Final Validation Results

The Validation Panel itself comprised of several expert remanufacturers acting in key areas of the remanufacturing process and all with experience of inspection procedures as well as multiple years spent operating within industrial remanufacturing activities at the top of their field. Following a similar format to the practices utilised in the academic workshop and industrial reviews the expert validation activity involved the use of feedback forms allowing for both grading and commentary by the participants in order to fully evaluate the various aspects of the DATF Models.

This activity involved an on-site visit in which several hours were blocked in for the evaluation workshop. The initial stage involved physical hand-outs of several documents detailing each section of the DATF Model (DATF, RaPID, POM and IICEA) in extensive depth ensuring that the reviewers would have every chance to provide a fully informed opinion and evaluation. After this a short discussion regarding the aim and procedures of the workshop were undertaken, this allowed for all involved to have a full understanding of all relevant factors such as, method of evaluating data, presentation style of data, time limitations and review procedures. When this was finished and all participants were satisfied with the function of the workshop a 1 hour presentation was conducted by the researcher. The aim of the this presentation was to detail the inception, development and purpose of the proposed Models; providing a solid foundation for their creation to the participants, with the presentation ending with a brief overview of each suggested model, including its benefits and limitations. After this stage the room was then open to discussion and questions during which the presentation was scrolled back and forth to the relevant slide in question for the purpose of the debate and features such as the justification, personal experience, identification of issues, possible unforeseen detrimental and positive features of the models and its potential further development were all discussed at length.

After this stage the workshop was then finished up with each member of the validation workshop receiving a physical copy of the evaluation form and additional pertinent data. After a final time for any remaining questions the participants then agreed to spend the next several days reviewing both the physical hand-outs they were supplied with as well as a digital copy of the presentation in order to fully evaluate the models. The results of the workshop were then collected by a liaison at the facility and received by the researcher within 14 days of the initial workshop. The key results from the reviewers can be observed below.

Rating – (1 2 3 4 5) +					
Question	**R1**	**R2**	**R3**	**R 4**	**Average Value**
1. Does the Inspection Process Overview Model constructed for use in this Model Application Review present a suitable overview of the various stages of Inspection that occur during the typical Automotive Remanufacturing Process?	**5**	**4**	**5**	**5**	**4.75**
2. Do the DATF damage categories sufficiently cover the key forms of damage that may be encountered by the operator?	**5**	**5**	**5**	**4**	**4.75**
3. Does the grading system used to assess these categories cover a suitable range of the potential levels of damage encountered?	**5**	**4**	**4**	**3**	**3.75**
4. Do you believe that the DATF damage categories/grading provide a useful method of conveying important and valuable information within a straightforward approach to the operator in question?	**5**	**4**	**4**	**3**	**3.75**
5. Does the POM (Pyramid of Methods) Model present potentially relevant and useful information on the available type of inspection technology to the user?	**5**	**4**	**5**	**4**	**4.5**
6. Does the POM (Pyramid of Methods) model present the information it contains in an effective and suitable manner?	**5**	**6**	**5**	**3**	**4.75**
7. Does the structure of the POM convey the differences in the various inspection "Levels" in a clear and concise format?	**6**	**4**	**5**	**5**	**5**
8. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that the level of personal judgement on the final assessment decision decreases due to the benefit of additional more objective data?	**5**	**4**	**5**	**6**	**5**
9. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that this level of additional data (gained through various methods beyond visual inspection and judgement) can only produce a positive impact on the final pass/fail decision for the part/core in question?	**5**	**4**	**5**	**6**	**5**

10. Do you find that the POM Database (which details the various methods described in the visual model level) conveys appropriate and suitable information to the user?	**5**	**3**	**4**	**4**	**4**
11. Do you agree that the 'Steps' detailing the actions to be taken in each method of the POM Database provide a detailed and comprehensive breakdown of the necessary steps for the user to follow?	**5**	**4**	**4**	**4**	**4.25**
12. Does the RaPID guide present a potentially useful and valuable tool to less developed Remanufacturing Companies?	**6**	**3**	**4**	**4**	**4.25**
13. Do the RaPID guide steps to successful "Inspection" cover the key factors and provide a suitably comprehensive overview of the requirements of this process?	**5**	**3**	**4**	**5**	**4.25**
14. Do you believe that the RaPID model in conjunction with the criteria discussed in the DATF model & POM could be used as a valuable training tool in turning unskilled labour into more skilled labour?	**5**	**3**	**5**	**5**	**4.5**
15. Does the IICAE (Internal Inspection Comparison Assessment Evaluation) present a potentially valuable tool allowing for the company in question to self-assess the efficacy of its operators in this area?	**5**	**3**	**4**	**4**	**4**
16. Do the methods stated within the IICAE to assess the operator allow for a relatively unbiased and objective result?	**5**	**4**	**5**	**4**	**4.5**
17. Do you find that each Model may be used independently or in conjunction to the benefit of the user?	**6**	**6**	**4**	**5**	**5.25**
18. Do you agree with the placement of the DATF models within the inspection overview as described in the initial point?	**6**	**6**	**5**	**4**	**5.25**

Table 23 – Expert Panel Validation

As can be noted these results display the model within the positive side of the scale. The accompanying commentary displayed the expanded reasoning for much of the grading given. The general consensus regarding the model by the review panel was that it provided a valuable and useful structure to those operating within the inspection activities and operations of automotive remanufacturing. During the expanded discussion and commentary of the validation workshop the need for closer refinement of the models to an individual company's needs in order to gain full effectiveness was noted. This feature is a highly essential aspect of the aim of the model and is one that has been previously discussed in earlier chapters, since the aim of this solution (The DATF Models) has always been to design an output that could develop and grow with the industrial partner that it is operating with. The early aims of the research were to develop such a solution that further modification would be unnecessary, however, this was quickly realized at an early stage as simple fallacy.

Remanufacturing as a field is rapidly growing and evolving due in relation to our societal and cultural shifts towards sustainability in recent years. This act has allowed for new opportunities and legislation to be enacted and observed which present many chances for change and potential greater success for individual companies and the sector as a whole. In conjunction with this the overall field of remanufacturing while investigated to highly developed extents in the last few decades still remains a relatively niche aspect of industry within the public consciousness and traditional manufacturing.

Due to these factors the remanufacturing field does not share as many similarities and organizational components across companies as the traditional manufacturing world does; the understanding and development of recent standards and terminology have done much to improve both the private practices and public image of the field yet substantial differences remain from company to company. As such the model developed from this research while limited to a particular sector (Automotive) is still limited by the differences and unknown factors of this aspect of the field. The model therefore walks the line between *generalization* and *specification*; an action which has remained difficult throughout the development process.

The models therefore act as a solid foundation and structured approach to multiple aspects of expected inspection activities encountered during automotive remanufacturing. The room for further specification or modification of individual model aspects or features for the purposes of ensuring that they are of greater aid to the specified company in question exists, however it is well noted during the model development and at these later stages that this is likely the work of post-doctoral studies.

Throughout this validation process it has been strictly stated by the researcher to all those involved that the evaluation and review of the output of the research must be as critical as possible. Due to the highly qualitative route much of the research has taken both in terms of data collection but also the validation process (Expert Review Panel) it has been essential that no level of bias either positive or negative towards the research or researcher or the participants be involved. As such no member of the validation Panel had met with the researcher apart from the official liaison for the process. It was re-iterated at the face-to-face presentation and discussion meeting that the aim of the model(s) are to be utilized by others operating in the same area of industry as themselves and as such should be judged as if each member were provided with such material in the undertaking of their day-to-day activities.

Due to this level of objectivity during the review and validation processes it can be safely assumed that the results of the workshop are a genuine representation of the potential value perceived by the experts selected from industry.

8.7 Summary of Chapter 8

In summary of this chapter, the DATF models which have been developed in response to the research and findings conducted during this thesis have been thoroughly evaluated and validated by expert members of industry and academia. The workshop scenarios set-up by the researcher have been designed to provide as much objective and impartial feedback as possible giving as true a result as can be obtained.

Due to the level of complexity in the models, practical application and the monitoring of long-term evaluation in an industrial context proved unfeasible. This is largely due to the time and resource limits of the research, since if undertaken such a form of validation would require large monetary expense primarily in the form of ensuring that any company involved did not suffer any financial losses from the time taken to implement such models into their company's daily operations and that it did not reduce lead times too far during usage.

While such a scenario would likely provide invaluable intel into the practical usage and application of each model within such a realistic environment it must remain an objective to be tackled at a later stage of the academic career.

CHAPTER 9: CONCLUSIONS

9.1 Introduction

Remanufacturing is defined as the process of returning an End-of-Use (**EoU**) product back to OEM standards and with new warranty (Ijomah, et al 2004; BSI 2009). Within this operation are distinct stages including; disassembly, cleaning, and inspection. The *inspection stage* is the assessment of EoU products or "core" post disassembly in order to ascertain the viability of parts and the necessary actions needed to bring the core back to OEM standard. In Hammond (1998) and Lund (1983, 1985) the critical nature on inspection with regard to remanufacturing is noted, as effective assessment ensures suitable actions are taken, and defect detected.

More recently Errington (2009) and Ridley (2015) have given this activity greater focus, with the need for structure first pointed out by Errington who developed a generic overview to cover the entire remanufacturing field. Ridley meanwhile took a highly specialized view and examined new strategic approaches to improving the efficiency of inspection from an economic perspective, based on extensive single company research.

Investigative studies conducted across the UK, Europe and US have shown that within the Remanufacturing and aftermarket sectors Aerospace, Automotive & EEE typically make up the largest segments of the market. (Parker et al 2015)

This research sought to assess the condition of inspection practices within the automotive remanufacturing sector, to understand what the issues faced by inspectors were, what procedures and, methods were used, and why guidance in this area was not already available. This research has aimed to examine these factors from an activity point of view rather than a business or economic one in contrast to previous work. This research also specifies a single sector of the remanufacturing industry to examine to ensure a suitable level applicability to real world industry.

It has examined the scope of the problems faced by inspectors across the UK automotive remanufacturing sector and identified a number of detrimental factors to the greater uptake of successful inspection, these factors were addressed through further research.

9.2 Key inspection factors.

The major problems in inspection include over-reliance on tacit knowledge and opinion, leading to assumptions and bias passed on as fact during training, difficulty in knowledge share between operators, and a clear lack of adaptability to new technologies or methods. These factors were those that would most clearly present problems for remanufacturing companies in the future as they attempted to either expand or remain relevant against increasing competition and new manufacturing designs.

The research has developed a 4-part model that targets these issues by providing, firstly a complete overview of all inspection activities as they occur across automotive remanufacturing, also a highly detailed criteria based approach to assessing core damage during inspection, and an extensive database of suitable inspection technologies and their benefits and limitations. This covers only a few of the many capabilities of the DATF models; the criteria based assessment system also acts as a data-gathering tool that can be used to observe trends in rising damage types or compare core condition pre and post storage. This model has been robustly validated by both industry at the highest level and key remanufacturing academics in the UK. The model capabilities allow it to be used as a thorough reference tool for training purposes across the automotive remanufacturing sector, regardless of company or core type.

9.3 The Significance of the research

The research is significant because it has tackled the main issues that face inspection within automotive remanufacturing, especially the lack of available knowledge regarding common practices and procedures. These issues include the over-reliance on personal expertise and the difficulty in knowledge share between an aging workforce and younger inexperienced staff.

- Over-reliance on expertise:

  Previous studies by Hammond (1998) and Errignton (2009) note through case study analysis that inspection as an activity can be heavily influenced by the skill of the inspector. The level of personal knowledge being seen as a core feature of successful inspection is further backed up by Ridley (2015), who proposes economical strategies to improve the speed and efficiency of assessment of highly specific core. However case study data from companies A – E has shown that there is a distinct over reliance on this personal knowledge, with a limited number of staff possessing the skills and expertise to successful carry out inspection. With further research showing that the issue of an ageing workforce severely affects this limited number, the need for effective guidance and structure for inspection is higher than ever before. This over-reliance on personal expertise does not reduce the capabilities nor limit the skill and knowledge of the operator but rather removes any external sources or reference tools that can be objectively judged and puts the decisions entirely within the inspectors personal judgment.

- Knowledge Share difficulties

  Papers by (Ijomah et al, 2004; Steinhilper 1998; Andrew-Munot and Ibrahim 2013) among others have shown that knowledge is king. The understanding and expertise of remanufacturing methods is a direct contributing factor to the success of the operation. Due to company IP and competition the majority of remanufacturers do not actively share knowledge developed in-house, as such the specific methods or tools developed by companies often stay unique to that company. Difficulties in common terminology are an issue that has plagued remanufacturing across the world until more recent advances in the research by Ijomah (2009). In particular inspection expertise has now become severely limited to a small number within the workforce, and at an increasing rate is also limited to an gaining workforce that has real issue in transferring this tacit knowledge effectively. Within training for inspection activities the ability to more impartially transfer skills and data is a highly valuable tool to the companies success and it is something that more and more remanufacturers in the UK are starting to struggle with.

9.4 Objective of the research

This research aimed to investigate the problems faced by inspectors within automotive remanufacturing and address them in a suitable manner. After the research completed it was clear that these objectives had been successfully met.

The key objectives met:

- Investigated inspection activities within automotive remanufacturing, detailing the routes, paths and stages involved..
- Identified the key issues affecting this are such as over-reliance on operator experience, lack of structure, difficulty in knowledge sharing and an aging workforce
- Developed a 4-part model (DATF) to combat these issues.
- Reviewed the model features with academia and industry at multiple stages to ensure value and suitability to the sector.
- Validated the findings through an expert panel.

9.5 Research question

The main research questions that were answered to satisfy the objectives of this research were:

- What is inspection in automotive remanufacturing?
- What practices and methods are used to undertake inspection?
- Are there barriers to inspection activities within automotive remanufacturing?
- Can the issues facing inspection activities be overcome?”
- Can criteria and models make inspection activities more accessible?
- Do these new models present inspection data in a valid and useful manner?

9.6 Contribution to knowledge and originality of the research

The principal deliverables of the research were;

1. A comprehensive overview of inspection activities and issues in automotive remanufacturing.
2. A structured multi-stage layout of inspection across the remanufacturing operation.
3. A descriptor and criteria based reference tool of the types of core damage encountered in inspection.
4. A 4-part model specifically designed to improve current inspection activities in automotive remanufacturing and provide a training basis for new staff.

The originality of the research lies in the fact that literature indicates that this is the first time that:

1. Inspection practices have been investigated from a procedure and method perspective. Up until this point the literature has examined this activity from a business and economic perspective, proposing strategies to make the process more economical rather than actually examining the procedures in place across the sector.
2. A more comprehensive and detailed overview of all inspection stages that occur throughout the typical automotive remanufacturing process has been developed than has been previously been detailed in existing literature**.**
3. A purpose designed criteria based damage grading assessment system that allows for greater impartiality from the point of view of the inspector has been created. This system also provides a specialized data gathering tool that aids in classifying damages in core, promoting knowledge sharing in-house and assessing the possible loss in value of external long term core storage.
4. A structured breakdown of the available methods and procedures that may be used by the inspector. Including new technologies that may be used to further improve inspection activities. The methods are structured into different tiers of a pyramid, with each tier ranking the increasing complexity and expense as the user moves up through the tiers of the pyramid. Factors such as "cost of required technology", "level of training needed", and "lead times for each method" are all taken into account.
5. An internal assessment system that can be utilized by the company to ascertain both the efficiency and effectiveness of their staff. This system involves a highly detailed 'stage by stage' method for ascertaining the characteristics of a successfully inspected part as it moves through the various stages of remanufacturing.

6. An analysis model that uses data gathered through grading stage to display common issues and conditions of core by make and model. This would allow inspectors to predict likely areas of failure before core enter the facility.

9.7 Beneficiaries

The main beneficiaries of the research are industry and academia.

Benefit to academia

- Academic:

  Provides a more in-depth review of current parts inspection practices than has been previously carried out, with emphasis on the identification of over-reliance and the justification/reasoning behind it. Provides greater basis for new avenues of research to be built on the findings of this research. By providing clear structure with the thesis models this research will act as one of the first steps in building a benchmark for all inspection activities across the sector. Additionally this thesis has also presented a new way of investigating the inspection stage of remanufacturing, the approach used here provided valuable data from industry sources and may be utilised as a structure to follow in future academic work.

Benefit to Industry

- Industrial:

  Displays objective review of available inspection processes, while providing operators with a structured less Qualitative approach to the assessment of parts and allows for further utilization of the data in the company benefit (Damage Prediction, Self-Assessment etc.) In addition RaPID and POM models allow for 'route-based' processes to be followed, provided more standardized training and approaches to method utilization than currently in widespread use. In particular the key advantage is that it could be used to help to design and implement effective and efficient inspection activities businesses, as well as to improve existing ones in use in automotive remanufacturing.

9.8 Methodology

The main research methods involved a systematic literature review and use of the qualitative research method Case Study analysis. Works by authors such as (Ijomah et al. 2005)were used to build the case study structure. Case Study approach was selected due to its highly suitable user based methodology, already noted for its effectiveness in other remanufacturing research. The Research Design and methodology can be found in Chapter 3.

9.9 Future

In previous sections the concept of applying the final output of the research, the DATF models based on aiding inspection practices within the remanufacturing field, has been briefly discussed with emphasis being placed on the use of the structure and styles of approach developed for this research being transferable in a new format as the most basic level.

Although the remanufacturing sector can be quite distinctly split into its constituent sectors there are similarities in terms of the technology and operational approaches across several of these sectors. When considering where to take the research forward after the doctoral stage of this thesis, multiple potential avenues of investigation and development became apparent. Refining the models with industry in the form of a consultancy based approach held significant merit when considered.

Two clear avenues of taking the research forward became apparent as the logical next stages in its continual progression, likely undertaken at a later date and with greater collaboration between academic and industrial bodies. The first was the considered transfer of the DATF model to alternative sectors of the remanufacturing field, for example the Aerospace or HDOR sectors in particular which sit alongside Automotive in the field of remanufacturing and share certain mechanical approaches. Due to a similar level of suitable technology in place in these aftermarket sectors when compared to Automotive it is likely that this would be the starting point when considering developing new forms of the DATF. Each specific aspect of the DATF models has been designed to operate independently or in conjunction with the purpose of aiding the act of automotive inspection during remanufacturing activities. As such each aspect has relied upon and focused exclusively on the automotive manufacturing and remanufacturing sectors when developing and generating the research outputs. There has been a small amount of overlap in terms of knowledge collection during the earlier stages of the project with academic literature review and initial industrial research referencing the developments and overlap of issues in other sectors of the remanufacturing field. In particular the critical nature of "Inspection" within the automotive sector is due in part to the level of core complexity and issues of standards and safety that typically require manual physical evaluation of parts and components. These factors are also present in similar sectors such as ‘Heavy Duty Off Road’ vehicles which maintain many of the same characteristics and manufacturing techniques as the former.

The second avenue of further research is the collaboration with a single industrial entity in order to refine the models features to further increase both its applicability and value to the entity in question. The DATFmodels have been designed to aid companies and organizations operating across the spectrum of size and development. Therefore, while the content and data communicated and provided is of significant depth and detail there are many instances where the factors such as the advisement and procedures of suitable inspection levels, communication of ideas or potential work routes that may be followed, have been displayed in such a manner as to provide a very effective ‘generic overview’ within this particular sector of the field. As such the models are of substantial value and aid to the sector but the use and positive factors gained from their integration into the typical automotive remanufacturing processes vary from company to company (often dependent on the existing technologies and strategies in place).

When discussing the further development of this research with external industrial operators during the validation phases of the research the value to industry as a whole was covered but the concept of developing a form of the DATF specifically designed to aid a single individual company and target its own needs and issues. The concept of generating this type of DATF model was very appealing as the opportunity to showcase the potential benefits to the company with such a developed and targeted version of the models was highly desirable. Different remanufacturing companies while operating similar operations will have sometimes significant differences in how the approach each activity as well as its own unique procedures and or technologies in places, sometimes developed in-house. Due to these differences while the DATF is designed to aid them there will be areas that are less affected or less applicable and some of the potential benefits are lost. By operating within a single company structure the DATF models developed in this environment would be solely targeting the areas that have been identified as 'problem' areas.

Response by Industry:

The DATF models have been met with positive responses from those companies involved in the Case Studies and Validation Review stages of the research; additionally further interest was expressed during ICOR 2017 and at SIR 2019. While the perception of the DATF models is good and the validation has proved successful the models are as of yet unavailable to industry, this is primarily due to aim of turning the application of the DATF models within automotive remanufacturing into an ongoing consultancy. This business concept would operate in conjunction with the SIR and the University of Strathclyde, however until this set-up has been established the availability of the models remains limited.

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APPENDIX A – Systematic Review Protocol

A.1 Literature review chapter – Systematic Review Criteria and justification:

A successful review of literature will present an account of the most relevant academic work that has been published in the field of interest (Dunleavy 2003; Phillips 2010), in this case - *inspection activities in automotive remanufacturing*.

A completed review should display the evidence that the project has been based around a sufficiently wide and far-ranging review of available data, showcasing knowledge from multiple types of sources such as articles, papers, journals and databases. The more diverse the exploration, the more inherently reliable the assumptions and hypotheses are to stand up to in-depth scrutiny at a later stage.

One of the ways to ensure that a review is successful is to follow an established review method or tool, such as Systematic review; this is considered highly in-depth and lends itself well to a comprehensive investigation of relevant academic work (Hart 2009).

There are 3 main types of systematic review:

Qualitative review: This type of systematic review prioritises the summaries and assumptions of the data gathered through the review process over the more qualitative statistical methods favoured by the other two types.

Quantitative review: This type of systematic review utilises certain statistical models to combine the results of two or more studies/papers.

Meta-analysis: This type of systematic review also uses statistical methods but in this case it integrates the estimated effects from selected studies and summarises the output.

Each type has its benefits, however the one selected as most suitable for this research was 'Qualitative Systematic Review". The justification for this choice is the expected format of the data likely to be encountered, in this case qualitative data. (Boland, Cherry, and Dickson 2013).

Remanufacturing still has a certain level of 'ill-definition' in relation to operational process and activities due to its relative immaturity in comparison to the more - established research areas (R. Steinhilper 1998; R. T. Lund and Hauser 2010). Unlike remanufacturing traditional manufacturing has an inherent level of rigidity within the operational structures is present.

Many academic papers attempt to provide both structure and improvements to the entire sector (Ijomah and Childe 2007; Ayres, et al 1997; Daraba et al. 2008).

A.2 The Review Protocol:

Systematic review involves the creation of a protocol, which acts as a guide for the review; specifying factors such as objectives, methods, and outcomes of the primary areas of interest. The protocol developed for this review includes various factors such as databases examined, the keywords used in the search, and the screening process to ensure the reader can follow the 'step-by-step' moments of the review. Allowing the key points when essential data was gleaned and review subtly changed direction, gaining increasing focus on the niche area of research - inspection (Boland, Cherry, and Dickson 2013).

Protocol: (Example)

Databases searched

Keywords used for paper/article search

Limits applied to the search

Screening process for identified papers

Key data to be obtained

Summary of data to be reported

Protocol: 1

Database: Google SCHOLAR, ScienceDirect, Springer.com

Keywords: Remanufacturing, Automotive, Operations, Process

Limits applied to the search: University & Industry Based

Screening process for identified papers: Academic work viewed in reliable journal.

Key data: *What are the current processes involved in the typical automotive remanufacturing operation? Have there been any recent developments? Any notable fact or observed opinions, regarding the standard and expected future of automotive remanufacturing operations?*

Summary of data: Awareness of remanufacturing sector becomes more mainstream and new legislation and policy pushes greater incentives in the form of take-back schemes and Zero Waste initiatives. As such the field is well suited to develop and expand in the near future with much range for academic research.

Protocol: 2

Databases searched: Google SCHOLAR, ScienceDirect, Springer.com

Keywords: Remanufacturing, Inspection, Testing,

Limits applied to the search: University & Industry Based

Screening process for identified papers: Academic and Industrial work stated either in reliable journal or as existing thesis.

Key data: *What is classed as Inspection? How does it and the testing operations overlap? How is suitable assessment carried? Does this change from sector to sector? Are methods potentially transferable?*

Summary of data to be reported: Inspection is a critical aspect of the remanufacturing process which appears to overlap with multiple aspects of the rest of the operation, methods are highly guarded behind IP and red tape.

Protocol: 3

Databases searched: Google SCHOLAR, ScienceDirect, Springer.com

Keywords: Remanufacturing, Inspection, Automotive, Methods, Procedures

Limits applied to the search: University & Industry Based

Screening process for identified papers: Academic and Industrial work stated either in high impact journal or as existing thesis, with a focus on PRIMARY Data.

Key data: *How can the inspection process be broken down? What standards exist?*

Summary of data to be reported: No clear industry standards exist yet., Rather the internal Remanufacturing Standard developed by independent companies is used in place (of?) or OEM technical data when required.

Protocol: 4

Databases searched: Google SCHOLAR, ScienceDirect, Springer.com

Keywords: Remanufacturing, Inspection, UK

Limits applied to the search: University & Industry Based

Screening process for identified papers

Key Data: *Does a gap exist for the application of greater structure to activities such as 'Inspection?'*

Summary of data to be reported: A knowledge gap exists in relation to inspection activities. While previous work has attempted to provide guidance to the overall inspection activity the actual knowledge of the procedures at use remains unknown or unavailable to the wider remanufacturing sector.

A.3 Protocol Development (1-4):

The above protocols designed for this literature review can be split into 4 distinct variations, Protocol 1 was designed with the aim of gaining a suitable overview of the field at the current time. While the exact nature of the proposed models still unknown this protocol was focused at providing details of the typical remanufacturing processes and any key points of interest that had occurred during the last several years.

From these results Protocol 2 was designed. This time the keywords used in the initial search were more targeted at a particular subset of the typical remanufacturing operation (inspection and testing). This was partly due to the fact that both factors had an overlap in terms of academic papers discussing the more intricate aspects of the core/part assessment process (Andrew-Munot and Ibrahim 2013). The aim of this protocol was to more easily identify papers and data that dealt more practically with the actual methods used. Due to the difficulty in acquiring this information, the scope of the search in terms of industry sectors was expanded from purples automotive to the entire field.

With Protocol 3 a more refined search to gather key papers dealing with inspection was put in place. These papers were those most suited to display the research gap.

Keywords used to search for papers were focused exclusively on the discovery of any data relating to the in-depth aspects of inspection, as well as examining the procedures that exist within the manufacturing side of the automotive industry and whether comparative technology could be used in the remanufacturing side.

The final stage of modification to the review protocol involved the development of protocol 4 where the parameters selected from the previous three variations were altered in order to target any examples or studies conducted within the UK based around inspection and assessment. The use of a location factor so heavily at this stage was with the aim of determining the possibility of real world comparison at a later stage.

A.3.1 Qualitative Systematic Literature Review approach:

Develop the research question
Define inclusion and exclusion criteria
Locate studies
Select studies
Assess study quality
Extract data
Analyse and present results
Interpret results
Update as needed as review progresses

Table 24 – Stages of a Systematic Literature Review

A.3.2 Application of approach:

The above guide of key steps involved in the systematic review was used as a basis for the procedures used when conducting the review of the available data (adhering to the factors of each protocol) (Boland, Cherry, and Dickson 2013). The research question was developed from the initial title supplied as the foundation for this research project. It evolved several times throughout the entirety of the project, however, barring some minor avenues of interest which were eventually deemed irrelevant or unsuitable to the desired aim of the project and its assigned funding conditions the evolution of the research question was more of a gradual refining of the ideal aim rather than any significant alteration of its overall direction.

The inclusion and exclusion criteria were developed based on factors such as the ‘rating of the journal the paper was published in’, the ‘apparent depth and level of detail of the data communicated by the paper’ and ‘the reliability of the apparent studies themselves”. These are just a few of the considerations taken during the review process. In conjunction with adherence to the protocols for locating the papers, these factors became more relevant for the suitable selection of the key papers. In addition, there was some level of researcher discretion used during this process. The use of review tools and methods is a highly valuable aspect of producing a successful literature review to build the thesis on, however, the aim of this type of project is also to promote the ability of the researcher to operate autonomously and to use judgement in conjunction with the established tools available. As such throughout this process the selection of key papers at times became a judgement call. Where some articles or studies, while not apparently the most suited to this reviews purposes, were deemed to convey or display data that was intriguing or useful.

The analysis and interpretation of the data from key papers was achieved through considered review of the article in question, assessing at which point the data discussed could be deemed relevant to this research project and to what extent the author appeared to be confident in the data. Acknowledgements or citations regarding points of interest were then followed back to their original source in order to ascertain the reliability of the assertions and assumptions noted by the secondary author.

APPENDIX B – Extended Research Methodology

B.1 Alternate Ontologies examined during the design of the research methodology

Relativism

Relativism postulates that scientific and physical laws are subject to the consensus belief and acceptance of the majority. As such the 'facts' in this scenario are highly dependent on the viewpoint of the observer. Ontological relativism operates under the belief that the degree of 'acceptance' of a 'truth' varies from individual to individual. Due in part to the nature of the 'truth' being viewed a human creation in this situation, the status and position of an individual within society dictates the range of 'influence' their perspective may have over the audience at large. As such an individual with a greater social standing may give greater acceptance to their perspective than an individual of lesser standing.

Nominalism/subjectivism

At the extreme end of this ontological spectrum is Nominalism, a viewpoint which strongly advocates the belief that there is no distinct 'truth' and that 'facts' are in fact a human creation entirely subject to our perspective. In a nominalist stance reality is made entirely of particulars and the universals (the fixed or constant aspects, such as 'facts') are of our own making. In this manner some aspects of nominalism can be clearly tied to 'epistemology', how we attempt to identify constants from subjectives. As such this ontological viewpoint is ideally suited to studies that focus on human behaviour and interaction, while it is less suitable for the more 'hard science' approach which values facts and primary data.

B.2 Alternate Epistemologies examined during the design of the research methodology

Positivism vs. interpretivism

These two distinct epistemologies form the opposing cornerstones of this philosophical area and the debate between these conflicting viewpoints continues to this day (Easterby-Smith et al. 2015). Due to the opposing clash between these two areas each epistemology has become a somewhat overblown stereotype of its true position. This type of action has occurred due to each opposing side attempting to directly pinpoint the most crucial and (from their viewpoint) perceived problem areas of the alternative stance. While an extensive list of the various methods and techniques could be linked to one viewpoint or another there is no clear-cut separation between positivism and interpretivism. Those using one position or another may actually expound some key aspects of the opposing side due to this somewhat 'fluid' nature between them.

Positivism:

Positivism focuses on the idea that the area of interest for the researcher should be measured and investigated objectively and therefore be unaffected by any personal viewpoints or opinions the researcher has. The investigation into the subject or area of interest should be conducted in as impartial a manner as possible, with quantifiable data being an integral part of the research. During this type of investigation the subject or area should be broken down to its constituent parts as far as can be.

Positivism can be tied quite strongly with ontologies that view the world as an external and objective reality, thus allowing for practical observation and exploration of a ‘fixed’ and unchanging reality in which the truth can be found. The key attributes and assumptions of a positivistic outlook can be seen below;

- Independence: the researcher must be independent from the area being observed.
- Value-Freedom: the choice of what to study, objective criteria rather than intuition or personal interest is used to identify this area.
- Causality: the aim of the social sciences should be to identify casual explanations and fundamental laws that explain regularities in human social behaviour.
- Hypothesis and deduction: Science proceeds through a process of hypothesising fundamental laws and then deducing what types of observations will demonstrate the truth or falsity of these hypotheses.
- Operationalization: concepts need to be defined in ways that enable facts to be measured quantitatively.
- Reductionism: problems as a whole are better understood if they are reduced to their simplest possible elements.
- Generalisation: in order to move from the specific to the general it is necessary to select random samples of sufficient size, from which inferences may be draw regarding the wider population.
- Cross-sectional analysis: such regularities can be most easily identified by making comparisons of variations across samples.

Interpretivism:

The concept of interpretivism or social constructivism postulates that the nature of ‘reality’ is not an external and fixed concept as previously stated but in fact is a social construct and given meaning by individuals or a consensus. In this type of scenario the gathering of data would not be achieved through an impartial manner attaining hard facts as detailed in earlier sections but rather than observe regularities within the subject area the researcher would aim to understand the human aspect, such as the experiences of the person. Human communication and the interaction between those giving meaning to the subject or area of interest are the focus for studies utilising this particular epistemological stance. Interpretivism in this case can be directly compared and contrasted to the key attributes of positivism that is detailed in an earlier section.

- The observer is part of what is being observed
- Human interests are the main drivers of science.
- Explanations aim to increase general understanding of the situation.
- Research progresses through gathering rich data from which ideas are inducted (Easterby-Smith et al. 2012).

Critical Theory:

This viewpoint is stated as one in which all participants undertake a ‘dialogue’ in order to reach that which can then be deemed as the ‘truth’, unlike other options in the natural sciences which rely on ‘monologues’ in which the truth is identified. While this can aid in ensuring that such heavy subject involvement provides a ‘real-world’ experience aspect to reach the truth the main limitation or detrimental factor of such an option is that the opinion and viewpoint of individuals in power can sway or bias the output significantly.

Hermeneutics:

This viewpoint states that the phenomenon can only be understood to any notable degree when considered within its proper context and setting. It states that the context can often display a variety of reasons and factors that directly affect the phenomenon being investigated and to consider it outside of these aspects would be to the detriment of the research and lead to miscommunication and misunderstanding.

Postmodernism:

This epistemological viewpoint differs significantly from those discussed and detailed above. In this view it is stated by Easterby-Smith (2012) that the development of science does not in fact follow a linear path but is in fact erratic, unpredictable and amorphous. Easterby-Smith (2012) utilises the idea of architecture to discuss the differences in this viewpoint from the more traditional. The main conceit of postmodernism is that it utilises experimentation and the idea of combing bits and pieces from other views in order to arrive at the most suitable option for the researcher in question. As such due to its swiftly changing nature this can be a highly suitable viewpoint for research into education and organisational transformation and development.

B.3 Alternate Methods examined during the design of the research methodology

Experimental:

Experimental techniques typically utilise a series of fixed and variable conditions within a highly controlled environment. Often such experiments are used to observe the behaviour of two or more groups, where differing conditions have been implemented in order to identify any effects or changes from the ‘Control’ Group and the ‘Experimental’ Groups. This method however requires a situation in which practically every element of the scenario is under controlled conditions and can be altered at the researcher’s whim or desire. Within certain small scale situations involving materials and technology this can be highly successful however when considered in application to human based interactions highly qualitative data this potential suitability of such a technique is diminished.

An alternative to this is quasi-experimental, in which the researcher attempts to modify a real world condition or situation to as close to laboratory conditions as possible. However, this is largely dependent on the ability of the researcher to control the variables, if not a certainty then the usefulness of the technique significantly decreases.

Survey:

As a technique surveys are typically utilised to collect data on the more quantifiable end of the spectrum, with many giving a fixed response to a series of questions allowing the researcher to mark and analyse the received data with ease. However the benefit of this technique can also act in a detrimental fashion, the rigidity often used to ensure that useful data is received back from such methods can also result in superficial responses. As such the data may only convey a small facet of the actual reality, and when pigeonholed into a limited number of responses the users merely select that which closest fits the reality. Although it is also true that the absence of the observer (researcher) lends a more ‘objective’ and true account lending itself to ontologies more akin to positivism (Creswell 2002; Easterby-Smith et al. 2012).

Ethnographic Research

Ethnographic research requires the researcher to become heavily involved with the field of study in such a way that they become ‘immersed’ in the group and those involved with the study. Such active participation on the part of the researcher therefore influences the bias and perception of the individual and as such is closer to interpretivism. This type of method could be suited to observation of an area or situation over time as it evolves and changes (potentially due to the researchers actions).

APPENDIX C – CASE STUDIES A - E

C.1 Case Study 1 – Company A

Company A is a small-medium scale automotive remanufacturing business, with a small-medium scale facility and relatively abundant resources and tools available. It focuses on many areas of the remanufacturing process and the information gathered during this study was substantial. The 3 core areas that will be the most heavily discussed are the "Torque Converter" section, the "Transmission Area" and the "Manual Engines."

Diagnostics Area:

The 'Diagnostics Workshop' is a large section of the overall facility and can hold up to a dozen vehicles at full capacity. It was stated that this section is where specific vehicle remanufacture or repair is conducted, as opposed to engines or transmissions sent in from dealerships or as part of the EoU take back scheme. These vehicles are typically brought in by those whose usual garage repair service either cannot identify the problem or are unable to fix it, as such they bring the entire vehicle to the Company A facility where it can be stripped down and tested as needed.

The operator in charge explained that the vehicles are brought in with an idea of what the issue could be from either the driver or from the previous investigation by the garage, however, this information can be incorrect, misleading or incomplete and it is therefore standard practice for those at Company A to run a more comprehensive assessment for their own benefit and use.

Logic computers are used to carry out these assessments, there are many different types and each type is only of use with a specific model or make of vehicle. As such there is a large selection stored at the Company A facility for use as needed. The operator explained that some models can be used on other cars due to design similarities and that less equipment was needed because of this. The makes and models compatible with each scanner are inscribed on the external casing.

Smaller hand held scanners can be used to assess the vehicle in specific areas such as pressure sensors and solenoids, and if there exists a technical issue unknown to the company the scanners can record the data so that it can be sent to an external company who will analyze the results to discover the problem and provide technical support. This can include new programs being written that can then be downloaded and integrated straight into the vehicle software.

Questions with Diagnostics Operator:

Q1. How can you tell when a vehicle has been brought in, that it has issues or problems beyond software?

A1. *"Usually due to the diagnosticians own experience and opinion on what they judge to be wrong a problematic issue beyond what is expected."*

Q2. Does diagnostic inform you of the key information or is it often provided by vehicle owner and accompanying documentation?

A2. *"Vehicles are usually brought in with a specific fault i.e. shifting between gears or losing drive. Due to the investigator's own experience and knowledge they can then use the diagnostic equipment available to discover whether the issue with the vehicle is related to a failure or issue in the electronic components, (solenoids, pressure etc.) or the mechanical aspects. If nothing shows up on the electronic or software side then the next likely cause is a hydraulic issue, potentially seal breakages."*

Q3. Once the issues have been discovered, and the problem is found to be mechanical is the engine then completely removed in order to repair it or only the needed components?

A3. *"In order to fully assess the mechanical fault removal of the engine transmission can occur often and if carried out the 'core' is taken to the beginning of the typical remanufacturing process and investigated in full detail."*

Torque Converter workshop:

The next area that was investigated was the torque converter [8] remanufacturing section. Separate from the other remanufacturing activities that deal with larger components and more complex assembles like the transmission and valve bodies the torque area still goes through their version of the typical remanufacturing process.

The converters are sent in or delivered usually in bulk and are stored in a large are towards the far end of the workshop. Due to the layout this means that as the part is moved through the various stages it makes its way from the far end of the work area to the one closest to the main door. This is an effective method of utilizing the available space (of which there is little) in a way that ensures that the operators do not encroach on each other's work areas too often.

After the converters are selected for remanufacturing from the input storage the operator uses a lathe to cut the welds holding the entire assembly together, with these bindings removed the operator is now free to disassemble and examine the internal components for damage or wear and then replace/treat where necessary. When discussing typical day-to-day operations with those in the converter department it was stated that due to the relatively straightforward design and easily accessible layout of the converter that any issues present can usually be seen very easily; wear damage due to moving parts grinding against internal surfaces is a prevalent problem that regularly occurs.

According to those spoken with there are only a few types of damages that are seen in the remanufacturing of torque converters so those involved in the process have become very adept at identifying and fixing them. The main issue that causes the damage frequently seen is the application of too much pressure onto the torque converter, forcing the internal mechanisms to increase speed and movement thereby causing grinding, wear and cracking.

As stated earlier after the outer shell of the converter is removed the inspector examines the inner mechanisms. This inspection is purely visual and utilizes no traditional or specialized equipment of any kind. The damage/wear caused to the bonding through high pressure being applied can result in difficulty with reassembly using replacement components if it is not treated properly. Replacement parts for converters are found in the supply storage area; a large section that runs the length of the workshop allowing easy access to the many hundreds of component parts that can be used in a variety of different models and designs. If the part is not found to be present then outsourcing to another company is necessary, this outsourcing is usually with companies located in England due to stock availability and as such can cost up to £1000 a time.

Company A operates a “1 day method” for converters, which involves the parts being delivered into the workshop and seen to before 12noon with the aim to have them remanufactured and boxed up by 3pm the same day. Obviously if outsourcing is required then that time can extend for a few days as parts are purchased and delivered. However, the “1 day method” has proved very effective at maintaining a high level of output with high quality results. Within the “1 day” the standard expected time for remanufacturing a torque converter (providing there is no significant damage) is around 1 hour (according to an operator), however due to the driving style of many automotive owners that time can extend by up to triple as serious defects or damages are repaired.

After the necessary parts are found and replaced within the converter and initial cleaning has been done, it is then taken and "blasted" and pressure tested to observe the results. It is at this stage that issues such as material cracking can become apparent, although material defects are relatively less prevalent than wear. Another problem that was observed and was reiterated by operators was that if another company has "treated" the converter before it reaches Company A facility then it can mean that it is "unsuitable for remanufacture" either due to the damage caused by less knowledgeable repair or because of modifications made to parts to allow non-standard replacement components to be used instead. Overall this is not a major obstacle and only occurs between 10 – 20 occasions per year, however with increasing interest in the remanufacturing sector this number may rise due to external local garages promoting "remanufacturing" capabilities that they do not understand or possess (Ferrer and Ayres 2000).

In terms of training provided to a new start in this area of the company, no actual standardized training is in place, the trainee is paired with older more experienced operators and allowed a period of observation (several days) before being given smaller task to accomplish and then given fuller reign over the workshop and their duties. This results in a series of "attempts" by the trainee to accomplish the task alone and without aid, with the end result examined by a more experienced operator in order to highlight what went wrong. While this type of training can appear effective and suitable for the needed requirements it relies very heavily on the expertise of the operator conducting the "on the job training" to be sufficiently skilled themselves and also allows for any bad habits or flawed opinions to be passed along without notice being taken.

Any type of training that relies almost entirely on the opinions and experience of few or even single individuals without standardized texts being consulted can result in highly flawed analysis being conducted by the newly trained operator within a short period of time, and can in turn lead to other misconceptions, or flawed reasoning occurring also, as noted by Hammond in 1998 During a company lifetime if several successive trainees are taught using these methods then the opinions and operating decisions of a later trainee may vary significantly from those of a trainee before him/her. This type of 'variability' in methods, opinions and the resulting techniques can lead to sub standard output and low or variable quality of remanufacturing, a factor that can easily cause a company to crumble as perceived quality and reliability of IR's is a primary method for business and recommendation (Subramoniam et al. 2009).

Parts supply needed for remanufacturing of the torque converters is another area in this sector where reliance on tacit knowledge and experience is readily apparent and may present problems. As stated earlier in this report if a part or component has been found to be damaged or defective the operator has to replace it with suitable parts from available stores. In terms of torque converter parts many may fit and appear at first glance to be suitable but are not and will cause further damage to the assembly once activated with new parts integrated. Part numbers are a key way to avoid these types of issues (BSI 2014) (although part numbers may not be present also) but operators at Company A informed me that many parts for alternative models can work and in some cases function more effectively. There are hundreds of different types of converters and converter parts and inexperience or mistakes in this area can result in loss of resources, increased 'treatment' time or as stated earlier if a wrong part is used, significant damage to overall assembly.

Material damage in converters is typically only found in the 'legs' area of the outer body shell, this type of 'cracking' is often only apparent towards the end of the process due to pressure and cleaning that takes place before making the surface or near surface defects more visible. When damage like this is found towards the end of the process the overall time is increased by up to 70% of the expected time for product completion.

Questions with Torque Converter Operator:

Q1. What in your opinion can be the most difficult part of remanufacturing in the area that you work?

A1. "*To me one of the areas of the process that can be most difficult is the rebuilding (i.e. reassembly) of the converters after replacement parts have been added. Although Torque Converters follow a very similar overall design there have been an increasing number of modifications and changes in recent years due to increasing standards for tolerances and combined with the internal complexity this has led to increased difficulty in converter remanufacture.*

These new designs have become more prevalent in the last few years and because of this, ensuring that the internal mechanism fit securely and within tolerance level has become much more of an issue."

Q2. What is the difficulty in question exactly and how do you overcome it?

A2. *" The difficulty is that when placing the new components back into the shell and using pressure tools to effectively 'bond' the parts together again, if the tolerances aren't adhered to and one piece is slightly off then the bonding either fails (which can cause damage) or fits enough for the converter to be tested which is when it then fails (typically causing more significant damage).*

Overcoming this particular obstacle is due mostly to the experience of the operator, after several years of doing the same job on a variety of converter types/designs dealing with this issue is easier, but for anyone new to the job I think this would be a serious problem."

Q3. In what way would it be a 'serious problem' and what do you suggest?

A3. "*Because of a new operators lack of experience and the in-depth understanding that comes with it of working with more simple converters the chances of reassembly /rebuilding being conducted improperly are probably quite high.*

To try and overcome it I'd say anything that attempts to try and provide a better understanding or communicate the intricacies of the process to the 'trainee' would be of great benefit."

Automatic Transmissions:

The area for remanufacturing transmissions takes up the majority of the workspace area at the Company A facility. The sections used for the disassembly and inspection procedures and later testing of the equipment make up around half of the overall facility size and appear to utilize the majority of specialized equipment and tools. When observing and discussing with operators in this section they stated their own reasoning and the processes behind the stages of inspection/disassembly/further inspection/remanufacture etc.

First the transmissions are brought in and taken to an industrial washer, which ensures a thorough overall cleaning of the assembly and makes the initial cursory examination much easier once the grime and dirt have been removed. After this the transmission is taken to one of the nine benches that are set up across this workspace. Each bench typically has either an incoming transmission on it ready for disassembly or the various components once it has been taken apart and is currently being inspected by an operator.

The transmission is then broken down into the sub-assemblies and the individual components that make them up, in order to more effectively assess the condition of each one. As in the Converter workshop the main method for assessment and examination of the components is mostly visual, although some tools and equipment are used to aid this by giving a more comprehensive view of the internal structures where needed (Errington and Childe 2013). An example of this is the examination of very small components, since due to size it can be quite difficult to examine these parts for less visible but still significant wear and tear. To enable this an operator will use a high strength magnifying glass to gain a better look.

When discussing this with operators at Company A it was stated that although they have a single large magnifying apparatus to be used for these purposes, other operators have also brought in other magnifying equipment (usually hand held) of differing levels of magnification to allow more variety to their methods. This can be a key aid with larger components as well in the inspection of small scale cracking that can appear in external surfaces (Ridley and Ijomah 2015). According to operators at the facility material damage like cracks and deformation is far less common than wear, often found on internal components caused by heat and pressure. When asked for a rough comparison between damage types that cause core to be unfeasible for remanufacture the percentage given was around 70% due to pressure and the remaining 30% to material damage.

A point that was brought up by operators during the investigation was that in the last 8-10 years the level of wear found in gearboxes has been steadily increasing. They believed this to be due to the introduction of newer more powerful engine designs which in turn increase the level of pressure being put upon the gearboxes themselves. This has resulted in 'wear' damage becoming one of the most prevalent types of damage found in the automotive remanufacturing industry.

Moving back into the area of inspection and investigation, another stage in the process of assessing transmissions parts and components is the use of specialized tools (typically constructed in-house for the company by other operators) to manipulate and 'move' certain components that were meant to in order to observe how well they functioned. Ensuring that the appropriate parts move in the correct manner is a vital part of the process as untreated faults could cause damage to the assembly when testing is carried out in later stages.
Noise is another factor that is investigated during the inspection part of the process, unusual or unexpected noise emanation heard during the assessment can be signs that small, internal or less visible areas of a component or sub-assembly have been damaged or broken (ball bearings shattered, corners breaking off, seals broken etc.). Finding the source of this type of noise(s) can be difficult and magnifying equipment discussed earlier as well as physical testing or movement are used to aid in identification (Ridley 2019)..

FluidLogic technology is used for this 'physical testing' side of the operation. These machines replicate a variety of conditions in order to simulate real world conditions, and can input pressure and air where needed to test aspects such as integrity and sealant. In terms of 'noise' detection operators may use one of the FluidLogic systems to put the assembly through real-world conditions, making the 'noise' (if there) more impactful and able to provide a more accurate idea of the damage sustained.

In relation to the increasing 'wear' issue discussed earlier, it was stated that this is shown by the state of many transmissions and gearboxes brought into the facility. The incoming condition of many transmissions (and also gearboxes) have shown a significant increase in the amount of parts appearing at first glance to be in satisfactory state but upon further investigation displayed clear signs of extreme 'wear' in internal surfaces and components; information that is vital to the successful remanufacture of parts and products (Ferrer and Ketzenberg 2004). This necessitates a full inspection and thorough examination in order to gauge other damaged areas (potentially more thorough than standard since multiple damage can be caused by 'wear') and may result in additional damage becoming apparent only during physical testing stages of the process, resulting in additional time, resources and energy being used. According to opinion of Company A operators this issue is becoming more prevalent in recent years.

Manual Engines:

Within Company A there is a section that deals solely with manual systems, and a significant portion of this is gearboxes. The majority of these are taken from active vehicles located in the diagnostics workshop area of the facility. This 'manual section' is relatively small compared to other sections of the facility in terms of both output and space however there does appear to be enough of a demand that justify the set-up and operation of such an area, and it has been found to be a steady and reliable source of income for the company.

The average turnover for gearbox remanufacture in Company A is determined in relation to the overall transmission and other engine parts that it was brought in with. A thorough assessment of the condition of the overall product(s) allows the company to decide a suitable amount of time for the remanufacturing of the entire assembly. Typically the range is between 1 – 2 days (as per the ‘1 day’ method that exists in other parts of the company, although, if significant damage is later noted this period can be extend by several days.

Like other aspects of the engine, the gearbox inspection procedures and methods follow a very similar path as the remanufacturing of torque converters and transmission components. The gearbox is assessed in terms of overall condition (worn appearance, visible damage, stationary parts moving freely or in unexpected manners) and is then disassembled and the components given a more thorough examination. However, unlike the remanufacturing inspection procedures followed in other areas of the facility the evaluation tools are much vaguer and less well defined. Since many of these gearboxes are brought in from vehicles housed elsewhere on premises there may be existing paperwork or opinions specified by the owner as to the source of issues/problems, in order to either verify or dismiss these effectively the pre-processing inspection is carried out (as described earlier) (Ayres, Ferrer, and Van Leynseele 1997). In terms of types of damage typically found the information is stated as described below.

Questions with Manual Gearbox Inspector:

Q1. So what types of damage are typically seen when assessing the condition of gearboxes coming into your area?

A1. *"We pretty much see all kinds of damage in the gearboxes brought in. A lot of them can look absolutely fine at first glance and after we've cleaned them and then begun disassembly all sorts of problems are found. Bits fall off; there are cracks across inner surfaces or other parts which are so worn that they just don't function properly anymore."*

Q2. So from that I would assume that experience and knowledge is even more vital in your area than it sometimes can be in others?

A2. "*It's certainly vital to us; we don't really use any particular tools or anything it's all down to visual inspection and what we can tell from looking at an assembly or part. From there we can decide whether a gearbox is worth fixing and how to go about doing it if so."*

Q3. I know some of your colleagues in other areas of the facility utilize different tools such as magnifying glasses and others to more closely examine or move certain parts, do you both do the same?

A3. 1 *"No we only use our eyes and of course what we can actually feel such as abrasions and rougher textures"*

A3. 2 *"Yeah it's pretty much our own experience that we can work out what the problem usually is and then go about with the rest of process."*

Q4. If you could elaborate on your "damage" identification method?

A4. "Basically *we have a look and then work out the origin of the issue, with a few years' experience you know what to expect, typically 'leaking' are 'wear on the gears' caused by the driver pushing the vehicle too hard and material deformation or cracking is far less likely than other causes."*

C.2 Case Study 2 – Company B

Company B is a small-medium scale automotive remanufacturing business, with sufficient facility size and relatively high resources available as needed. The company focuses on many areas of the remanufacturing process and in particular specializes in engines used in truck/bus/coach vehicles.

Discussion

As an aid to gaining more effective identification of potential issues, a similar study of observation and questions was conducted at Company B. This is also an automotive remanufacturer although specializing in slightly different engine types. Since the company has a relatively similar level of resources, staff and operations it was deemed suitable for use to either verify or dismiss assumption and conclusions drawn from the data collected at Company A.

Earlier sections in this report detail the specific actions and operations involved in the inspection areas of the remanufacturing process. Due to size limit and with the aim of not repeating stated information the following aspects of this report will deal with any verification or contradiction to data found previously.

During the observations it was found that like the Company A operators those at Company B rely heavily on their visual skills and knowledge to identify problems and issues with parts and assemblies. In terms of equipment the areas for disassembly and inspection appear more spartan and minimalist than expected (although this may be due to the larger nature of engines being examined) however, magnification equipment was observed to be present as well as some hand held lighting for better illumination of internal components and conditions.

The most significant difference between the two companies is the approach to training that takes place. Company B, although now operating separately from manufacturers, originated as a company with links and connections to an OEM. As such the company had access to a level of insight and aid to their work from those at the OEM that most other remanufacturing companies do not (Ferrer and Ketzenberg 2004; Kapetanopoulou and Tagaras 2009). In particular these benefits involved 'training' conferences, where operators from companies tied or owned by the OEM in question could be sent to, to work alongside manufacturers and others involved in the production or remanufacturing process and learn from the benefit of their experience, information regarding parts design and potentially specialized tools/equipment, improving their abilities and allowing them to undertake their work with greater proficiency. Due to obvious company guidelines and legislation the exact contents of these training sessions are not freely available and therefore only the vague overview mentioned above can provide an idea of typical contents.

However although the specifics regarding the exact training methods employed cannot be stated, other useful information was obtained from operators at Company B.

Questions with Company B Operator:

Q1. How many people and companies were typically at these ‘training’ sessions?

A1. *“Well usually about 2 – 4 people from each company and there were around 5 or 6 companies linked to the manufacturer at those points.”*

Q2. How many companies do you know of that operate such training days?

A2. *“ I think that we were probably the majority since doing a lot of in-house training for remanufacturing isn’t a widespread thing across the UK yet. I would be surprised if there were more than 10 companies with that level of access to information and structured training seminars, normally we are kind of aware of most other people or companies doing similar stuff.”*

Q3. What do you find are the most difficult obstacles to successful automotive remanufacturing?

A3. *“Education. Education is priority, a lot of work we get can involve engines that have been poorly repaired or “remanufactured” in the past by companies who just* *don't have the understanding or knowledge to complete the job as effectively as we can."*

Q4. Are there specific factors causing this poor level of work other than lack of knowledge?

A4. *"Sometimes the level of understanding of a part or assembly combined with available technology being low level can result in poor output. A lot of automotive remanufacturers don't have access to the same level of resources that we do and I think it can show in the quality of the work produced. Basically it can be stated as a contributor that combined with the 3 main issues results in the issues we've discussed."*

Q5. Those issues being in your opinion?

A5. "*Lack of knowledge, lack of understanding and lack of effective training."*

As seen from these responses and discussed earlier in this report a distinct and vital need for effective tools to improve training and knowledge transfer among automotive remanufacturers is definitely needed. Those tied to OEM's have the advantage of occasional training sessions that no doubt improve their overall effectiveness, while the vast majority of IR's do not. Though current training practices may have been sufficient in the past, the increasing investment, interest and awareness of Remanufacturing as an industry means that unstructured methods may not be appropriate moving into the future (European Remanufacturing Network 2016; Ferrer and Ayres 2000; Meredith and Burkle 2008)

As stated during the question sessions with Companies A & B, independent remanufacturers manage their training in house in a way that provides the necessary information and skills is not without room for improvement. The issue of variability due to inherent assumptions and opinion derived from knowledge passed from operator to trainee is another factor to consider.

C.3 Case Study 3 – Company C

OEM's (Original Equipment Manufacturers) are the foundation of modern industry, and have been encouraged by both popular sentiment and legislative and financial benefits to move towards more sustainable methods of operation. This study examines the operational activities as they currently stand at the Company C facility while analysing the recent modifications made in terms of both logistics and available technology, with the aim of using the data collected (in particular regarding the use of NDT such as MPI and Ultrasonic Washing for 'crack' detection and cleaning as well as the free flow on information from manufacturing side of operations to remanufacturing) to effectively discuss the reasoning behind such changes and also to display the need that IR's and Contract Automotive Remanufacturing operations have to likewise improve if they hope to remain viable businesses in the near future.

Company Overview:

In the previous case studies, discussed in earlier sections, the focus was on Contract or Independent Automotive Remanufacturers and their operations. However in this case the subject of the case study was Company C, a remanufacturing offshoot of the manufacturing corporation Company CC. This facility deals exclusively with diesel engines that range from typical automotive (cars and smaller vehicles) to much larger engines more suited to construction vehicles or trains.

Initially existing as a previous manufacturing facility, the site was bought over by Company CC in the early 80's with the purpose of developing a 'Remanufacturing' base in the UK. Since then the facility has grown and adapted to become a significant aspect of the Company C business family on this side of the world. The UK facility is one of two major centres that Company C operates, with the other being based in Mexico.. Apart from these major facilities Company C also operates a number of smaller plants that focus solely on specific components, sometimes unique to the country in question or surrounding area.

A range of diesel engines sizes are handled by the Company C facility, these begin at 4 litre engines and rise to 19 litre engines. The reasoning behind the stipulated engine size is quite clear; anything below 4 litres is often an engine that has been 'run into the ground' and is simply no longer economical for remanufacture. The accepted range still has engines which have been 'pushed' in a similar manner but there are fewer occurrences in which none of the internal components or parts can be salvaged and remanufactured. At 19 litres the engine size has become significantly increased and is viewed as the upper cut off for what the Company C facility can physically remanufacture on site. Any size above 19 litres is not feasible as transportation and storage alone could cause potential issues. However certain components like cylinder heads are remanufactured on site; the heads are sent from wherever the 19+ litre engine is originally from and are fully remanufactured at the facility before being sent back to the source at the end of the process.

The facility itself has begun to change in recent years as the increasing focus and awareness of the benefits of remanufacturing have become more prominent. Although the facility is of substantial size the aim of transferring into a new purpose built facility was considered as a potential direction in the recent past before the option to expand into an existing nearby facility space became available. If in 5 years the need arises for more space and with additional investment then a new facility may become a reality. The new additional space has allowed for new storage to be created and process allocation to be transferred, freeing up areas within the main facility work-floor.

In terms of staff the number has grown considerably in recent years as new directions to improve the operation of the facility have taken place. Before 6 years ago the staff number was around 60 people, although that could rise and fall by a few as some retired and others were brought on. Since then the number has continued to rise, and now there are over 110 people working at the facility, nearly double the original staff. Part of the reasoning behind this is the intentional aim to be top-heavy in terms of staff with a large amount of engineers brought on board from either outside sources or from the more traditional manufacturing side of Company CC.
In terms of their market, Africa and the Middle East make up significant portions of the customers and the majority of remanufactured engines go out to those areas.

Remanufacturing Process:

Core Storage

The beginning of the Company C remanufacturing process starts at the incoming cores storage area. The engines themselves are sent to the facility from a storage plant located in Belgium, the Belgium plant provides a cursory inspection to gauge the overall condition of the engine and whether it appears viable for remanufacturing at Company C. This set-up is a relatively new state of affairs that has only been in place for several weeks. Before this the engines came straight to the Company C facility. In the previous practice the initial assessment of the new 'cores' was done on site and as such any engine termed as 'unsuitable' would be stripped of any potentially useful components that would be remanufactured separately and then stored till required.

When the engines have arrived at the facility they are stored outside (the case in both types of operational style), set up on a Company C approved frame to hold them securely (though some staff have used pallets in the past to detrimental effects). While they are wrapped in a plastic covering the fact that the engines are stored externally subject to the inclement weather prevalent in Scotland does have a damaging impact on the condition of the cores. Due to the sheer number of engines stored in the grounds of the facility (easily over a 100 and in the past being significantly higher) some engines have been stored there longer than others and have a wide variety of wear and damage due to weather conditions.

According to those at the facility engines or cores can be stored for a significant amount of time before they are taken into the building for processing, visually some engines appear to be very close to a 'like new' condition with little obvious dirt or damage and effectively sealed in their wrappings waiting till needed. Others however have no longer any wrappings and appear to have been exposed to the environment for some time gathering a significant amount of rust and discolouration and in extreme cases the corrosion is so severe that the integrity of the structure of the engine is compromised.

As stated earlier before the introduction of the Belgium warehouse into the process, the cores were assessed on site on a case-by-case basis, this coupled with the sheer volume of engines previously stored there meant that until the new system was put in place it was very difficult to gauge exactly how many engines of 'suitable' condition were contained in the storage yard. Now that the new system has taken hold those at the facility have been conducting a widespread assessment of the current surplus in store and removing those deemed 'unsuitable'. This combined with any incoming engines now going to Belgium first has resulted in a significant reduction of cores in storage, allowing for space to be freed up and the remaining engines to be more effectively stored in a proper manner with ease of visual inspection when necessary.

Disassembly

The next stage in the process is the disassembling of the engine down to its primary components and 'core' body. An engine is selected, either through specification of particular engine or due to current condition. The engine is then brought in from the storage yard and taken to the disassembly point just inside the facility doors. The bay doors are situated at the rear of the facility and lead directly from yard to facility inner work areas without any distance. This reduces the chance of damage occurring during transportation across the facility grounds, an unlikely occurrence but a potential happening if an engine is transported long distance in poor weather or with poor procedure by operators.

Once in the facility the operators at the disassembly point begin the task of breaking down the overall structure into its separate parts and components; the main body of the engine is put aside for different processing. The methods of disassembly in the facility are very straightforward, the operators have a wide range of tools and equipment to hand (some specialised, some standard) which they use to reduce the assembly and sub assemblies to their core components. Attempts to procure more specialised tools and training is another aspect of improvement desired by management levels of the facility, the methods used at the moment while effective do result in a level of damage caused to some parts during the disassembly procedure. Not a serious issue but one that if solved would aid in improving the process by saving time that would potentially be utilised repairing said damage. The main barrier to changes in this area is one of stagnation more than anything else, the operators involved in this aspect of the process are used to undertaken the work in this manner and have little inclination to change, but if given new tools and training in new methods would be willing to adjust as needed.

Cleaning

After the disassembly stage is complete the parts and body go through 2 separate series of processes, as described below.

Core Body – The core body is placed on a metal shelf and loaded into an on-site furnace. The furnace can be used at 2 separate temperatures depending on the material in question of the pieces being placed in it; these two materials being Cast Iron and Cast Aluminium. The purpose of the furnace is to ‘burn off’ any dirt, debris or contamination on the body parts; this contamination can include rust accumulated during external storage, grime naturally built up during engine usage over lifetime or impurities the engine has been exposed to due to garage works, poor maintenance etc. It also burns away other aspects such as paint, carbon and non-metallic materials by increasing the heat to around 900 degrees Celsius.

These contaminations are burnt away within the furnace and the resulting pollution is collected and exposed to extreme heat and filtration to generate the least amount of damaging toxins. When the engine is removed and allowed to cool its outward appearance can look 'burnt' or darkened but this is merely a side effect of the high level of heat used and can be easily removed during the 'wash' stage of the cleaning process. After the furnace, the engine body is put into the 'Shot-Blasting' container. Shot-blasting involves the use of abrasive materials such as powders or sands being 'shot' at high pressure, with high velocity onto the 'part' in question. Here it is used as an added layer of cleaning to remove specifically very deep layers of rust and contamination potentially encrusted to grooves and indentations along the shape and inner surfaces of the engine body.

This 'shot-blaster' and furnace method of deep cleaning has been in place at the facility for a number of years though it is another aspect of the process that the company has been looking to improve in one way or another. A new concept discussed was the idea of replacing this method with a single form of chemical cleaning (potentially saving time and energy), however there are issues relating to health and safety that surround this avenue to 'cleaning'. Chemical cleaning can be highly effective and in set-up and conducted in a proper manner could lead to highly successful results, the downside of this however is that chemical cleaning if undertaken improperly can result in hazardous materials coming in contact with operators and causing either short or long term health deterioration.

A potential solution to the increased levels of danger would be the introduction of (chemically) protective clothing allowing operators a measure of safety even if issues were to arise; the likelihood of this coming into effect is low though. Company C operates a policy of only necessary protective equipment being used, such as protective lenses, high-visibility jackets where appropriate, and protective footwear. This is the level of 'gear' to be used as expected in a workshop environment, with heat resistant gloves and protective coverings available at the furnace section for moving and removing parts there. This is far removed from the hazardous material protection suits that would be necessary just to operate in a nearby environment where chemical cleaning may be occurring which is what would be needed to be put in place if this method was taken forward as is. The company aims not to put its employees or operators in situations here where that level of protection would be needed just to undertake everyday tasks.

After the shot-blaster the body is passed to the conveyor section beside it, this allows for the body to be moved into the first inspection area. This inspection involves the first use of NDT (Non Destructive Testing) observed in any case studies so far. In this case the NDT method used is MPI (Magnetic Particle Inspection), a process which involves passing a current through the engine body, magnetising it and then spraying the surface with a UV Fluorescent Magnetic liquid. The particles in the liquid are drawn to any 'cracks' or material damage across the surface of the body and can be clearly seen when the UV light is turned on. The form that the process uses in this case is quite basic with a plastic shed-like apparatus used to shield the MPI equipment from external light sources, and a long cord containing wiring joined to a generator device. This cord is then wound round the body part by the inspector before the application of the spray, which is stored on a nearby shelf.

This marks one of the first occasions that NDT has been seen to be present as an integrated aspect of the remanufacturing process in any of the primary research (case studies) so far. In previous investigations at companies Y and Z NDT methods were not present or active in any form, one of the main reasons behind this is the highly expensive nature of NDT equipment, even the most basic types can easily cost upward of £50,000 and for more advanced or in depth forms of technology that number could easily double. As such this initial cost combined with the training and maintenance needs makes this aspect of "inspection" a very risky venture for any independent or contract remanufacturer. In the long run the increased level of investigation that the NDT provides may contribute to fewer irregularities in output and higher overall quality may be achieved but in the near future the financial impact of such technology could potentially increase customers costs significantly, increase lead times per 'core' and possibly bankrupt the business.

In the case of Company C, part of the OEM corporation (Company CC) the availability of such technology becomes a much more straightforward situation. In the context of considering the remanufacturing industry, in terms of its comparability to the manufacturing industry it has to be noted that one is significantly larger than the other. As 'remanufacturing' is an offshoot of traditional manufacturing, specifically created to lessen the environmental impact of manufactured products end-of-life situation, it is expected that as a sector it is substantially smaller (in terms of market size, operational size and resources) than its counterpart.

As such any business operating purely in one aspect of these two sectors (Remanufacture & Manufacture.) specifically remanufacture will not have access to the wider variety of resources such as information, financial and technological that companies operating in both will have. As Company C does just this they have the capacity to introduce and utilise more expensive types of technology without as great a risk to the detriment of their business that other companies.

After the body section is removed from the UV Inspection it is moved further down the work-floor where it can be thoroughly washed using more conventional methods.

Parts – Taking a far less intensive route through the cleaning process than the body core the parts disassembled from the original engine are given a cursory inspection (performed visually) after the initial 'breaking down' and any found to be obviously unsuited to further remanufacture (i.e. Heavily corroded, broken into numerous pieces) are removed. The parts deemed suitable for further remanufacture are then washed using a combination of industrial washing and ultrasonic cleaning, intensive traditional washing was the accepted method of cleaning in the facility until relatively recently (last 6 months) and is used widely across the spectrum of the automotive remanufacturing industry. The main type of contamination or impurity that the operators try to remove from the parts is oil; because many of these parts form the internal structure of the engines they become coated heavily in oil residue and carbon. The purpose of the washing is to successfully remove this debris from the external and internal structures of the parts which aids in further inspection later in the process.

However the main downside of this that the Company C facility faced was that the oil washed from the parts would settle on the surface of the water forming a kind of 'viscous layer', when the parts had been thoroughly washed and deemed to be sufficiently clean they would be raised from the water and the oil layer would cost them again making the entire previous process a waste of time, energy and resources. To counter this the use of ultrasonic washing was introduced into this stage of the process relatively recently in the hopes that the oily layer forming at the waters surface would be dispersed by the ultrasonic vibrations allowing for engine parts to be effectively cleaned without issue. Though the theory was sound the real world application of this technology has not been as effective, since when being used the vibrations have created significant disruption of the water during the cleaning process. These disruptions have become so significant that areas outside of the washers have become affected by the cleaning process; oily residue appears to leak from many corners of the machine's upper surfaces and surrounding floor. The cause of the increasingly chaotic disruptions during usage is due to the variables of the process not yet being completely worked out; each application of the technology has to be carefully calibrated to the exact specifications of the use it is in place for.

Inspection

Inspection - proper and full assessment of the 'core' takes place at this stage of the process. As in previous case studies the main 'tool' or 'method' of inspection is Visual Inspection, where the operator is question's experience and personal opinion drives the decision making process based on the condition of the parts and components.

After the cleaning described in earlier sections has been completed the parts and body section are moved through the facility to the next area of the workshop. Here different components can be sent to different areas for inspection as suited, with these areas focusing on differing techniques or parts (typically due to the particular experience of the operator in question).

Body Core - The body sections are examined for any remaining *Grit* left over from the shot-blasting during the cleaning stage, if any is found it is removed through conventional hand washing. As MPI was utilised to determine the level of cracking or surface damage to the body by the time that the inspection stage arises a quite thorough assessment of the condition has already taken place. This is further detailed as a hands-on visual inspection is conducted by an operator in the examination of whether all contamination and debris has been successfully removed in earlier parts of the process.

Also the condition of the overall structure of the body section, while it may be clean and free of rust and any obvious cracks or material deformation identified during the MPI inspection, the shape and features of the body must also be closely investigated. Smaller scale abrasions and wear may not be as prominent as other signs of damage but can still cause issues during the performance of the re-assembled engine if not attended to. There are close tolerances between cavities in the engine core and the parts that should fit there, deformation or damage to these areas of the body can result in parts ill-fitting and making re-assembly difficult and functional use unlikely.

Parts – These components are taken to the inspection stage after the ultrasonic cleaning has taken place, they are given added ‘cleaning’ to remove any oil or contamination that lingers.

A clear advantage that Company C has as a company over independent and contract automotive remanufacturers is the access to full technical specifications and data as needed regarding different parts or products. Because it is a subsidiary of an OEM access to that companies manufacturers notes and information is freely available and as a result a certain level of stress (usually associated with the issue relating to reverse engineering) that many smaller companies face is not present here.

Parts Storage and Reassembly - After the parts and body sections have been thoroughly assessed and passed examination they can be stored on site in large containers, waiting till needed in the assembly of a new engine based on remanufactured parts. The containers in question are sorted by parts number, ensuring that those with the same number are stored together, allowing for quick and easy access by those searching for relevant parts. The main issue that exists to the complete and successful operation of this area is the variation in models of some parts. Certain parts although having the same parts number are actually slightly different model variations that appear almost exactly similar but can have a slightly different geometry resulting in ‘ill fits’ when the reassembly process begins. This either wastes time and energy on attempting reassembly with an incorrect component or if the variation is small enough can result in a functioning product but one that stands a high chance of under-performing or complete failure upon usage.

These variations can occur due to slightly different designs being employed in certain engines as well as newer (or sometimes older more obsolete) engines or engine parts coming into the facility. Ideally these could all be stored in separate containers but as newer designs replace those used in current designs, the new parts may be identified by the same number as the older engine parts as these are cycled out of common usage. Remanufacturing is the area of industry where the difference in these models of parts becomes an issue again. Any method that could be used to identity the differences in these parts without time consuming laborious effort on the part of the examiners would be ideally suited to aid those in this area of the automotive remanufacturing sector.

Info - Books

This level of available information and the use it has in the remanufacturing process is effectively displayed during the inspection stage in the form of 'info-books' that are available for the operator is question to utilise as a way of accessing supplementary knowledge in addition to their own personal experience.

These 'Info-Books' are short folders set in place at key areas of the remanufacturing process, most specifically used during the 'inspection' stage. Each book is designed to provide a clear overview of the typical operations in use at that particular station using knowledge acquired from the manufacturing side of the company's operations.

An example: In the case of the inspection of a component from one of Company C's incoming diesel engines due for remanufacture, the part is first put through the typical dismantling and cleaning steps described in earlier sections of this study. After it has dried and is viewed as 'suitable' for further assessment it is taken to one of the work-areas in the inspection section. There it is then stored, waiting to be assessed at an appropriate time, when this time comes the inspector will utilise the main tool of the trade (visual inspection) and his/her own experience to decided what areas of the part require ‘treatment’ or ‘replacement’ as part of the remanufacturing process. To complement this however Company C has created clear ‘picture and text’ based set of pages as tools to clearly display what the part should look like (from OEM equivalent model) and any notable technical detail regarding its original manufacture.

This type of structured approach to improving inspection using methods other than purely an inspectors own knowledge and experience is a significant positive conscious attempt to bring areas of remanufacturing into a more standardised setting. Due to Company C having the resources (in terms of both material and information) any and all technical detail can be passed along to the remanufacturing side as is needed. With the addition of this material in the form of these short ‘info-books’, the inspector can gain access to relevant information as needed. This is of clear benefit to an OEM subsidiary but is an option that many independent or contract businesses will not have access to. An independent remanufacturing operation will not have the ability to quickly and efficiently view the technical specification for the products in questions; the OEM’s and any OEM subsidiary guard the specifics very highly. This means that IR’s are forced to try and reverse engineer their own technical specifications for the product and parts based on their opinion and judgment of what they find. This is often a very time consuming and intensive task with results containing a high degree of variability, the output of the reverse engineering can end up being mostly kept in the head of the operator in question, or in very shorthand notes which only collect some the key points and are often only of use to that specific inspector who fully understands them.

Although allowing independents to have full access to the technical specifications that they require from OEM's will never happen, a method of more stringently collecting the data observed and gained by inspectors during operations and presenting it in a fully detailed and easy to understand manner could be the beginning of a significant resource that any in the company could utilise in order to gain additional data or info on.

This then leads back to the info-book system in place at Company C. As stated above these overviews of operations in inspection are fairly simple and straightforward, and by being backed up by data coming directly from the manufacturing side the information contained can be assumed to be up to date and correct. However the need for improvement in knowledge proliferation within the company sees another in-progress development for those at floor level operations, since a digital version of these info-books is being devised and put in place. The end result is hoped to be a freely available interactive system that anyone in operations of the company can access as needed at their workstation in order to perform the relevant tasks with ease. The idea of creating such a system for independent or contract remanufacturers is an interesting idea that should be explored later in more detail.

Current situation:

During discussions with management at the Company C facility in-depth talks regarding remanufacturing in general as well as the continuing improvements that are currently being developed for the company were discussed. As stated earlier in the study several significant changes have been put into place across the company in recent months including re-arrangement of the external core storage area, installation of new ultrasonic wash equipment and the re-routing of initial core assessment and transportation to Belgium.

Areas for improvement:

The Company C facility is very much from appearance and operational observations a strong, highly effective system. However as noted in the descriptive notes earlier in this report there are sections that could benefit from new methods, new technology or from real streamlining of the processes.

Core storage is the first area of the process at the facility and is also the one most recently undergoing significant re-structuring to improve its operations. The Belgium facility appears to have been introduced in order to function as a “buffer”, a mid-way point in the process between the acquisition of the engine and its delivery to the Company C facility. This additional stage to the process would seem to be targeted at having a two-fold benefit. One is to reduce the number of cores stored at the facility (overcrowding of stock being an issue), and secondly to to ensure that all cores are given an initial assessment before being delivered for processing. These points were confirmed as definitive policies points that have arisen from the introduction of the mid-way point by those at Company C, though further refinement and improvements will be made in future they have stated.

Ideally the cores would not be stored externally as this allows poor weather conditions to have a detrimental effect of the material composition, however as the volume of cores is significantly high (around 100) even after the removal of many to Belgium or for disposal the sheer size of added cover would be financially substantial.

Also noted is the disassembly phase of the process, where difficulty has arisen as to the adaptation of new methods and tools by the existing staff. Described in further detail in earlier sections those involved in this stage of the process typically utilise relatively crude methods of disassembly (whatever is at hand to get the job done in a timely fashion) as such there is a certain level of damage that can occur at this point that is directly related to the actions of the dismantler. Attempts to rectify this issue have included the use of specialised tools allowing for intricate and less damaging work to be conducted when dismantling core. However this has met resistance in the form of “bad habits” where those who have undertaken the job for a lengthy period of time already established their methods and understanding of what constitutes ‘good practice’ in these circumstances and inevitably these habits appear to reemerge shortly after alternatives have been suggested or put into place.

Another barrier facing those in OEM Remanufacturing is drawing staff into the workplace. In recent years it has been noted that fewer new staff have come into the operation and it does not appear that this will change soon. Many of those in the Company C facility have been there for at least several years and an average age of those working on the shop floor would appear to be closer to middle age than younger recruits. However the older general age of those at the facility is not an inherent detriment by any degree, as stated and observed in earlier sections of this case study and the thesis in general the experience and understanding that comes with long term employment in remanufacturing operations is highly valuable. However as is becoming a steady trend in the case studies the majority of expertise regarding inspection is limited to the older side of the workforce. This means that those at the facility likely contain a large amount of valuable experience and tacit knowledge between them, however this is knowledge that is not being passed on to new staff..

Company C has some advantages in this area as they occasionally rotate staff from the manufacturing side of the company at the main Company CC operations for some time before rotating back. This has the added benefits of not only breaking up the typical duties of those involved but also giving both sides of the product life cycle equitation (Manufacturing & Remanufacturing) a chance to appreciate and understand the others work. It also presents a potentially valuable opportunity for a 'design for remanufacture' operation to commence where those moving between each side provide opinion and information on where they believe the original manufacturing process or design of the parts/core could be modified (Design for Remanufacture). So far it appears that Company C is yet to take advantage of this opportunity though this may change in the future since overall improvement and effectiveness of Company C has been a significant motivator for change in the facility and the company in the last several years.

Moving back into the area of employments for new staff, it is unclear yet whether this difficulty in bringing in new members of the company is a problem faced by many across the automotive remanufacturing sector but it is a significant issue that will be further explored in later work.

Benefits of information book supplements:

Company C, a company specialising in the remanufacture of Company C diesel engines utilises information booklets in some areas of its daily operations. The purpose of these is to provide a basic overview of operations at the specific station.

During discussions with management it was noted that Company C plan to digitise these notes into an online system allowing for data to be shared more easily within the company. However that plan is still in early development and when completed would result in merely the basic overviews of data being available as a pdf to view as needed.

While this plan clearly increases the potential for free flowing information within the company it also has the potential to be significantly more. It is noted by the author and also stated by those in management at the Company C facility that independent remanufactures do not have access to anything close to the level of information and technical data that an OEM based remanufacturing company does, and as such has to rely extremely heavily on personal experience and knowledge and opinion to judge the best method to proceed. In regard to this existing situation and the difficulty associated with the transferring of skills and tacit knowledge in this field the application of a shared ‘information system’ among either the internal staff of independent remanufacturers or across non-OEM companies presents a potentially exciting opportunity.

An interactive system built to aid the new operator/employee of a remanufacturing company could vastly improve certain training styles currently in use. In the case of IR’s the majority of training is completed in an “on the job” style with very little standardised training across the board. As such this can lead to variation in product output and result in poor perception of the company in question. This may become a significant issue for new independent companies wishing to break into the market as they will have to compete with existing IR’s with years of experience and OEMs with greater technical knowledge and resources.

A method to potentially aid the new companies wishing to 'break-in' to the market would be the use of such a interactive system being used as a training tool, allowing for companies to train numerous members of new staff in typical remanufacturing operations with relative ease.

Ideally in an automotive remanufacturing company those involved at every stage of the operations will have access to and acquire their own specific knowledge and understanding of the most beneficial methods of accomplishing the operations. This knowledge is built upon experience and is often highly unique to the one who initially experienced it, though some aspects may be known to others in the same area of the company. This use of these info-books is an initial attempt to provide a basic 'overview' of operations at hand, in a manner that would hopefully make it available to everyone.

Comparisons between Independent and OEM Automotive Remanufactures:

The point of the previous sections of this report has been to provide in sufficient detail a succinct and thorough overview of this OEM remanufacturing operation with emphasis placed on the recent modifications to daily operations made to improve the overall effectiveness of the processes. Analysis of these changes leads to the understanding that this recent drive to improve is significantly encouraged by the increasing awareness and interest regarding the entire remanufacturing field. From this increasing focus it is likely to assume that more businesses and companies will either move into the remanufacturing sector or if they are OEM's they may potentially create a subsidiary of the company to bring this aspect of their product lifecycle back under company control as is evident in the case of Company C. The need for OEM remanufacturers to improve their approaches in order to remain as effective (due to newer more complex part designs and materials) provides another string indicator that independent entities will have to ensure their continuous improvement to remain relevant.

. IR's can have several benefits over OEM based remanufacturing companies such as lower cost to the customer, potentially local based location and due to lower volume typically shorter lead times in the operations. Likewise OEM based remanufacturing activities can have significant advantages over IR's such as levels of resources (in terms of facility size, staffing and financial backing), available technology, free flowing information from the manufacturing side of the operation and ability to redesign for remanufacture if needed. By comparison the IR can have more immediate benefits to the small-scale customer but the OEM has the capability for larger scale high quality output to retailer or other businesses.

Primarily the main and perhaps most significant advantage that OEM based operations have over independent ones is the level of information available regarding any product/core that is brought into the facility in question. This information (including but not limited to, manufacturing practices, design specifics, technical specifications, material properties, initial material processing, design for remanufacturing attributes etc.) provides enough relevant material to allow those involved to begin the remanufacturing process from the most informed point of view. This combined with the technology typically in place on site for an OEM operation (due to higher levels of resource compared to IR) provides a strong platform from which a company such as this may tackle remanufacturing operations in one of the most effective methods for large scale operations.

As noted in Case Studies A & B the use of NDT methods in independent automotive remanufacturing is not always a viable option primarily due to its high set up and maintenance costs. Also effective training on the technology including its successful integration into the remanufacturing process can be obstacle that smaller companies may find it difficult to overcome. There is strong reasoning behind the use of NDT methods in the remanufacturing process, in particular the automotive sector. NDT as it states is a form of testing/evaluation that involves negligible to no significant damage to the part in question. The results from such an assessment provide valuable information relating to typically invisible properties of the material of the part (such as stresses, areas of strain, sub-surface and near surface damage and surface cracks) allowing for a more fully realised view on the condition of the internal structure of a part or component.

Since this is such a useful addition to the evaluation process there are those of the public or other areas of industry that may wonder why this method is not used more predominately across the remanufacturing field if it yields such useful results. The main point behind this factor is cost; NDT equipment such as Magnetic Particle Inspection or Ultrasonics tools can easily cost upwards of £20,000 - £50,000 to begin with and for more accurate/advanced models the price can increase tenfold. In addition the initial set up cost, the use and training required to operate such machinery effectively can be problematic without suitable experience of the area, and the final part of the decision is whether the cost of utilising this type of equipment is a suitable payoff for the information that can be gathered by it. Although the information gathered can be vital in establishing the most complete and detailed understanding of all aspects of the structure and material properties of use for this form of processing, the level of information gathered can often be surplus to requirement. It is true that the in-depth investigation conducted through NDT produced valuable data however it would be incorrect to suggest that typical and successful automotive remanufacturing operations cannot occur without it.

In the cases of Companies A and B both are considered successful in their area of work and bring in a high share of the available market to meet company financial needs allowing for successful operations, as has been the case for several years. This continuing work has been conducted with no NDT equipment available to provide additional information and is a positive indicator for non-NDT related remanufacturing, however despite earlier statements displaying that in the past there has not been an empirical need for NDT technology in place for successful remanufacturing it is worth noting that looking toward the future this may present a very different viewpoint.

Improvement for the future is a key basis for any company wishing to enjoy longevity in its specific market, ideas and technology will also be examined for improvement or positive modification by others in an attempt to capitalise on the originality of the OEM in question and provide potentially more attractive alternatives to the customer market. This is a major factor that businesses the world over have to deal with and provides strong incentives to avoid ‘sitting around’ after the introduction of a new idea/process/product. To that end ‘continuous improvement’ is a vital part of the foundation of any business then it must also be a critical factor in remanufacturing area of industry and can be viewed as an intrinsic part of planning for the future.

Improvements in non-OEM related remanufacturing operations are of vital importance if those companies wish to continue to operate as separate independent entities while still remaining relevant in the near future. The successful integration of affordable NDT equipment into the Remanufacturing process in IR's could be an effective and substantial leap forward for the so panties in question and those in similar circumstance, although there are other methods or directions to be explored that could also aid in the improvement of operations and duties.

The main issue with moving down the NDT route is that while more affordable/feasible applications of NDT into the process for IR's is a valuable and laudable goal the locale of the undertaking could potentially be a research project better suited to a team of researchers with significant funding and resources as opposed to the purposes of a PhD bound by time limits, and could also entail extensive periods of time with little to no real world reward for the work in question. As such alternative methods that have a more immediate and practical benefit to automotive remanufacturers and stand a greater chance of being successfully realised within the constraints of the project are better suited as the direction moving forward. Moving along this trail of thought the research utilises the data collected during the literature review sections at the beginning of the study and used in conjunction with the primary data gathered during case studies A, B and C as well as semi-structured interviews with other reliable sources experienced in Automotive Remanufacture to identify and justify the direction of the research problem and begin the task of constituting a viable solution that can be effectively and properly validated as to its benefits and contributions to knowledge by the end of the PHD.

Conclusions:

In conclusion, this study has examined the current practices of an OEM remanufacturer, in this case Company C in an attempt to access real world primary data regarding the typical operations of a facility such as this but also the improvements and modifications made in recent months and to understand the reasoning behind these changes. As discussed in earlier sections of this report a significant amount of restructuring involving the logistics of the transportation and storage of engines which has come into effect in recent months; concurrently the addition of new ultrasonic cleaning technology and the on-going discussions relating to new processes to more efficiently remove contamination combined with the acknowledgment of many new ideas being considered have shown a determination to maintain the concept of ‘continuous improvement’ within the company.

Analysis and discussion relating to the barriers that diesel is facing and the solutions that have been devised to aid the process have resulted in questions relating to the ability to bring adequate staff into the field of remanufacturing due to a variety of circumstance such as perception, awareness and belief in the longevity of the employment. These are questions worth pursuing at a later date in order to more deeply understand the thoughts processes behind those reticent to embrace this area of industry and devise potential solutions to overcome them.

The integration and use of NDT equipment in diesel remanufacturing processes (in this case Magnetic Particle Inspection and Ultrasonic Cleaning) provides a key discussion in relation to the benefits of the use of NDT in typical remanufacturing operations and whether the information gathered from such actions is sufficient enough to compensate for its high equipment cost. It has been stated here that NDT does indeed provide valuable information in relation to the condition of an examined part/product and may be a key aspect of the future more stringent and efficient remanufacturing processes, however currently it appears only as a viable option to either significantly larger IR's or OEM based remanufacturers due to cost.

Overall this study has examined these issues and undertaken an extensive comparison against Companies A and B in order to better identify and justify the direction of any future research into the improvement of the automotive remanufacturing, which from the data collected is tied to ensuring that IR's remain relevant in the coming years through improvements made to increase the efficiency and effectiveness of their operations (specifically Inspection) through more affordable and practical avenues. A valid option in this case is the improvement through training of staff to ensure a higher degree of free-flowing knowledge occurs within a company and that the aptitude to change or alter processes in order to streamline activities is built in to the company structure.

C.4 Case Study 4 - Company D

Introduction:

Company D is a remanufacturing company that focuses on the automotive sector. Located near Nottingham the company has existed for over 20 years and is one of the most reputable remanufacturers within Europe. With a focus on the successful remanufacture of the entire engine as 'core' as opposed to parts (i.e. transmission or gearbox etc.) Company D has ensured that the service they provide can be considered comprehensive, with no need to work in concert with other remanufacturers to ensure full-engine treatment.

Company Operations:

This ‘comprehensive’ approach to automotive remanufacture may be part of the reason why they are now Europe’s largest independent remanufacturer of automotive engines. As opposed to many remanufacturers Company D does not deal with the aftermarket in any capacity, their operations are targeted entirely with the exclusive supply of remanufactured parts and engines to their OEM partners. This is a highly positive situation for the company in several respects, firstly by working exclusively with large scale OEM corporations the company is able to access all of the relevant technical data and knowledge that is typically withheld from outside remanufacturers due to IP reasons and can require extensive reverse engineering on the remanufacturers part to generate suitable remanufacturing standards for the part or core.

Secondly, Company D’s competition is significantly reduced, since they do not deal with the aftermarket side of remanufacturing. As such there is no reason for them to be a threat or rival to other companies operating in that area. Their customer is the OEM and what can benefit Company D can then hopefully benefit the OEM as well. To that end the only real issue that Company D is facing in terms of competition is the ability to obtain relevant parts for the remanufacturing operations from the suppliers. The suppliers are the same ones who supply components to the OEM’s as well, meaning that though Company D and the OEM’s may work together and for the same purpose the high level of demand and scale of the OEM's means that if both sides are looking for the same items then it is Company D who will likely lose out.

From the facility visit and discussion with managers there it is clear that Company D is highly invested in the continued success of their business and are keen to remain consistently at the top of the market in their area. The idea of a 'continuous improvement' mindset is most present in the so-called "Management meeting room" based in the lower half of the facility. This room is covered in data and notes relevant to each and every process/operation undertaken by Company D and if viewed correctly provides a very clear and detailed overview of the current and past operations of the company (performance, efficiency, issues etc.). Once a day the managers of the various sections of the company meet up in this room to discuss any issues and quickly evaluate the daily operations. Typically these are short meetings of no-more than 5-10 minutes. This nevertheless provides a highly useful period in each day when even minor problems or questions can be addressed face-to-face. Additionally the physical hard-copy format of the data displayed in this room allows for a much easier method of visualizing the needed information for any managers or operators within the company.

Company D Remanufacturing Process:

Company D like many automotive remanufacturers follows the overall basic stages of 'core' remanufacture, however due to their aim of comprehensive remanufacture (including the various sub-assemblies of the engine) the structure of the process can become slightly complicated as various sections deal with specific components and sub-assemblies. In these sections Company D is utilizing some of the most state-of-the-art technology in order to ensure that its processes remain to as high a standard as possible (a factor even more vital for them as they have to deal with OEM directly and failure or decreased quality on their part could easily spell financial disaster for the company).

This high level of standard includes the use of methods such as Coordinate Measuring Machine (CMM) technology to fully assess the condition and dimensions of certain components down the micron level, with tight tolerances and effective examination Company D can then ensure that all parts undergoing these processes are suitably up to standard.

NDT was also found to be an integrated part of the process for the company. This stat-of-the-art technology is present as MPI (Magnetic Particle Inspection) used to identify and more easily find material damage and near surface defects in the core structure.

In terms of the remanufacturing treatment processes, Company D has begun utilizing its own “coating process” known as ‘Plasma Transferred Wire Arc’ (PTWA). This process involves removing a small amount of metal from the bore in cylinder blocks and then spraying a new coat of molten metal that can then be thinned and smoothed to the relevant specifications. This is a significant technology for the company in that new and more advanced manufacturing methods combined with the desire to reduce emissions has led to newer engine designs containing less material and becoming much lighter. While this can be considered a positive aim for the manufacturers it has had a negative impact on the remanufacturing industry, since with less material to work with the ability to ‘remanufacture’ components back to OEM standard has become much more difficult.

Company D has been a highly useful and valuable study, providing insight and explanation of the operations and techniques used by one of the leading remanufacturers in Europe. In previous sections it has been stated that there is believed to be a high over-reliance on tacit knowledge and experience in many remanufacturing companies. It is believed that this is most prevalent in the inspection processes that takes place. The differing levels of resources available at various companies (i.e. financial, Manpower, technological) mean that the methods used in these instances can easily range from purely visual to more clearly defined technology however it is an issue that in these companies the reliance is on purely skilled, knowledgeable operators with whom effective knowledge sharing can be difficult. Company D supports this assertion and has already taken steps to remedy such situations from occurring, by building "stage-by-stage" methods for their processes,.. However each operator follows a clear set of instructions based on company information and guidance as opposed to their own ideas or methods. This leads to a structure of multiple semi-skilled operators that can be replaced or re-trained easily if needed as opposed to a heavy reliance on the knowledge of few skilled operators undertaking various stages of the process.

Inspection Practices in Company D:

Inspection practices in Company D showed many of the same features noted in the earlier studies, with individual operators utilising their own level of skill and personal knowledge to successfully conduct thorough inspections. Visual means were still viewed as the main driver in the assessment process, with the operator in question making use of a number of specialised tools in order to access and fully inspect all the key areas of the various parts.

However as briefly discussed earlier in this study this company has already taken some measures in order to reduce the need for the operator to rely purely on their own personal knowledge alone; due to the available technical data gathered through contract operations with OEM customers the variety of core that is likely to pass through the facility is much lower in terms of variation as of make/model than might otherwise be experienced from independents. As such a system is already in place which allows the operator to view a digital model of the OEM version of the core in question. This allows for focus and detail to be directed to any single part. In this manner the operator can follow the ‘stage-by-stage’ layout determined in house to ensure that the activity is conducted in a successful manner. In these circumstances suitable technical identification is highly essential and the visual aspect of inspection is highlighted again. Company D’s facility size and significant staff display a highly driven company mind-set and one which has aimed, through the introduction of such a system as discussed, to reduce the level of inherent bias within the operator. While these attributes do signify a possible path to lowering the level of purely personal skill within the company, it still remains that this set-up is of most benefit to this particular company needs and due to IP will remain very much an in-house development.

When discussing the level of importance that the knowledge of the operator in question has, even with such a system in place, it was stated that the most successful inspectors were those who exclusively worked within this aspect of the remanufacturing process and that those with the longest experience were typically viewed as the ones with the greatest authority in terms of judgment and assumption.

Initial inspection of the core, determining whether any parts could be viewed as unsuitable for later processing and remanufacture was still conducted using primarily visual techniques with the quick judgment of the operator allowing parts viewed as unfeasible or uneconomical to remanufacture being removed to areas to await suitable disposal.

Core storage again followed a slightly different manner than previously observed with a much larger section of core being stored internally within facility buildings than expected. The decisions on core storage are complex dealing with both the inherent value of the core in question as well as the expected volume of certain orders. The storage methods are thereby calculated with the aim to ensure that all the core stored internally is in the main that will is most readily required as well as that of greatest value.

Conclusions:

From what was observed, Company D are a highly competent and forward-thinking remanufacturer and in terms of their typical operations and scale of their market these areas would appear to be as successful as could be hoped for.

Parts availability is one the largest issues for all remanufacturers and Company D is no exception, although they work exclusively with OEM’s and their suppliers the issue of obtaining difficult or high-demand parts is still very much present.

During discussions with the manager of Company D it was stated that their usual options if a part is unavailable are to try and modify an older or existing part to function in the same manner as the desired component or look for supply elsewhere (though this can often turn up nothing). An option for them to improve could be new methods for creating or obtaining these difficult to find parts. 3-D printing is advancing at an incredible rate with the type of materials used to print becoming more varied. A potential possibility could be research into whether metallic 3-D printed parts conforming to the original OEM specifications could be manufactured to the desired standards. Alternatively manufacturing capabilities for certain parts could be introduced as a smaller addition to the overall facility.

C.5 Case Study 5 - Company E

A study of typical operations and the company approach to part assessment during the reclamation (pre-processing stage of remanufacturing) of aftermarket core: Like previous companies selected form case study Company E is located within the UK and is a remanufacturer operating within the automotive market. Upon arriving at the company the managers involved were very accommodating allowing significant access to their typical practices and provided extensive feedback regarding their typical operations as well the changes or development their company had undergone during the last few years (as the remanufacturing sector has gained more interest).

Introduction:

This study was focused on exporting the typical operations and approaches to the automotive remanufacturing process within a highly developed OEM remanufacturer. The aim of this investigation was to observe the concepts and ideas in play within the company management structure and how these features factored into the company's recent shift towards a more highly focused idea of continuous company enhancement and improvement. The remanufacturer in question is noted within the market for remaining at the top of their field in terms of both quality of output and its operation within the sector.

Previous studies conducted across several other remanufacturing companies has led the research to build certain assumptions and posit key viewpoints regarding potential novel concepts that could be having detrimental effects on the success of typical automotive remanufacturing inspection operations within companies and the small-medium sized end of the business spectrum. As such this case study was conducted in order to observe whether these viewpoints which had evolved and developed through the cross-referencing and analysis of previous company set-ups would potentially be present or a relevant factor to this company in question.

Operations:

The basic operations of Company E follow a very similar route as many found within the automotive remanufacturing sector, the parts are collected and stored before being taken through the reclamation processes to bring them up to remanufacturing standard.

Core Storage:

In a somewhat different approach than many other larger scale remanufacturing facilities Company E ensures that all core is stored internally within the physical facility itself. This is different than what has been observed and noted at other companies. Due in part to the highly variable nature of incoming core in terms of size, the suitable storage and maintenance of core once it arrives at a remanufacturing facility often results in large amounts of core is stored externally Thus subjecting it to prolonged periods of time withstanding the elements and sometimes inclement weather. This practice is a common occurrence at many facilities however Company E have a strong desire to ensure that any and all core they receive is stored in suitable internal conditions. The core that is dealt with at Company E is generally smaller than other automotive assembles that are remanufacturer however this factor alone does not provide the complete reasoning behind this decision. When discussing this feature with operational managers the explanation was given that external storage (noted in earlier papers and past chapters to cause additional damage to core and parts) causes damage to the core they receive. While this level of damage is dismissed in some cases as an unfortunate but unavoidable consequence of core storage Company E have ensured that space has always been made to allow the accommodation of as much core as possible. The idea that once the core is received its condition remains as expected and recorded until it reaches the start of the remanufacturing operation and no additional issue or damage occurs.

Issues regarding over-reliance on opinion and experience within inspection operators:

As mentioned earlier in this paper the issues regarding the potential over-reliance on personal opinion and particularly tacit knowledge gathered through prolonged experience within the process have been explored in a past section by this author. In this previous section the issue was discussed thoroughly and across several companies, the output of that research was the finding that this level of over-reliance does exist and that companies with smaller staff and less established structure to daily operations and specified training run the risk of this issue becoming a critical negative factor to the businesses long-term prosperity. During discussions with work-floor managers in direct contact and daily evaluation of the operational processes this issue was raised again, with the collated data gathered during the previous section as a reliable foundation for the assumption. In the case of company E it was discovered that they too share the same issue to a certain extent and that it is much more highly suggestive of this being a more prevalent factor that previously believed.

Within Company E, which has a significant number of staff at its facility (50+) there are 5 or so staff that are used for the detailed 'Core' assessment that takes place at the beginning of the process. As opposed to the more conventional approach to inspection which typically occurs *post-disassembly* and *cleaning* the main type of part evaluation that takes place occurs during the '**Initial overview**' stage of the process. Those select few who are relied upon to provide this type of judgment do so through purely visual means and it was stated that their personal experience is the foundation of all assessment occurring within the company. While multiple experienced operators conducting this task may appear to alleviate some of the problems relating to over-reliance (with the knowledge being relied upon being spread across several individuals) the age of the staff in question is another factor to be considered.

The more experienced staff with this type of knowledge are those who have been with the company since its early days, some having started when the company existed in its first interaction over 30 years ago. While these members of staff are highly valuable and a key part of the smooth and efficient daily operation the fact that the reliance is on an ageing workforce is a serious issue. Once past this initial inspection/assessment section the cleaning process takes place, with extensive methods utilised in order to ensure that the parts are returned to as close to like-new condition as possible. The later processing stages also involves '**Parts inspection**' operations taking place. However in these cases it occurs during the processing of parts to bring them back to the company internal remanufacturing standard/tolerances. As such it is conducted as a purely visual examination of the parts outward appearance before any drilling, grinding or other activity is used. Those conducting this type of assessment are considered only partly experienced as their key area of interest is to observe any noticeable material deformation or damage (cracking etc.) as opposed to more in-depth assessment methods. After the reassembly and processing the newly rebuilt product is subjected to Pressburg testing in order to ascertain structural/functional condition. When asked about the chance of part failure at this stage it was noted that this can happen and if so then time and resources would have been spent on a failed product, however the level of products that this occurs with was stated to be low. This set-up for inspection appears to work within this company confine however the chance of this set up being utilised in a less experienced operation could easily result in a significant amount of lost revenue and time as failure parts (so far unnoticed) make it to this end stage if the process.

During discussion with a manager the concept of using models to present 'guides' or 'blueprints' to develop more effective inspection practices was discussed. The idea was viewed in a very positive manner with a marked interest in the possibilities for impartial training and the possibility of using highly visual guides. Additional concerns regarding the ‘external storage’ of core leading to additional damage through exposure (costing potential profit in after market parts) were expressed and the validity of the issue corroborated with a desire for available methods of assessment between initial arrival and condition post-storage was expressed.

When discussing the potential benefits of more detailed data (in the form of complex assessment methods) becoming available to the operator, the managers involved stated that the introduction of additional data is a highly valuable factor and that as much information as possible being within reach of the operator in question could only result in positive outcomes. However the issue they felt was not with the availability of the data but rather the judgment that accompanied such decisions based on the data. The difference of opinion occurring between operators/assessors can cause both loss in quality and increased lead times (due to later identification of missed issues discovered in the part at the end of the process). Even the different opinions are not always mutually exclusive, two operators within the same company can approach the same core or part and through assessment have differing opinions in which they are not both entirely right or wrong. Where possible the internal remanufacturing standards or available technical tolerances should always be adhered to and used. However the aim of this research is to tackle the areas where this type of data is not available or cannot be quantified in the same manner.

Approach to internal company records

Company E had undergone several changes during the last few years in which the company both developed and then later merged with another automotive remanufacturer. Before this merger however the concept of 'reviewing and rebuilding' the existing operation of the time was undertaken. Previous set-ups had developed in a highly hap-hazard way and did not make best use of the available resources to the company and its operators. During this period of change the ideals of LEAN manufacturing were heavily adopted and implemented by managers within the facility. An entirely new set-up in terms of the internal operation and remanufacturing processes was designed with these principles in mind. LEAN principles involving the 'routes' of working personnel, the placement of different machinery and equipment and the time considerations of operator actions during processing were all factors identified and considered during the evaluation and later modification of Company E's operational set-up. Semi-structured interviews with managers involved with these procedures detailed the aim of 'continuous improvement' that has been refocused within the company and has aided in the noted improvements to the general efficiency that has occurred in the time since. A specialised work area on the work-floor with easy access to any that wish to review it contains highly visual representation of the relevant data for each stage of the processes and details issues discovered and rectified by date as well as any outstanding points of interest. The increased internal records has allowed Company E to more accurately assess both themselves but also to continue their aim of developing the company set-up further to reduce any areas of issue or lag time.

The adoption of certain LEAN principles in conjunction with the company's own internal decisions for improvement led to discussions on the potential value of an internal auditor system for remanufacturing processes, to be used by companies to self assess their effectiveness of a particular aspect of the process (in this case inspection).

The merits of such a system available to the industry as a whole was explored, with the benefits of a more long term experienced remanufacturer having the ability to potentially develop such a system over more small scale or newer organisations operating within the sector.

The concept of 'continuous improvement' within a remanufacturing context is a highly positive note and one that needs to be seen across more of the industry as a whole. In this situation the company in question has the benefit of significant resources as well as a highly developed infrastructure that allows for operations to continue despite alteration and changes occurring in regards to theundertaking of each individual process (analysing the effectiveness of current methods, staff, movement patterns etc.). However this is often not the case or many at the smaller end of the remanufacturing sector (with focus on the automotive), in the majority of cases this refers to independent remanufactuers, companies that operate with usually highly constrained resources and a very limited staff. Despite these obstacles it is estimated that the work undertaken by independent remanufacturers actually forms the majority of the market, many of these will be automotive parts remanufacture as opposed to entire core. Due to the size and limits of available resources the ability to 'improve' within this type of context (Small Independents) can be difficult, any dispersion to typical operations to make modifications could cause serious delays in processing and distribution while internal records allowing for the identification of areas requiring improvement and how to judge its success may not be present. In order to allow for any 'streamlining' or LEAN principles to be adopted to any extent by all aspects of the sector the various operations would have to be broken down into clear distinct factors that can be analysed and reviewed at the companies leisure, allowing for decisions based on aligning with LEAN principles to take place.

C.6 Conclusions:

From this study it can be observed that Company E has developed significantly in recent years with reference to their internal operational procedures. The aim of utilising LEAN principles in order to improve both workflow and general efficiency within the company structure has allowed for a more adaptable and dynamic approach which may reflect itself in the companies continued success and potential long term viability as a UK based remanufacturer. The improvements in their internal record keeping and maintenance of process structure has allowed for a large volume of data available to staff in order to try and more effectively assess where problem issues or areas of improvement may occur. Their inspection procedures confirm many of the hypothesis noted in earlier studies; the core assessment of pieces which are worth remanufacturing is conducted by a very small percentage of the staff who achieve this process through expertise and experience and make judgments based on their expert opinion. The reliance on such individuals is acknowledged as a potential issue due to the gradually noticeable trend of an ageing workforce in this area.

APPENDIX D – DATF Criteria

D.1 DATF Grading Criteria:

Grade 1: This is the lowest end of the damage spectrum; at this stage the damage regardless of type is very low.

(i) The outer surface of the core appears smooth and unblemished at first glance; the overall structure and appearance of the core are exactly as expected of a fully functional core. Once disassembled and cleaned there are no apparent signs of cracking or distress on the surface of the core components.

(ii) The shape and geometry of the core is within all tolerances and does not appear to be have been deformed or changed in any way due to wear, pressure or ill usage.

(iii) The individual parts of the core once cleaned do not present with any noticeable ‘wearing’ down or reduction of the material that they are constructed from. Corner edges and complex shapes remain almost entirely intact.

(iv) The part appears to be undamaged and whole, no area shows signs of leak or obvious damage suggesting a compromised structure.

(v) The level of contamination present in the core has been removed and there is no remaining degradation present once this has occurred (rust etc.).

(vi) Any motorized sections have been manually turned and examined and do not produce an acrid or ‘burnt’ odour, as such they can be deemed suitable at the moment though further testing will occur later in the process.

(vii) A

ny sections of the part requiring ‘mobility’ testing shows expected range of movement and friction/speed.

Grade 2: At this point the level of damage present begins to increase to a noticeable degree, with some types of damage being more easily identified than others.

(i) The surfaces of the outer core and parts appear to have a slightly distressed look and there are subtle signs showing of the parts having completed a full functional lifecycle. Very small surface abrasions can be observed potentially signalling minute cracks or near surface defects within the part.

(ii) The overall shape and geometry of the core and its parts remains intact but it is no longer the exact duplicate of a newly manufactured equivalent. Some subtle warping of the parts is present however it is of a very low form and does not present any significant obstacle to efficient remanufacturing.

(iii)The components of the core show small signs of light wearing in certain section due mainly to the usage of the core during its functional lifecycle.

(iv)The part appears whole and shows no clear sign of structural issue, however its overall appearance and condition suggest minor ‘wear’ and ‘tear’ has occurred during functional lifespan (suggesting possible damage for the part in question from a visual standpoint).

(v) The level of contamination and degradation in the core is low but there are signs of it present, heavily exposed areas of the outer surfaces of the core show signs of degradation due to its exposure to the elements during its 1st life and storage thereafter. However the level of contamination is so low that typical cleaning processes are expected to remove such impurities.

(vi) Motorised components do not appear to have an acrid odour and move easily when physically turned but small amount of dark residue found after cleaning potentially indicating some burning of parts (further examination needed).

(vii) Sections of part requiring ‘mobility’ test move as expected, though manual ROM suggests some ‘unevenness’ or ‘friction’ when manipulating the piece suggestive of low-level damage.

Grade 3: At this stage the level of damage is noticeable and highly actionable, it can be considered that this level of damage as a halfway point between the grades is the expected ‘norm’ condition for the incoming core and its components.

(i) The surfaces of certain components of the core show a distinct level of usage that even cleaning cannot remove; scratches and abrasions can be found where external areas have been in contact with high-powered parts and have withstood pressure and jarring during their lifecycle. Chance of cracking at weak points within the structure.

(ii) The overall shape and geometry of the core remains intact but examination of key components show signs of warping and deformation likely due to high pressure during usage. Though noticeable easily to the visual inspection the deformation is not strong enough to signify serious reprocessing and does not impair the expected time need for full remanufacture.

(iii) The components of the core show signs of wear from their lifecycle; corners, edges and more delicate features show noticeable abrasions and reduction of existing material.

(iv) The part appears whole however a noticeable level of discolouration and ‘damage’ to external surfaces of part suggest that structural integrity is likely not 100% of desired and further testing methods are required (if not already actioned).

(v) The level of contamination and degradation in the core is more noticeable with contamination present in several areas and a significant amount of it causing deterioration of the external areas of the core that can be seen after cleaning. Although not enough to cause any serious issue for the processing the damage is enough that some work will have to be carried out to reclaim and remanufacture these external parts in terms of material structure.

(vi) Motorised components present faint acrid odour when friction is applied to surrounding surface, indication of possible burn of motor within however no residue present.

(vii) Section of part requiring ‘mobility’ test presents reduced ROM in comparison to specified details. Majority of ROM is still achievable through more difficult suggesting mid-level damage.

Grade 4: At this point the level of damage present is a significant problem and requires experience, knowledge and skill in order to accurately determine the feasibility of the part in question for further remanufacture.

(i) The surfaces of the outer part and inner sections appear to have a seriously distressed look and there are clear signs showing that the part has completed a full functional lifecycle. Cracking can be detected at strain points over its surface and at critical area ‘welds, joins, etc.).

(ii) The overall shape and geometry of the part has been significantly altered through either operational lifespan or external damage. While still recognisably the same part there is enough damage present that remanufacture is possible but may not be economical depending on the inherent value of the part in question.

(iii) Areas of the part who's signs of ‘wear’ to a high degree, erosion or reduction of key features has not yet occurred but a noticeable ‘wearing’ across the part has taken place.

(iv) The part shows clear signs of overall damage indicating that the likelihood of a ‘hard seal’ being achieved during pressure testing as low, however regaining structural integrity through minor processing cannot be completely ruled out yet.

(v) Contamination of the part is substantial; cleaning has removed much of it however degradation remains in many places making the feasibility of processing the part in an economical manner doubtful.

(vi) Motorised components have a noticeable acrid tang in terms of odour/black residue is present around the surrounding surface area indicating significant burn damage within the part.

(vii) The part requiring the ‘Mobility’ test displays reduced and impeded ROM; the expected/specified rotation/movement is difficult or not achievable however a degree of manipulation remains signifying that replacement or processing of the part may return it to the desired condition.

Grade 5: At this end of the range the level of damage present is very high and part are potentially unsuitable for remanufacture from a feasible standpoint or an economical one..

(i) Surface areas of the components show extreme distress and visible and substantial cracking can be easily observed with the naked eye, this damage is particularly noticeable around sections where flat surfaces are joined to perpendicular geometry or parts, as strain is likely to be found at these areas.

(ii) Sections and certain areas of the part show substantial and serious deformation, standard geometry of the part has been radically altered through either pressure or impact. The level of change is extreme and without significant rework would not even reach functional status, with further work required to reach remanufactured status.

(iii) Internal components of the part show high levels of wear with features and complexities obscured, reduced or missing due to the gradual 'wearing down' of the existing material.

(iv) Part appears heavily damaged across other categories suggesting compromised structure, examination from a visual standpoint suggests that structural integrity in terms of a 'hard seal' for relevant areas of the part is a high unfeasibility, substantial rework and possible additive processing methods may be required in order to 'add material'.

(v) Contamination is very high is this case and after cleaning has resulting in exposing significant degradation to the overall structure of the core and certain components in particular. The degradation's spread through the very material of the parts has resulted in their reliability and strength being compromised severely. Potential parts at this point no longer suitable for remanufacture.

(vi) Scratch and Sniff test of motorised parts has resulted in extremely acrid odour and leakage of dark, soot residue from component s area. New motorised parts required immediately.

(vii)

Sections of part requiring ‘Mobility’ test have shown no functional ROM, moveable/rotational sections have either sized up entirely negating the feasible or economical remanufacture of the part or the ROM now exceeds the specified range by a significant margin indicting serious internal damage.

APPENDIX E– RaPID Model Breakdown

E.1 RAPID MODEL

Overview of Core:

This is the first stage of any inspection process, it occurs as soon as a core has arrived at the facility in question. This scenario does not require the core to be entering the initial stages of the remanufacturing process and is used on all core being received, regardless of condition. The purpose of this stage of the process is to simply provide a Visual Inspection of the core, matching the perceived condition with that specified by the supplier. Data regarding the condition or technical information of the core (Make/model/type etc.) can be provided by the supplier; however this is not a constant factor and can vary depending on supplier and core.

Independent remanufacturers have to deal with more aftermarket suppliers in order to receive core than Contract or OEM who either bring the entire process in-house with their own logistics or aid in a similar set-up for the contractor in question.

This process occurs as follows:

Start: Facility ready to receive core

Has shipment been received? Y/N

Is core present? Y/N

Is there any accompanying paperwork (external)? Y/N

Does core condition match paperwork (external)? Y/N

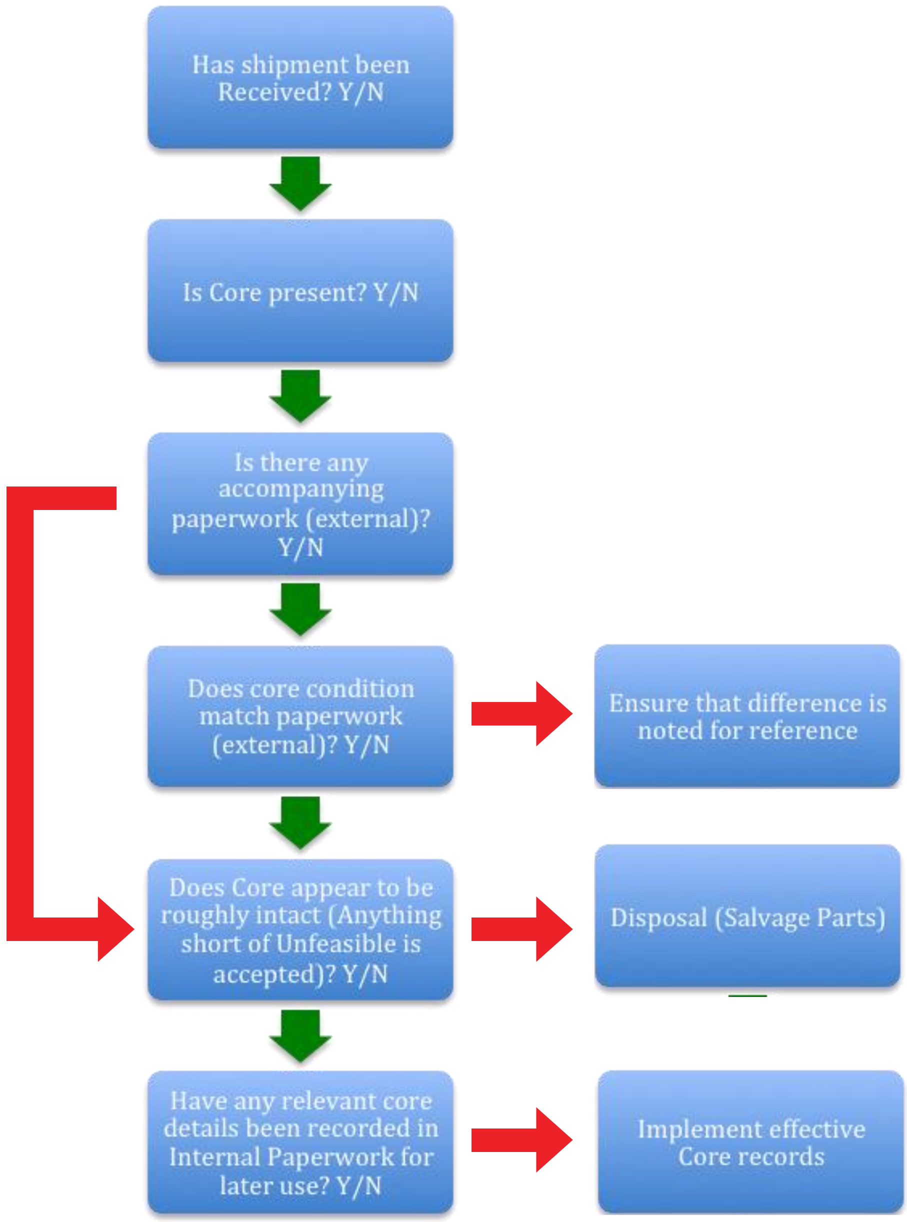
Does core appear to be roughly intact (Anything short of unfeasible is accepted)? Y/N

Have any relevant core details been recorded in internal paperwork for later use? Y/N

End: Core is passed to Storage

Visual:

Start: Facility ready to receive core



End: Core is passed to Storage

E.2 Initial Inspection

This stage occurs when the core is brought out of storage to begin the remanufacturing process. This stage also relies on visual assessment regarding the condition of the overall piece before its disassembly. This process involves the operator briefly assessing the part for any *significant* issue that may hinder the core from being disassembled and later cleaned before full ‘Parts Inspection’ can take place. By ‘significant issue’ this refers to scenarios where the piece has become so degraded or contaminated that disassembly of the core will likely result in substantial parts damage to a core which already leans towards “Unfeasible/uneconomical to remanufacture” from a purely visual standpoint. Alternatively the issue may be substantial material damage, where large sections of the core are either so damaged or missing that core remanufacture is no longer a possibility and disassembly for parts reclaim becomes the new goal.

Start: Core enters the beginning stage of the Remanufacturing Process

Is core present? Y/N

Has every external surface of the core been examined through visual assessment? Y/N

Are there any noticeable negative features regarding core? Y/N

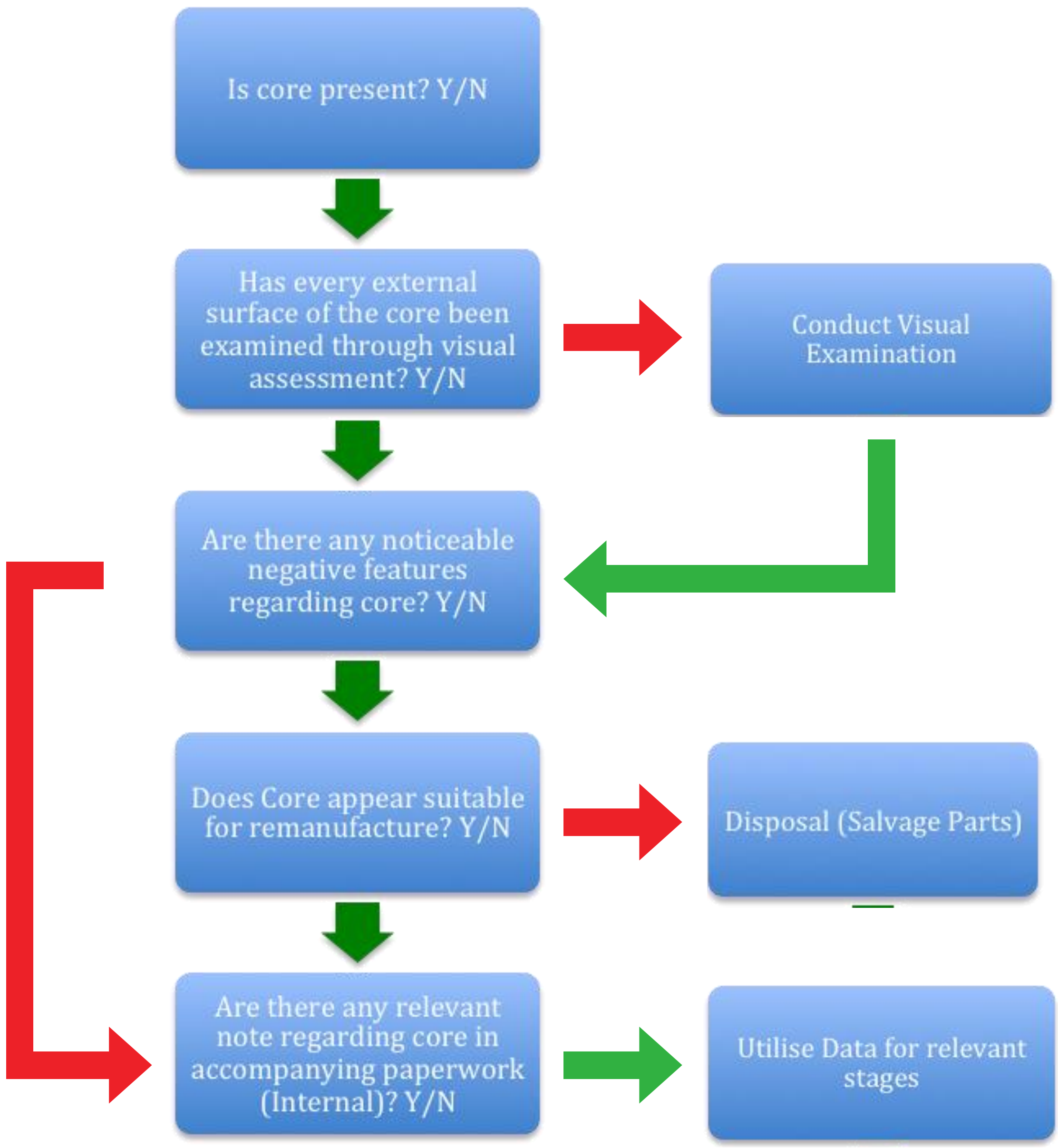
Does core appear suitable for remanufacture? Y/N

Are there any relevant notes regarding core in accompanying paperwork (Internal)? Y/N

End: Core is passed into Dismantle

Visual:

Start: Core enters the beginning stage of the Remanufacturing Process



End: Core is passed into Dismantle

E.3 Parts Inspection

Basic Part Inspection

This stage of the process is the most detailed and critical to later processing of the parts and components. Post disassembly and cleaning the components of the core should now be broken down into their various sub-components and assemblies. Barring very few parts linked in ways that disassembly cannot occur without destructive force all “core” components should be broken down to their very simplest parts in this stage. Full assessment of the parts at this stage of the process allows for issues, problems and all relevant data to be collected. This is then used to ensure that the most suitable and appropriate processes are used to bring these individual parts back to OEM standard later in the operation. This task is carried out through numerous techniques based on the part in question and the level of available resources at the company.

Visual inspection is the cornerstone of all remanufacturing assessment and it is here that this becomes the focus more so than at any other point. The part is examined through the visual medium in order to observe any obvious signs of damage present; this damage may be shown in many forms (Which are detailed and categorised within the data criteria). All external and internal surfaces are observed if possible, if the part is geometrically complex then the use of magnification equipment may be necessary in order to more accurately observe the parts condition. If the geometric complexity is so advanced that there are internal surfaces that remain non-visible even with magnification equipment then the use of a borescope (a device which allows for the user to view magnified areas of objects through a small pipe which can be inserted within gaps of the piece) is advised.

It is during this stage that the relevant technical knowledge of the part can be collected, this allows for suitable replacement parts to be used during the later rebuild process if any fail to be brought back to remanufacturing standard later on or it is found to be more expensive to do so. This data also allows the company to record the relevant information for use in internal records as well as the DATF damage prediction model at a later time.

The part is then measured to ensure that it is still within suitable tolerances of its original specification, if not then this is recorded for use during the processing phase (at which time it can be decided if modifying the part back to specification is too expensive so part replacement is a better option). This type of measurement can be conducted using standard methods (ruler, protractor, measurement tape etc.) for the majority of parts, which provides a relatively accurate result. However with surfaces and shapes that are based around circular planes and which rotational tolerance is a significant factor this type of measurement may not be enough. Measurement practices are also used to gauge that the shape and surfaces of the part have not suffered deformation or warping due to treatment or pressure.

In some cases the part may need to be tested in terms of structure, this can be necessary for parts which typically operate as a closed environment and therefore have to remain 'sealed' across the majority of their structure. If the part requires this form of assessment then the use of 'pressure testing' can be utilised. This method involveds high pressured liquid or air being passed through the part to simulate real world conditions, with the aim that any cracks or structural damage will be easily observed through visual assessment of the part during this process.

If the part contains motorised components then the use of the scratch sniff test is undertaken, in which pressure and friction is applied to the relevant area of the part. If an acrid odour occurs this is an indicator of burned components. Rotational components which are either single or linked and typically have full or partial movement during functional lifecycle are physically moved in order to observe whether the part in question has full range of expected mobility/rotation.

Start: Core part are received by the Inspection Operator

Are all parts of the core present? Y/N

Have all parts been suitably cleaned so that their condition can be visually assessed without issues or hindrance? Y/N

Has the part been visually observed across all external surfaces? Y/N

Has the part been visually observed across all internal surfaces? Y/N

Does the part contain any significant forms of observable damage? Y/N

Have the relevant technical identifiers of the part been recorded (Model, type, manufacturer etc.)? Y/N

Have the forms of damage been recorded in relevant format for later reference? Y/N

Does the part appear to be the suitable part for the core in question and non-modified? Y/N

Has the part been examined using advanced observation methods (Borescopic examination)? Y/N

Has the part been measured to observe whether it fits specified tolerances? Y/N

Has the part been measured to observe whether it fits the specified shape? Y/N

Does the part fail in terms of measurement at any point? Y/N

Have the failed parts been recoded in relevant format for later reference? Y/N

Does the part contain any ‘rotational’ or ‘moveable’ sections? Y/N

Do these sections move as expected during manual operation? Y/N

Does the part have any area where these sections do not ‘move’ as expected during manual operation? Y/N

Have the ‘movement’ issues been recorded in relevant format for later reference? Y/N

Is the part a motorised part or contain a motorised section? Y/N

Does the part appear to be producing any noticeable odour (Acrid or Burnt)? Y/N

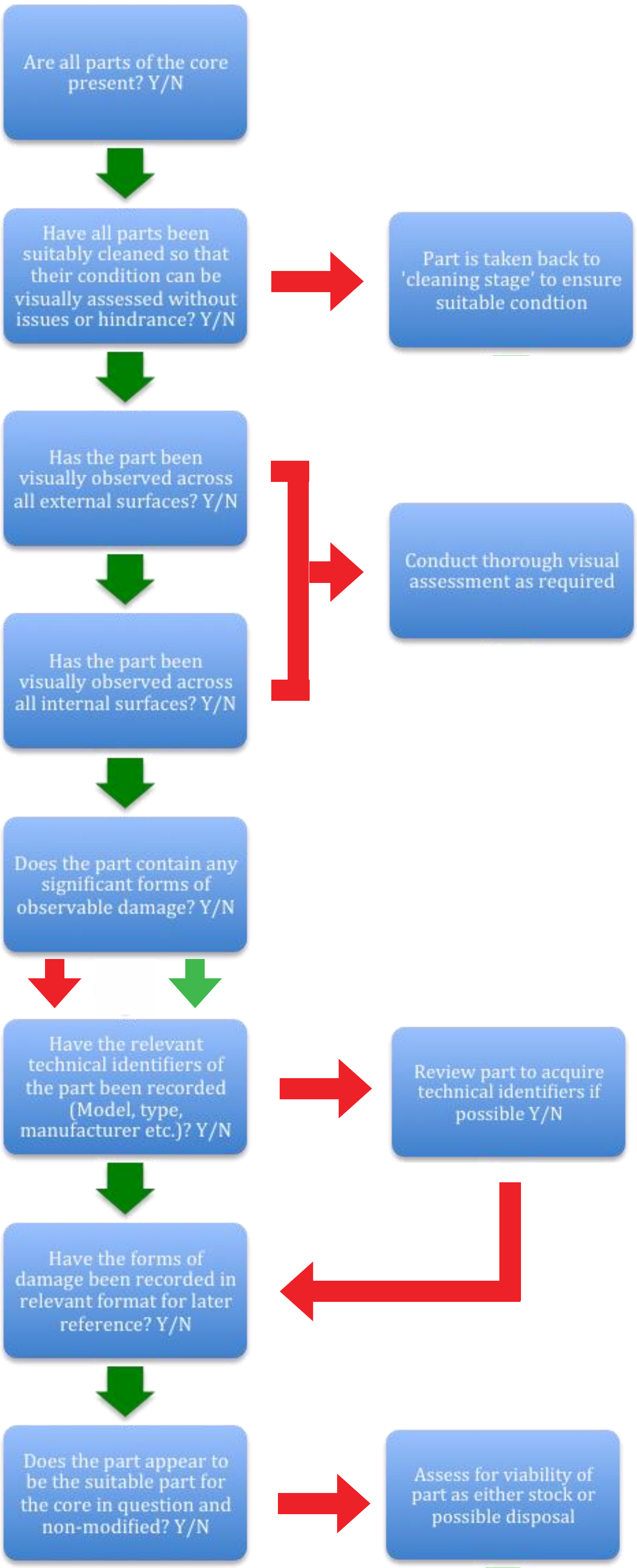
If a small amount of friction is applied to the part does this odour increase? Y/N

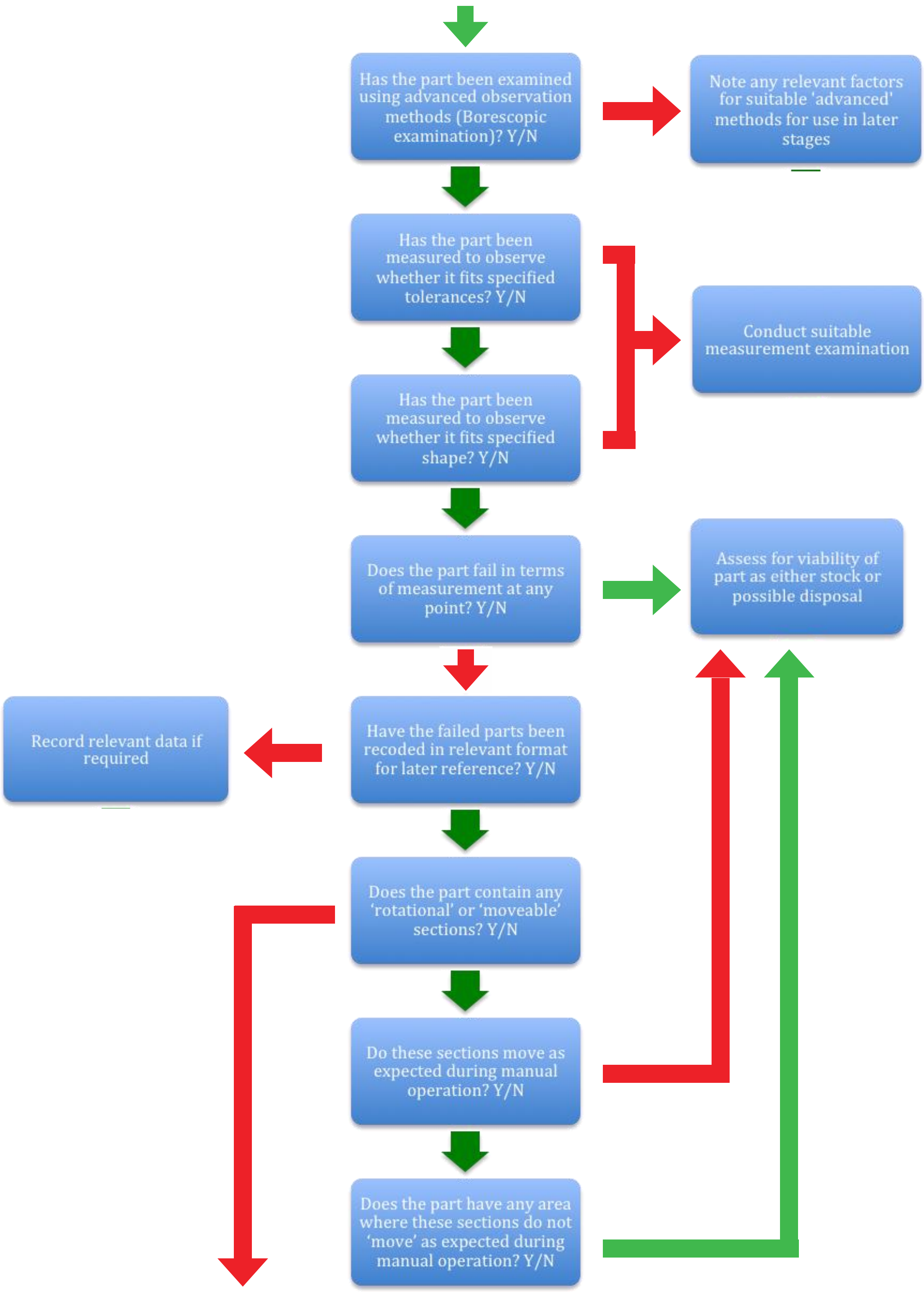
Is there any residue emanating from these sections post-odour examination? Y/N

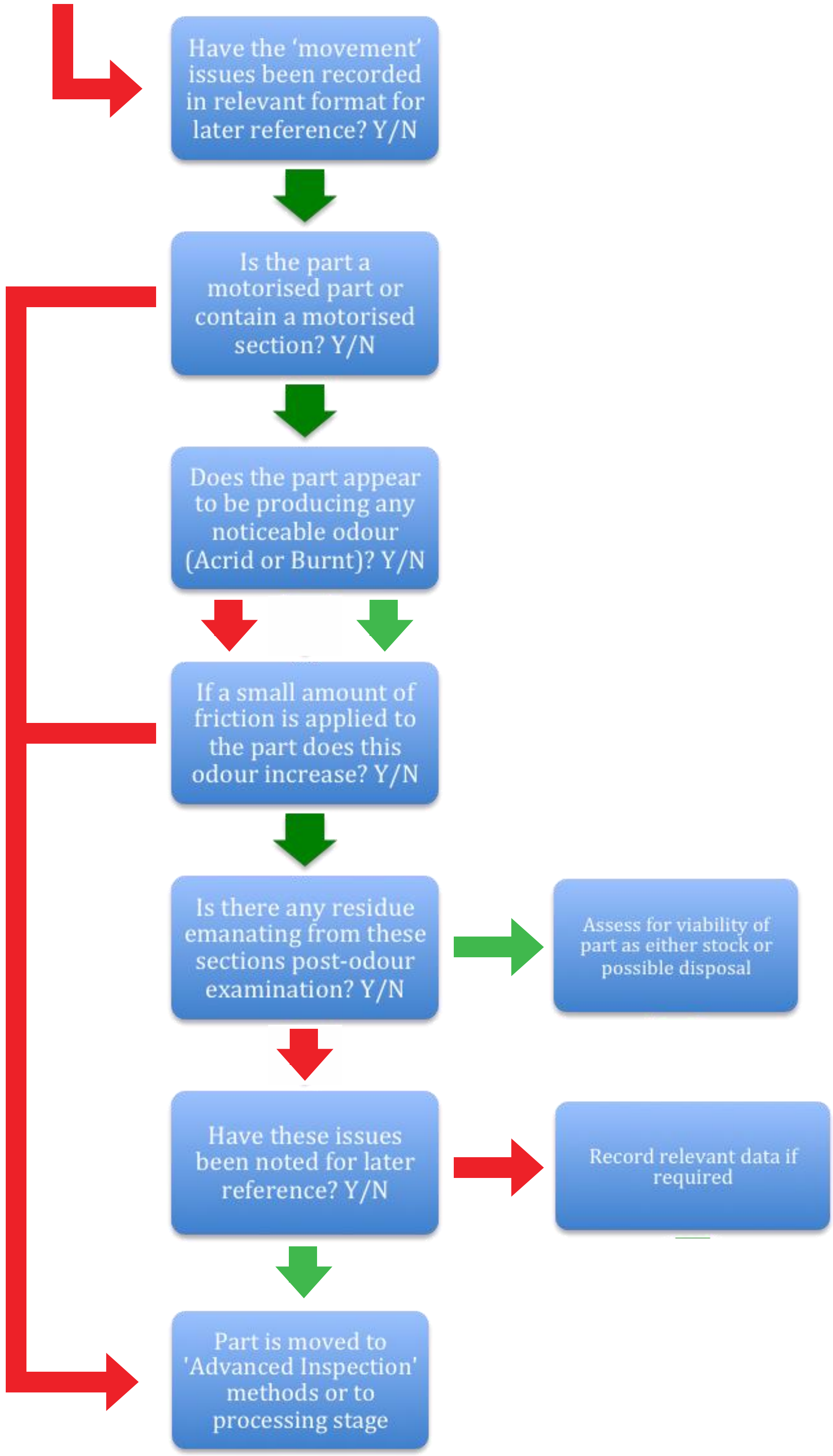
Have these issues been noted for later reference? Y/N

End: Core Parts are passed to Processing stage/ or alternatively onto Advanced Parts Inspection

Start: Core part are received by the Inspection Operator


Are all parts of the core present? Y/N
Have all parts been suitably cleaned so that their condition can be visually assessed without issues or hindrance? Y/N
Part is taken back to 'cleaning stage' to ensure suitable condtion
Has the part been visually observed across all external surfaces? Y/N
Conduct thorough visual assessment as required
Has the part been visually observed across all internal surfaces? Y/N
Does the part contain any significant forms of observable damage? Y/N
Have the relevant technical identifiers of the part been recorded (Model, type, manufacturer etc.)? Y/N
Review part to acquire technical identifiers if possible Y/N
Have the forms of damage been recorded in relevant format for later reference? Y/N
Does the part appear to be the suitable part for the core in question and non-modified? Y/N
Assess for viability of part as either stock or possible disposal


Has the part been examined using advanced observation methods (Borescopic examination)? Y/N
Note any relevant factors for suitable 'advanced' methods for use in later stages
Has the part been measured to observe whether it fits specified tolerances? Y/N
Conduct suitable measurement examination
Has the part been measured to observe whether it fits specified shape? Y/N
Does the part fail in terms of measurement at any point? Y/N
Assess for viability of part as either stock or possible disposal
Record relevant data if required
Have the failed parts been recoded in relevant format for later reference? Y/N
Does the part contain any 'rotational' or 'moveable' sections? Y/N
Do these sections move as expected during manual operation? Y/N
Does the part have any area where these sections do not 'move' as expected during manual operation? Y/N


Have the 'movement' issues been recorded in relevant format for later reference? Y/N
Is the part a motorised part or contain a motorised section? Y/N
Does the part appear to be producing any noticeable odour (Acrid or Burnt)? Y/N
If a small amount of friction is applied to the part does this odour increase? Y/N
Is there any residue emanating from these sections post-odour examination? Y/N
Assess for viability of part as either stock or possible disposal
Have these issues been noted for later reference? Y/N
Record relevant data if required
Part is moved to 'Advanced Inspection' methods or to processing stage

End: Core Parts are passed to Processing stage/ or alternatively onto Advanced Parts Inspection

E.4 Advanced Parts inspection

Described in the above section is the more basic 'Parts inspection' process; this forms the foundation upon which any further work is built. During advanced parts inspection, operators at companies utilise more complex and technical means of parts assessment to conduct more in-depth examinations of parts through the use of these methods. This stage is highly relevant in companies operating with OEM's who may require more detailed methods to be used within their contract regarding the undertaking of their remanufacturing work.

These processes and methods act as a supplementary addition to the process chart shown above; this section details the more advanced tools that are utilised by the inspectors when conducting more detailed forms of assessment.

After basic inspection the part is now ready for advanced parts inspection; depending on the properties of the part in question the next stage, which is to more fully examine the material condition of the part, can vary. The previous section detailed the use of visual inspection when observing cracking or similar surface damage.

Start: Parts enter the advanced inspection processes

Has the part undergone preliminarily visual inspection? Y/N

Have any previously identified forms of damage or issue been recorded for later reference? Y/N

Is the part suitable for material examination? Y/N

Have any issues been observed during advanced material examination (MPI. Ultra-Sonic, Eddy-Current Testing etc.)? Y/N

Have these issues been recorded for later reference? Y/N

Has the part been measured using advanced methods (CMM – Flat Plane)? Y/N

Has the part been measured using advanced methods (CMM – Circular Plane)? Y/N

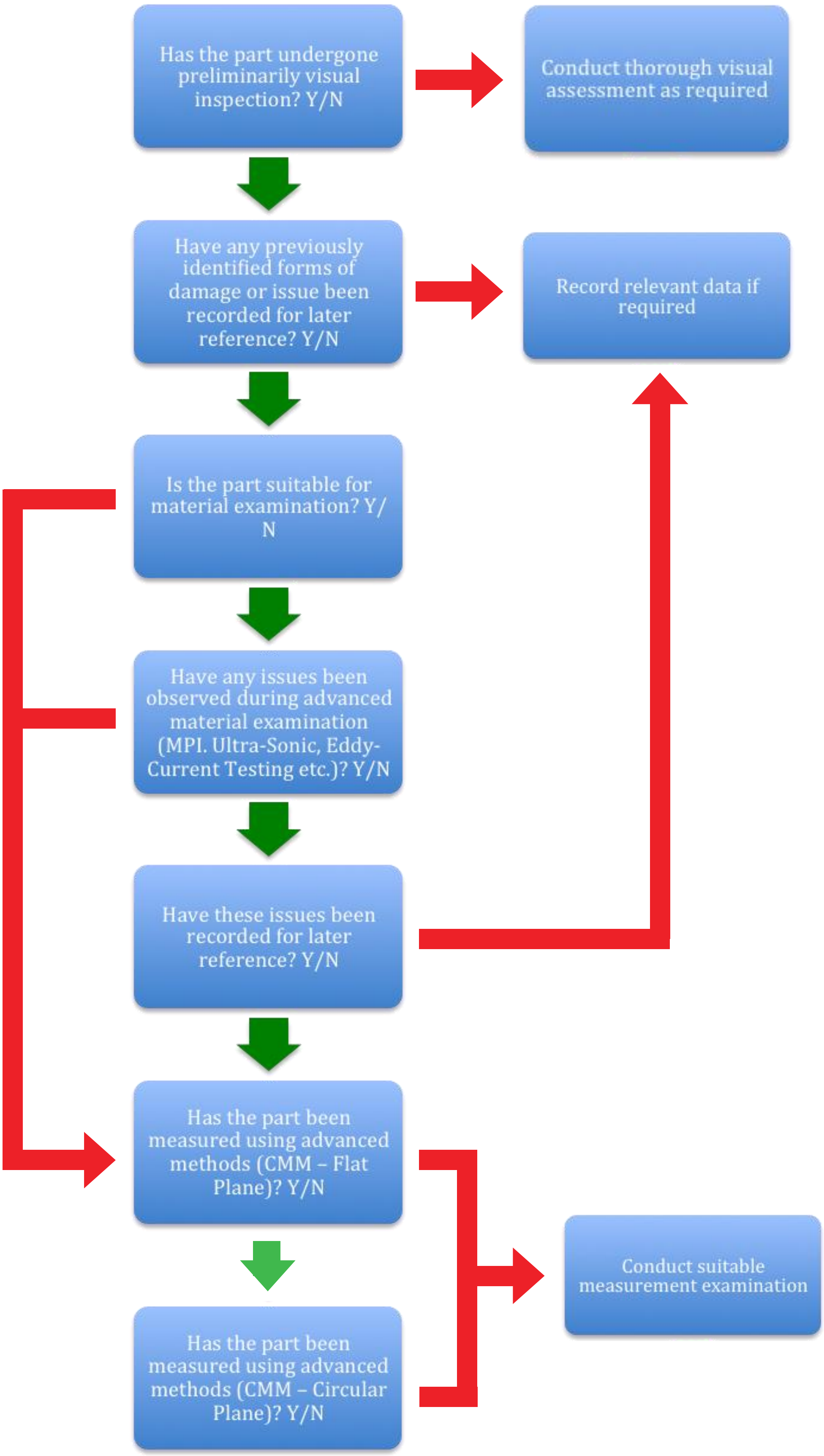
Have the results been recorded for later reference? Y/N

Does the part require structural assessment (Pressure Testing)? Y/N

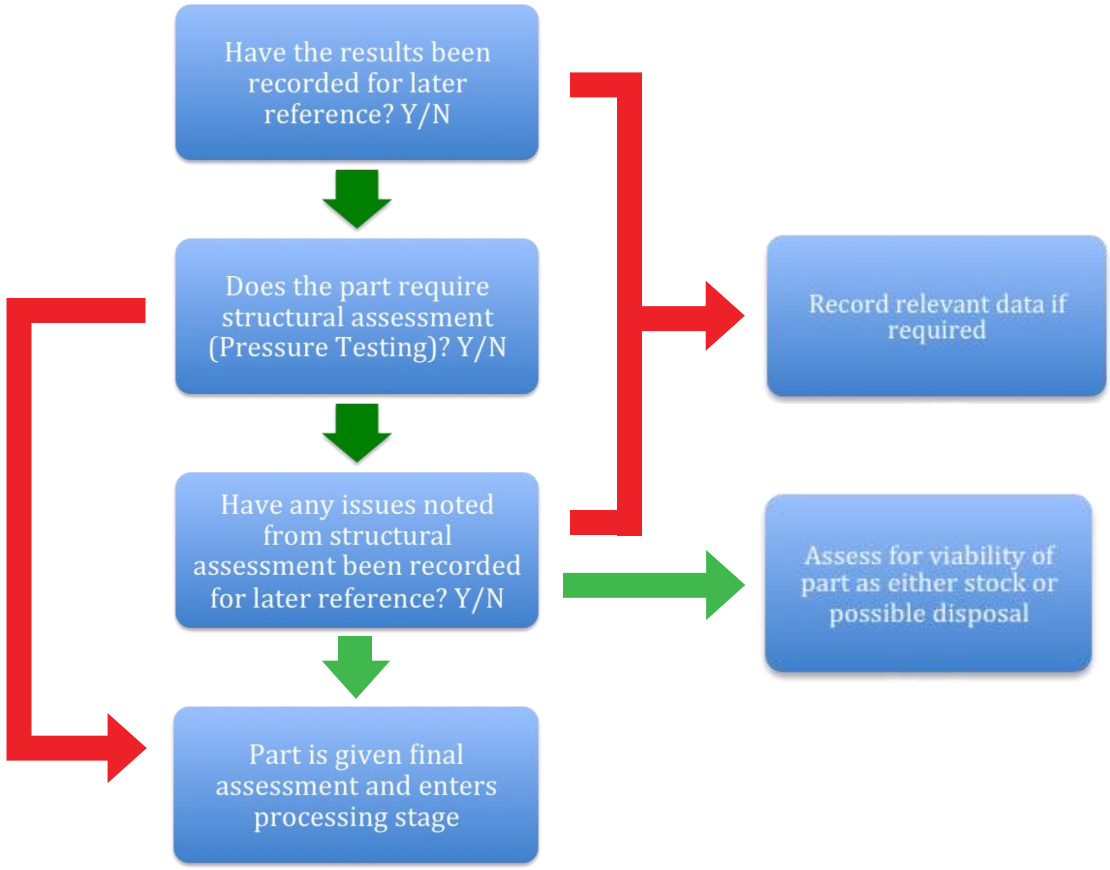
Have any issues noted from structural assessment been recorded for later reference? Y/N

End: Parts are passed to the Processing Stage

Start: Parts enter the advanced inspection processes



Has the part undergone preliminarily visual inspection? Y/N
Conduct thorough visual assessment as required
Have any previously identified forms of damage or issue been recorded for later reference? Y/N
Record relevant data if required
Is the part suitable for material examination? Y/N
Have any issues been observed during advanced material examination (MPI. Ultra-Sonic, Eddy-Current Testing etc.)? Y/N
Have these issues been recorded for later reference? Y/N
Has the part been measured using advanced methods (CMM – Flat Plane)? Y/N
Conduct suitable measurement examination
Has the part been measured using advanced methods (CMM – Circular Plane)? Y/N



End: Parts are passed to the Processing Stage

E.5 Post-Processing Inspection

After the 'processing' of a part it should now be ready for rebuild of the remanufactured core. The term rebuild is used in this situation because reassembly though more widely used in reference infers the reassembly of the same components in the same condition, however due to either replacement or processing this is no longer the case so the reassembled and remanufacturer core in this situation is referred to as being rebuilt (inferring some modification or replacement during the overall process). At this stage the assessment is carried out typically on a visual level by the operator conducting the processing of the part(s). This process involves performing a brief but detailed visual examination of the part to ensure that all have been ‘treated’ and ‘processed’ in the relevant manner and are now ready for the rebuild.

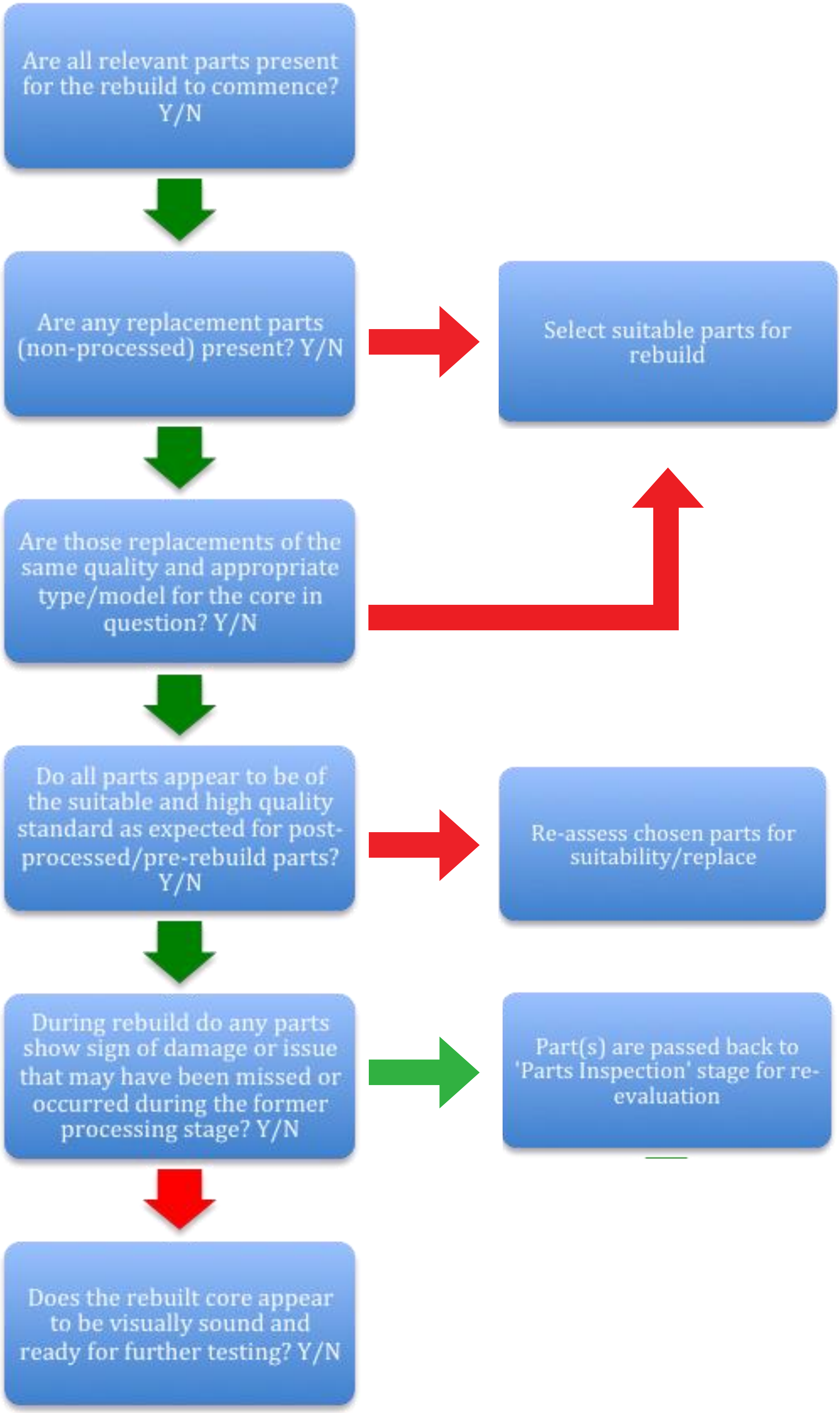
Start: Part ready for Rebuild stage of the process

Are all relevant parts present for the rebuild to commence? Y/N
Are any replacement parts (non-processed) present? Y/N
Are those replacements of the same quality and appropriate type/model for the core in question? Y/N
Do all parts appear to be of the suitable and high quality standard as expected for post-processed/pre-rebuild parts? Y/N
During rebuild do any parts show sign of damage or issue that may have been missed or occurred during the former processing stage? Y/N
Does the rebuilt core appear to be visually sound and ready for further testing? Y/N

End: Rebuilt Core is passed to ‘Testing’ stage of the process

Visual:

Start: Part ready for Rebuild stage of the process


Are all relevant parts present for the rebuild to commence? Y/N
Are any replacement parts (non-processed) present? Y/N
Select suitable parts for rebuild
Are those replacements of the same quality and appropriate type/model for the core in question? Y/N
Do all parts appear to be of the suitable and high quality standard as expected for post-processed/pre-rebuild parts? Y/N
Re-assess chosen parts for suitability/replace
During rebuild do any parts show sign of damage or issue that may have been missed or occurred during the former processing stage? Y/N
Part(s) are passed back to 'Parts Inspection' stage for re-evaluation
Does the rebuilt core appear to be visually sound and ready for further testing? Y/N

End: Rebuilt Core is passed to 'Testing' stage of the process

E.6 Performance Inspection

This stage of the process folds into another aspect of the remanufacturing operation and forms the other most critical area of inspection and assessment (Testing). Testing within the remanufacturing process is the vital stage at which a rebuilt core is tested (typically on a purpose built rig designed to simulate real world conditions and above) to ensure that it performs as expected when back out in the real-world. In this scenario the 'inspection' side of the Testing stage occurs through visual means as in earlier stages however the aspects being viewed are different. During this situation the operator is visually observing both the results from the testing rig and also the rebuilt core itself in order to gauge that the results being collected represent a sound and accurate representation of the qualities of the remanufactured piece. As such the operator is still required to visually assess the piece before and after it is utilised with the rig but the aim is to simply ensure that the 'testing' hasn't resulted in any detrimental effect on the parts and that no hidden issue has become noticeable through the external extremes of the test (i.e. Sub-surface material weakness or cracking becoming external cracking and part damage through pressure).

Start: Rebuilt Core enters the testing stage

Does the rebuilt core appear to be visually sound and of a suitable standard post-rebuild? Y/N

Are there any areas of issue noted by the operator or the internal paperwork that requires further attention? Y/N

Is the core performing as expected during the 'Testing' stage? Y/N

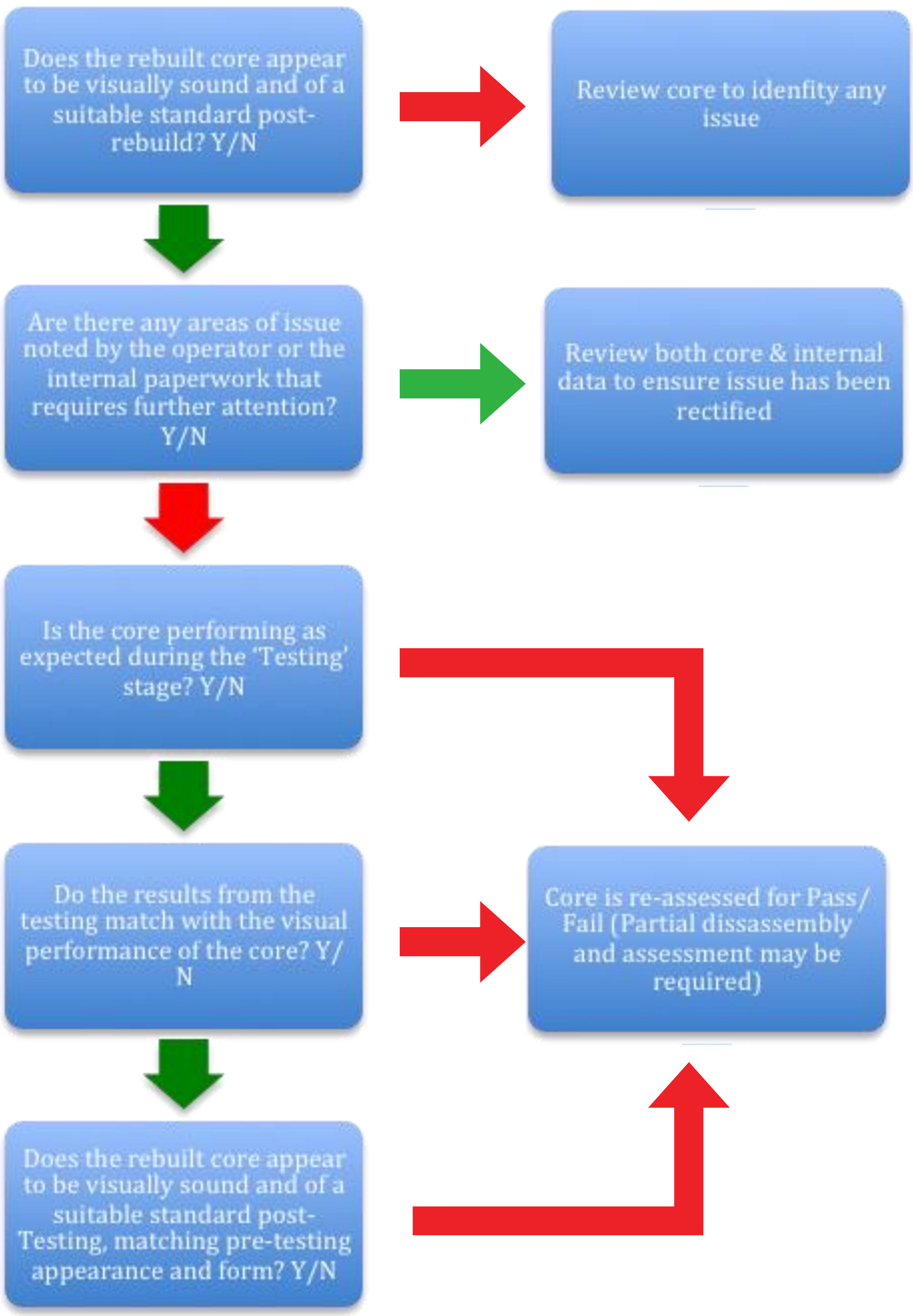
Do the results from the testing match with the visual performance of the core? Y/N

Does the rebuilt core appear to be visually sound and of a suitable standard post-Testing, matching pre-testing appearance and form? Y/N

End: Rebuilt Core is passed to packaging and storage

Visual:

Start: Rebuilt Core enters the testing stage



End: Rebuilt Core is passed to packaging and storage

E.7 Final inspection

The final stage of the inspection process, this stage occurs at the very end point of the remanufacturing operation and like the overview of core it occurs at a highly brief and visual level with the aim being the supplementary data gained through physical examination to confirm the expected and noted condition of the remanufactured product before it leaves the facility. This stage involves the operator viewing the core as it is packaged, this is to ensure that the product is as specified with reference to both the company's internal paperwork and that the appropriate core has all suitable documentation for its next stage of the journey. This type of inspection also ensures that there has been a final "eyes-on" view of the finished core before it leaves the facility, so that in the case of an issue regarding its condition after this point (During transport, at customer end etc.) the company has both written and visual confirmation that it left the company in suitable condition.

Start: Remanufactured core enters the final inspection stage, parallel with Packaging

Does the core appear to be in the suitable condition of a remanufactured output of the company? Y/N

Is the associated paperwork (Warranty, records etc.) present? Y/N

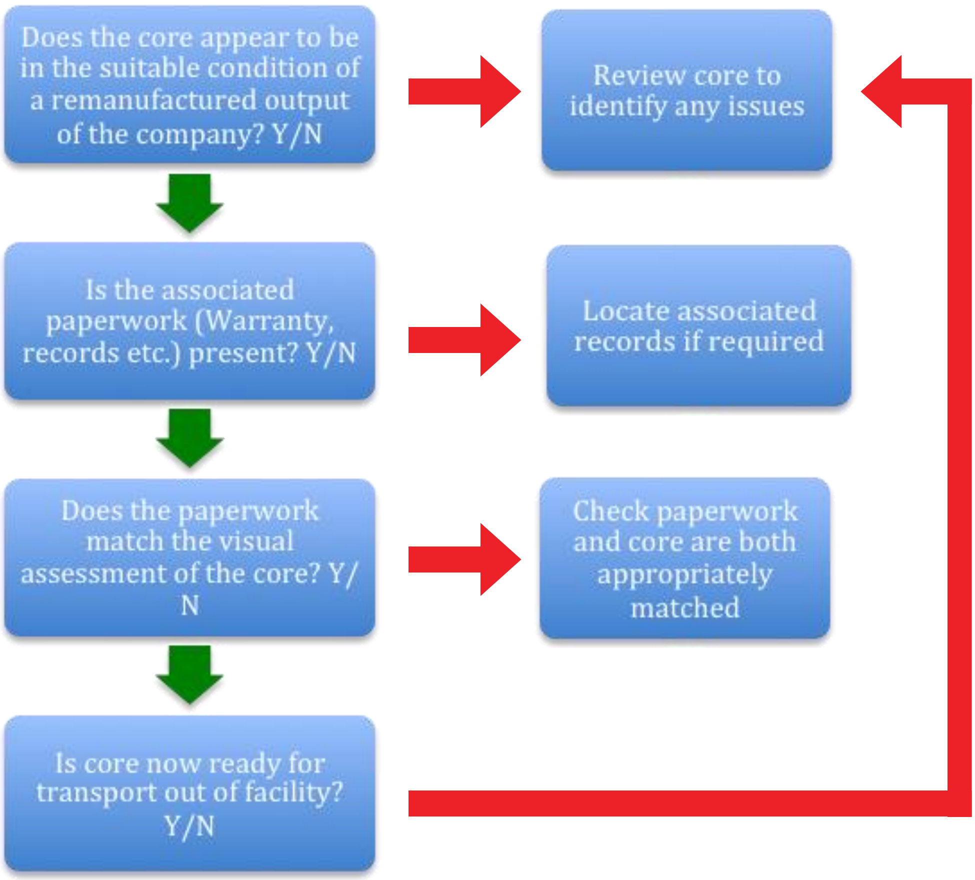
Does the paperwork match the visual assessment of the core? Y/N

Is core now ready for transport out of facility? Y/N

End: Packaged Core is transported out of facility

Visual:

Start: Remanufactured core enters the final inspection stage, parallel with Packaging



End: Packaged Core is transported out of facility

The above sections which detail the various stages of inspection within the typical automotive remanufacturing operation are designed to be utilised by operators within this field in order to 'streamline' the process if possible.

In this scenario the 'pictorials' which accompany each of the stages described above contains a 'flow-chart' decision tree which allows the user to follow the relevant steps to conduct effective inspection at each stage, with very little need to rely on guesswork or assumptions. The idea of the RaPID is that it may be used as a ‘guide’ for company's already operating within the sector, allowing for the potential of current methods that may be overly complex or inefficient to be compared to the routes detailed here and so possibly improve the day-to-day operations of the company.

The other main aim of the RaPID is to act as a guide and training tool to new or developing companies within this sector of the remanufacturing market; the RaPID outlines all main aspects and relevant factors associated with automotive inspection, regardless of part or core in question.

Within the automotive sector of remanufacturing the types of core can vary with some companies operating solely on gearboxes, transmission, alternators, engine blocks and more. Some companies remanufacture multiple sections of the engine while others focus exclusively on a single sub-assembly. The aim of the RaPID is to provide all companies within this field with a detailed, relevant and comprehensive overview of all inspection and assessment processes that may occur. In this fashion companies moving into this field can follow the routes and details specified within the RaPID system and in combination with their own developing experience and expertise perform successful and effective inspection in an efficient and timely manner.

APPENDIX F – POM Database

F.1 Level 1:

Visual Inspection – Breakdown:

Step 1: Identifying Part:

The first stage is to check that this is the appropriate part for the core in question. The operator must examine the part and identify which part within the assembly it is as well as which manufacturer it is the product of. In addition to this the user must also identify if possible which type of part it is, by this what is meant is what model of the part is question is the currently examined piece. Different models of the same type of part may be used in the same core by the OEM manufacturer themselves as the differences between the parts may be very small (minor alterations to shape or material composition) yet allow the part to remain suitable for use in a core whose other components may remain unaltered.

The relevance of ensuring that adequate identification and recording of this information is conducted is that as well as providing suitable record keeping for company purposes the relevant information can be input into the "Damage Tracking" segment of the DATF

Step 2: Examining for Degradation:

At this point the operator examines that part for any sign of material degradation that may have occurred during its functional or aftermarket lifecycle. The user will be looking for areas where the surface of the material appears discoloured or showing signs of rust and material breakdown. A potential sign of breakdown is the external surface of the part appearing ‘flaky’ (which at its worst may make it look as though the material was constructed of numerous fine layers of this flaky discoloured material that is now very uneven and coming off).

Step 3: Examining Wear:

The examination for wear involves the operator looking at every facet of the part in question to examine if and where ‘wear’ may have occurred. Since ‘wear’ has been earlier classed as the ‘reduction and removal of part material through external pressure’ the operator is likely to find it most clearly appearing as erosion on the surface areas of the part. While erosion on a large scale can be very clearly observed by the operator the more subtle areas of ‘wear’ can be more difficult to identify at first glance.

Step 4: Examining for Material Damage:

Material damage at the more subtle end of the spectrum can be almost impossible to observe through the use of the visual medium alone. The damage that can occur in material damage (such as near-surface defects and cracking) typically requires the use of advanced NDT equipment to suitable identify it. Processes such as MPI can be considered the norm for this practice. However these factors should not discount the value of the visual inspection of the operator when conducting this type of assessment.

When conducting this stage of the operation the user should be on the look out for surface cracks (particularly where different sections and planes meet signifying that during the initial manufacturing processes welding and other joining processes may have been used there).

Step 5: Rotation & Movement:

A key aspect of conducting purely visual inspection is to ensure that any observable functionality of the part or piece in question is conducted. This includes the 'rotational' or 'movement' ability/capacity of a part.If the part in question is expected to have a specified range of movement or rotation then the inspector is required to manually operate the part in order to observe from a visual display the apparent capability of the reclaimed part. If the part moves as expected then the inspector is confident that if the other criteria for the levels of visual damage to the part are relatively low then it is highly suitable for remanufacture. If on the other hand the part does not move as expected then the inspector can decide at that point whether this fact compromises the parts feasibility for remanufacture from an economical point of view.

Step 6: Does part require further processing (Higher Levels of Inspection):

After the purely visual inspection has been completed the operator has the option to move onto more detailed/advanced forms of assessment and part evaluation. The necessity or suitability of utilising more advanced inspection methods for the part in question can be tied to 3 distinct factors; the condition of part post visual inspection, the type of part in question and the applicability of the advanced methods.

Condition: If the operator when conducting the visual inspection identifies the part as being highly suitable for remanufacture and to be in highly good condition the need for more detailed forms of inspection may not be required within that operators opinion. Smaller less developed remanufacturing operations can be highly variable in terms of operational structure with a smaller staff and as such changes and decisions relating to the operation process may be changed on a part-to-part basis.

Some parts in the core have such a low economical value that if any form of extended inspection is required to more fully examine the part instead of a straight pass/fail from a visual perspective then the time alone is an expense too high and the part is immediately discarded for recycling or disposal.

The applicability of the advanced method relates to its potential usage for investigating the part in question, for example MPI is only suitable on ferromagnetic materials while hydrostatic testing is only applicable to parts utilising fluid transference or pressurised sections during functional usage. Other considerations include the expense required to evaluate components with each of these methods. The cost in terms of man-power, technology and time may be more expensive than the overall economical value of the remanufactured part.

Step 7: Part Evaluation:

DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail markers for inspectors to utilise at these stages. All previous data gathered through steps 1 – 6 can be factored into the DATF criteria and an accurate and suitable summary of the part condition can be generated for internal company usage. The DATF data can also be utilised to aid trainee operators in this area with identifying the real-world equivalents to criteria described, lowering the reliance on pure tacit knowledge and aiding in the successful and more standardised transfer of information.

Mobility Test:

This ‘test’ is a highly rudimentary process, it occurs where components or parts contain ‘moveable’ or ‘rotational’ sections that can be operated manually when core has been disassembled to sub-components and parts. In situations such as the part can be manipulated by the operator in order to evaluate the Range-Of-Movement (ROM) available in comparison to the range specified in technical details or within the expectation of the operator (full rotation, partial rotation etc.).

Step 1: Ensure that part is clean and dry, no contaminants that may hinder or impede the parts rotation/movement.

Step 2: Ensure that part is clear of excess fluid or liquid that may aid standard movement and provide false indication of range and speed of rotation.

Step 3: Check expected/specified range of movement and speed against company knowledge.

Step 4: Perform movement/rotation test, manually manipulating the piece until a full evaluation of its capabilities in this area has been gathered.

Step 5: Note any relevant additional damage or notable issues found.

Step 6: Used finished data gathered to evaluate whether part passes/fails based on pre-defined criteria or opinion of inspector. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

F.2 Level 2:

Magnification equipment:

A relatively standard enhancement utilised with visual inspection, the use of magnification equipment is required when the operator desires a more accurate and focused look at sometimes key areas of a part. Within the typical assessment operation a handheld magnifier may be used or in the cases of more intricate or smaller components the use of a high intensity magnifier necessitates a more stable foundation. The more advanced magnifiers can allow for variable levels of magnification, providing the operator with the ability to alter the intensity of the visual examination as required.

Step 1: Ensure that part is clean, allowing for detailed examination of key areas and features.

Step 2: Ensure that suitable lighting is in place to allow for maximum visibility of all part surfaces.

Step 3: Use selected magnification equipment to examine the required areas.

Step 4: Note any relevant additional damage or notable features found.

Step 5: If required alter or add additional light source in order to more effectively illuminate the selected area of the part.

Step 6: Use finished data gathered to evaluate whether part passes/fails based on pre-defined criteria or opinion of inspector. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

Borescopic Examination:

Borescopic examination or *Optical Internal Inspection* can be used to examine parts which are geometrically complex and as such present an issue when conducting traditional internal visual assessment. Certain automotive component parts can be very difficult to internally examine without this type of visual enhancement. Borescopic examination is the use of a 'probe' which is fitted with either an electronic or angled lens at the end of a long rod or endoscopic cable. The user then inserts the optical equipment into the part through which ever opening is present or most suitable (Cable is typically between 0.5-1.0 cm in circumference); through the lens at the end the operator should then be able to observe sections of the previously unobserved interior and from there visually inspect its condition. The more advanced optical equipment can allow for greater resolution and multiple forms of visual evaluation (Infra-red, UV etc.) if desired. Modern examination equipment is typically fitted with an external screen or panel which can display the readouts and information gathered by the probe for the user to review.

The Borescopic set-up can consist of;

The rigid or flexible length of endoscopic cable (possibly videoscope for real time viewing on monitor or eyepiece).

Suitable light source to illuminate the desired area during evaluation.

An optical system that can include a *rod lens system*, a *fiberoptic imaging cable*, a *rely lens system* or a camera (either *CCD – Charged Coupled Device* or *CMOS – Complimentary Metal Oxide Semiconductors*).

An external (LCD) monitor to view the data.

An external eyepiece to view that observed image from the end of the cable.

Step 1: Ensure that part is internally clean, allowing for detailed examination of key areas and features.

Step 2: Select the appropriate type of Borescopic probe to examine the desired part (rigid, flexible, videoscope etc.).

Step 3: Insert probe and ensure that selected light source is calibrated to illuminate desired internal section in a suitable manner.

Step 4: Conduct internal inspection of part.

Step 5: Note any relevant additional damage or notable features found.

Step 6: Use finished data gathered to evaluate whether part passes/fails based on pre-defined criteria or opinion of inspector. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

It should be noted that a wide range of Borescopic technology is available on the market and in recent years the introduction of videoscope technology in this area has aided in the development of many much cheaper forms of advanced borescopic inspection.

Scratch-Sniff test:

The scratch-sniff test is a fairly ill-defined method used when examining components with motorised sections. The operator in question will use a tool to gently ‘scratch’ the surface at the motorised section and then observe if any noticeable odour can be detected. The aim of this method is to observe whether an acrid tang can be detected or if any residue (typically black) is released through the physical interaction/friction. If either of these situations occurs it is a very strong indicator of burn damage and the likely unfeasibility to remanufacture of that component.

Step 1: Ensure that part is dry.

Step 2: Ensure that part external surfaces are sufficiently illuminated for inspection purposes.

Step 3: Check the motorised section of part for any obvious signs of external scorching or ‘blackening’.

Step 4: Proceed with ‘scratch-sniff’ test by applying low level friction to motorised areas.

Step 5: Try to detect any acrid odour surrounding part.

Step 6: If necessary undertake steps 4 & 5 in different sections or areas of the part with greater friction if required.

Step 7: Use finished data gathered to evaluate whether part passes/fails based on pre-defined criteria or opinion of inspector. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

Typically in this scenario if any odour or black discharge is released from the part then it is unusable and unsuitable for further processing or remanufacture, however this is not always the case; if the part in question is highly valuable then more detailed evaluation may be required.

F.3 Level 3:

This level of the POM method details those which are used in advanced forms of measurement and structural assessment of the part/core. Like previous levels these methods are slightly more advanced in terms of complexity in both usage and the technological aspects of the processes. These terms will be described in detail, including both the benefits and limitation of each method as well as the most suitable usage of the method when conducting parts inspection procedures.

Pressure Testing:

Hydrostatic testing is the use of pressure and fluid in order to assess the structural condition of a part or product. The process involves the use of a fluid (possibly water, typically dyed in order to more easily be visually observed) being used to ‘fill’ the fluid bearing capacity of a part such as pipes or fluid links in complex parts. Once the part has been ‘filled’ the part is then pressurised in order to recreate functional conditions of the piece at capacity. The inspector then observes whether any fluid has leaked from any section of the part (Visual Leak detection) as well as consulting the database providing from the pressurisation machinery which can display the expected and current levels of pressure within the piece.

The pressure supply can then be shut off while the piece is observed for any detectable pressure loss or leak. The ‘*testing’* level of the pressure is typically much higher than the expected ‘*operating’* pressure in order to allow a high margin of safety. This higher factor is typically shown as 166.66%, 143% or 150% depending on the legislation or regulations in place.

Within the automotive aftermarket side of the operation this process is widely used to evaluate the condition and properties of parts of the automotive transmission or gearbox that utilise pressure or fluid movement during their functional operation.

Step 1: Ensure that part is completely clear of all contaminants and is dry.

Step 2: Ensure that relevant and necessary pressure data relating to the part in question is at hand, although the ‘safety margin’ used when pressure testing (150% etc.) allows for a greater range of pressure than expected during functional lifespan, the use of incorrect testing pressure can display incorrect or worthless data or in some cases cause significant damage to the part.

Step3: Ensure that suitable ‘fluid’ used for the pressure test is ready for use (dyed water typically).

Step 4: Align the part with the hydrostatic testing system in order to ensure that when fluid is filled into the part that no excess can escape and the ‘filled’ part can then be pressurised without issue.

Step 5: Fill the part using the selected dye fluid.

Step 6: Pressurise the part to the specified limit (166.66%, 143% or 150%).

Step 7: Observe the part for any noticeable leaks or areas where part integrity may be comprised, causing pressure loss.

Step 8: Stop part pressurisation and observe if internal part pressure decreases; signifying issues of structure.

Step 9: Data is recorded for internal company usage.

Step 10: Use finished data gathered to evaluate whether part passes/fails based on pre-defined criteria or opinion of inspector. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

Pneumatic testing:

While Hydrostatic testing is a highly valuable and useful method for evaluating the structural integrity of parts, in some cases due to the design or manufacture of the part in question its suitability for hydrostatic testing is not applicable. In this case an inert gas, such as nitrogen or if necessary air to pressurise a system beyond its expected functional limit in order to observe and record its structural integrity. Typically a part is subjected to 110% of its stated limit, this 'pushing' of the parts safety limit is to ensure that any piece passing this test when assessed is structurally sound. The benefits of this set up include, no need to dry or clean the part after this process due to the pressurisation occurring through air/gas, it does not allow for contamination of internal surfaces through pressurised medium and can produce highly accurate results that can back up the perceived integrity of the part. The use of this process can be highly valuable when hydrostatic testing is not possible due to the weight and pressure of the water system being too high for the structure of the part in question. Due to the nature of the pressure medium (in this case compressed gas) there does exist a level of significant risk to human welfare in terms of mis-use or accident.

If this process is desired to be implemented into the traditional remanufacturing process of the company the user must ensure that suitable and detailed risk assessment practices have been carried out, following all relevant safety regulations and procedures for process use.

Step 1: Ensure that part is free of contaminants and is clean and dry before testing begins.

Step 2: Ensure that pressurisation system in place is suitably calibrated for use with part and does not exceed specified pressure tolerance (risk for user & part).

Step 3: Aligns part with pressurisation system to ensure that full seal has been achieved.

Step 4: Begins to pressurise part up to ½ of pressurisation test limit.

Step 5: After this point the remaining test pressure is added in stages of 1/10 to 1/8 in order to observe whether any perceivable strain begins to show in part as test pressure is reached.

Step 6: Pressurisation is stopped once limit is reached.

Step 7: Part is then examined for leaks or loss of pressure in any area.

Step 8: Data is recorded for internal company usage.

Step 10: Use finished data gathered to evaluate whether part passes/fails based on pre-defined criteria. (DATF criteria can be used at this junction to more accurately grade damage to part and potentially build pass/fail marker for inspectors to utilise at these stages).

CMM:

CMM refers to a **Co-Ordinate Measuring Machine**, a computerised piece of technology which is used to measure the physical parameters and geometric features of a object (or in this case 'Part') with a very high degree of accuracy. The machine operates within 3 axis (X, Y,Z) with a probe attached to the 3rd moving axis allowing for the measurement of the piece in question. The probe can be controlled manually by an operator or through programmed instructions DCC (Direct Computer Control), with more geometrically intricate parts the use of programming can allow for a more accurate and efficient operation (with DCC the program can also be set to repeatedly evaluate parts by the same measurement input this allowing for a 'conveyor belt' scenario to occur if required or desired). The computer is aware of the position of moving probe and can identify its position relative to the 3 axis when it is recording its movements. Through this the user can gain highly accurate measurements of the overall part and the specific sizes of particular sections if necessary. This accuracy is typically conducted to within micrometer measurement allowing for parts or components with particularly tight tolerances to be evaluated effectively.

The data gathered through this method is recorded and collated in the computer and presented as a fully formed 3D model which can be examined in detail by the user. This method is used widely throughout the manufacturing industry for ensuring that all outgoing products are produced as desired and specified by the original design technical specifications. Statistical modelling such as regression algorithms allows for the original manufacturers to identify and predict how (*Independent variables*) particular features will be affected by changes or alternations made to a specific point (*Dependant variable*).

The use of this technique within the aftermarket reclamation and remanufacture of automotive parts and components has become more noticeable within larger scale OEM's and particular contractors in recent years. Depending on the automotive parts being remanufactured the need for CMM can vary. Components with circular planes such as pistons, crankshafts and cam shafts are required to be very carefully examined due to the need for these parts to rotate or move with surface to near surface contact during functional operation.

Step 1: Ensure that part is clean and dry (any contamination or fluid may cause issue for the probe being used).

Step 2: Ensure that sizes desired for measurement have been specified and appropriate probe attached to CMM (This is necessary for suitable data gathering and reference sizes).

Step 3. Calibrate the probe in question for use.

Step 4: Measure the reference sizes from Step 2 in order to ensure that probe data is reliable and calibrated effectively.

Step 5: Designate the axis for the probe and part mapping (CMM Model), Z axis, the secondary axis and the part origin.

Step 6: Conduct the required measurements and build model.

Step 7: Evaluate data gathered through measurement and model generated against pre-defined criteria (Tolerances).

Step 8: Data is recorded for internal company usage.

Step 9: Part either passes or fails based on criteria. If part passes then any necessary processing for remanufacturing purposes (Additive processes etc.) should be noted for internal paperwork.

The key area where issue can occur during the use of CMM is the aligning of the part for measurement purposes (Step 5), this is essential for ensuring that minute variation in measurement (microns) is actually measured properly and recorded for later reference. However the design, shape and geometry of certain parts can mean that aligning the part in the most effective manner is a skill that only experience and time can teach to CMM users. However, if the CMM is a highly accurate machine (a dependency on the quality and maintenance of both air bearings, and the guides either ceramic or marble).

Within the context of aftermarket part assessment CMM technology can be used in two scenarios; when examining the condition and accurate measurement of flat planes (geometric features and areas operating within the confines of a typical three-dimensional objects constrained by block configuration i.e. Rectangular or cuboid parts with little curvature or spherical design) and circular planes (geometric objects that feature spherical parts and curved features in part design i.e. Crankshaft, camshaft etc.). Circular CMM examination is a highly valuable assessment method allowing for the extremely accurate measurement and close tolerance to the circular diameter of certain parts, this is particularly necessary when dealing with multiple parts that require contact/near-contact when operational and in some cases involve external parts moving around or over the outside edge of the part.

F.4 Level 4:

MPI (Ferrous)

Magnetic particle inspection or MPI is a non-destructive form of Testing which can be carried out on a variety of parts and components which are constructed of ferrous metals. The method is highly useful for clearly displaying material damage to the user through a visual means (issues such as surface or near-surface damage can be examined in highly effective conditions).

This process is only applicable to parts constructed of ferromagnetic material such as iron, cobalt, nickel and several of their alloys. The process involves a magnetic field ring placed upon the part, either through **Direct Magnetisation** (Electric current is passed directly through the piece in question) or **Indirect Magnetisation** (Magnetic field is applied to piece from outside source negating the need for direct current). The magnetic lines of force (which operate perpendicular to the direction of the current being used) then pass through the piece allowing for any surface or near surface discontinuities or such as cracking or ‘damage’ to produce magnetic flux leak. This ‘leak’ can then be detected through visual means when ‘Ferrous’ particles are introduced to the piece’s surface; the ‘leak’ causes the particles to ‘collect’ at these areas producing a clear representation of areas of concern.

The ferrous particles can be applied in either dry or wet format (within the context of automotive remanufacturing the dry form is the most observed method in use).

As stated above this process can only be utilised with ferromagnetic materials which limits the applicability of this process to all parts within automotive aftermarket recovery. As such the information regarding material composition of the core/part being received and then processed by the facility in question is paramount in order to ensure that time and resources are not wasted in ineffective and pointless procedures.

The most common examples of automotive components that can be tested/assessed through MPI includes crankshafts, engine gears, camshafts, engine blocks, engine bolts, nuts, washers, connecting rods etc.

The action of operating MPI occurs as thus:

Step 1: Ensure that part is completely clear of all contaminants and is dry.

Step 2: Ensure that suitable level of current in order to magnetise the part is known (based on pre-process calculations. If part of typical remanufacturing operation, a set of pre-calculated levels based on type of part is advised to be on hand at operation).Suitable information can be gathered at (Standard Practice for Magnetic Particle Testing – ATSM E1444/E1444M) the price for such access is relatively low and includes all relevant data required to generate necessary calculations.

Step 3: The inspector applies the Ferrous particles to the part. This occurs while the pulse magnetising the part is operating. This pulse lasts for 0.5 seconds and the particles have to be applied during this time. Application of the particles past the end point of the pulse will render the results worthless, in order to apply the articles within a short time span the use of 'spraying' is advised.

Step 4: The inspector then uses ultraviolet light to examine the part for any defects or discontinuities; the ferromagnetic particles are typically luminescent under UV conditions allowing for more effective observation of areas where they have collected.

Defects will only appear from 0 to +/- 45 from the direction of the current.
The magnetic field will be running 90 degrees from the direction of the electric current.
Complex geometry requires the inspector to visualise the direction of the paths in order to successfully inspect (parts such as crankshafts and camshafts may fit this category).

Step 5: The inspector either passes or fails the part based on evaluation criteria developed before the process was implemented into typical operations.

Step 6: Data is recorded for internal company usage.

Step 7: The magnetic field of the part is then returned to normal through demagnetisation.

Step 8: This is an optional step but if required or desired the orientation of the magnetic field can be shifted 90 degrees in order to assess defects that were not previously noticeable through the previous direction method.

Part Demagnetisation is achieved through the use of specialised equipment which passes a greater current through the part than previously used to originally magnetise it, this new greater current is then gradually reduced in turn lowering the magnetic properties of the part till it returns to normal.

ECT-Eddy Current Testing (Non-Ferrous):

Eddy Current testing is focused on detecting surface or near-surface flaws or cracks, allowing for material assessment of the part to take place in a manner similar to that of MPI, although operating under less strict limits to the materials examined. Unlike ultrasonic testing or other methods ECT does not require the use of coupling liquids in order to operate and in addition to crack detection as mentioned above this method also allows for other factors such as material 'hardness' to be examined if desired. In terms of operation any deformities or defects present in the examined piece cause a change in the eddy currant and as such a change in the phases and amplitude of the measured current being received.

Eddy Currents are generated during electromagnetic induction, during this process the alternating current is passed through a conducting apparatus such as copper wire creating the magnetic field used to assess the part in question. Eddy Current density is highest near the surface of the part, so that is the region of highest test resolution. The standard depth of penetration is defined as the depth at which the Eddy Current density is 37% of its surface value, which in turn can be calculated from the test frequency and the magnetic permeability and conductivity of the test material.

Some of the key benefits of this technique include the capability of detecting very minute near surface cracks within the examined piece, the ability to examine physically complex parts with varied geometries, and the ability to perform such test without the need for couplant as in other testing methods. Eddy Current testing permits crack detection in a large variety of conductive materials, either ferromagnetic or non-ferromagnetic, whereas other non-destructive techniques such as the magnetic particle method are limited to ferromagnetic metals.

In addition to this the potential portability of the testing system makes it highly suitable for operations requiring a level of portability, either within facility grounds or externally if desired. A smaller remanufacturing company, still in the relatively early stages of its life may be less entrenched in initial facility operational layout and set-up. Changes occurring through ‘lean’ ideology or increasing resources will likely cause change in both structure and facility operation, the mobility of this particular testing method allows for adaptation to these changes with ease. While some older Eddy Current instruments used simple analog meter displays, the standard format now is an impedance plane plot that graphs coil resistance on the x-axis versus inductive reactance on the y-axis. Variations in the plot correspond to variations in the test piece.

Step 1: Ensure that part is free of contaminants and is clean and dry before testing begins, this allows for smooth operation of the testing.

Step 2: Ensure that appropriate equipment set-up is in place for the testing (Alternating current 'cooper' coil, probe, Impedance Plane Plot).

Step 3: Part in question has been set in place for Eddy Current Testing.

Step 4: Probe in question has been calibrated for part and material in question.

Step 5: Ensure that all relevant standards are adhered to when conducting assessment.

Step 6: Alternating current is applied to coil and magnetic field is generated around the probe.

Step 7: Data passed back to transducer or probe in question. Data is then read by user through the Impedance Plane Plot in order to observe whether further assessment is required.

Step 7: The inspector either passes or fails the part based on evaluation criteria developed before the process was implemented into typical operations.

Step 8: Data is recorded for internal company usage and potential training.

Ultrasonic Testing:

Ultrasonic testing is a method that involves the use of ultrasonic pulse waves being projected/transmitted into parts or material in order to determine their condition with relation to internal flaw or defects. There are several methods within this specific technique and each are used to assess a particular facet of the parts condition, such as material thickness, material density and corrosion. This method involves the use of a transducer being passed over and around the part in question. This transducer is connected to pre-programmed diagnostic equipment which interprets the data collected and presents it in an easily understood manner to the user. High frequency sound waves move in a very directional manner, as such when projected they will move through the air (or similar medium) until they meet a material and are then reflected back at the origin projector (transducer in this case) allowing for features such as material composition in terms of part and feature thickness and potential internal damage to be assessed.

The 'pulse waves' discussed earlier are transmitted much higher than standard human hearing, operating from within the 500 KHz – 20 MHz range. Internal material thickness can be valuable when assessing the condition of part structures that are otherwise inaccessible through more traditional examination methods such as

Borescopic examination; the level of accuracy that can be achieved through this method with direct relation to wall thickness (caused by wear/corrosion of a part) is very high. Ultrasonic thickness gauges can achieve accuracy as high as +/- 0.001 mm.

In terms of ‘defect detection’ or ‘flaw detector’, the equipment is used to generate a visual representation called a ‘waveform display’ which can be interpretation by a trained user to identify any deviations from norm signifying cracks or damage.

The main limitations of this method involve the fact that this technique relies heavily on the training and effectiveness of the operator conducting the assessment. Also parts with rough surface texture can cause poor/inaccurate results to be gathered and surface dents or cracks remain undetectable by this method.

Step 1: Ensure that part is free of contaminants and is clean and dry before testing begins, this allows for smooth operation of the testing.

Step 2: Ensure that appropriate equipment set-up is in place for the testing (Waveform equipment, transducer, material thickness gauge etc.).

Step 3: Ensure that appropriate couplant has been provided for use when conducting the testing.

Step 4: Part in question has been set in place for ultrasonic test.

Step 5: Probe or transducer in question has been calibrated for part and material in question (suitable level of pulse wave KHz, MKz).

Step 6: Couplant is then applied and ultrasonic transducer passed over are selected for assessment.

Step 7: Ensure that all relevant standards are adhered to when conducting assessment.

Step 8: Data passed back to transducer or probe in question, data is then read by user in order to observe whether further assessment is required.

Step 9: The inspector either passes or fails the part based on evaluation criteria developed before the process was implemented into typical operations.

Step 10: Data is recorded for internal company usage and potential training.

Like many NDT methods ultrasonic testing requires a very high level of skill on the part of the user, in order to both set-up the examination and to effectively conduct its operation and analysis of results.

F.5 Level 5:

Automated Parts Inspection:

A key aspect for future work within the parts inspection process is the move towards autonomous or automated practices becoming an integrated part of this highly specialised aspect of the operation.

The inspection stage of the remanufacturing process can be a potentially time-consuming process depending on variables such as the complexity of the parts in question as well as the skill and personal knowledge of the inspector. As discussed earlier in this chapter the potential for ‘variation’ in inspection knowledge and opinion is a factor that the DATF model aims to combat by providing a comprehensive overview of the available practices in order to determine and categorise key damage. In turn the additional model sections allow for self-evaluation as well as the capacity to utilise the models data to anticipate/predict the condition of incoming core and if desired attempt to map said condition back through the supply chain to ascertain whether any aspect of the condition once delivered to the start of remanufacturing process is due to manageable areas on the part of the company (i.e. Company transport, company handling, on-site storage etc.).

The overall aim of the DATF model is to provide a data heavy tool which provides relevant and reliable information to both experienced and inexperienced users allowing for successful and suitable automotive parts inspection that aids in reducing the personal bias and assumptions and the current over-reliance on personal knowledge on the part of the inspector while simultaneously incorporating any personal knowledge as supplementary information to more fully ‘’flesh out” the model for the company needs.

In terms of an automated inspection processes, this concept is a highly desirable one as it would potentially provide the most efficient and effective form of impartial and objective inspection. However the key issue regarding the straightforward and wide scale implementation of automated inspection is the highly variable state which core and the component parts arrive in at the facility. Automation occurs most effectively during highly standardised processes with the features and conditions of single or sometimes multiple parts being within a very close tolerance range. Automated manufacturing, such as parts manufacturing has a very specialised range of variables in terms of the raw material and the shape of the parts that are constructed from it. In more advanced methods such as vehicle assembly, again this process operates under the assumption that parts selected as part of the process are all of the same standard condition.

Inspection as discussed multiple times throughout this thesis is a highly variable process with typically unknown conditions of incoming parts. As such it is currently a process that relies heavily on human interaction and informed opinion to successfully undertake and complete it. This is a situation which this author and the research all agree is a highly effective scenario. However the aim of the DATF model is not to disregard or impugn such a situation as unfit but rather to aid this situation in its continual improvements allowing for adaptation and integration of new more effective tools and methods and the ability to recognise and disregard those which have become out-dated or less efficient.

APPENDIX G – Expert Validation Review Sheet example

G.1 DATF Model Evaluation Form:

Please use the below listed sections to grade the various factors of the DATF model and sub-models. Each section can be graded on a scale of 1 – 6, where 1 is the negative grade and 6 the most positive. Please keep in mind that the DATF model is aimed at firstly small independent remanufacturers that may operate with lower resources in terms of both staff and structure where it acts as a training tool/guide to the various options and steps involved with the inspection process. In addition the model can be utilised by larger contract/OEM based companies as an possible addition to their own methods supplementing their already structured approach with any benefits it may present.

Example:

1. Q. "Question"

   Grade: "Range 1 – 6" Negative to Positive

   A. "Answer in terms of comments or any further information".

Factor:

In your opinion;

1. Q. Does the Inspection Process Overview Model constructed for use in this Model Application Review present a suitable overview of the various stages of Inspection that occur during the typical Automotive Remanufacturing Process?

   Grade:

   A.

2. Q. Do the DATF damage categories sufficiently cover the key forms of damage that may be encountered by the operator?

   Grade:

   A.

3. Q. Does the grading system used to assess these categories cover a suitable range of the potential levels of damage encountered?

   Grade:

   A.

4. Q. Do you believe that the DATF damage categories/grading provide a useful method of conveying important and valuable information within a straightforward approach to the operator in question?

   Grade:

   A.

5. Q. Does the POM (Pyramid of Methods) Model present potentially relevant and useful information on the available type of inspection technology to the user?

   Grade:

   A.

6. Q. Does the POM (Pyramid of Methods) model present the information it contains in an effective and suitable manner?

   Grade:

   A.

7. Q. Does the structure of the POM convey the differences in the various inspection "Levels" in a clear and concise format?

   Grade:

   A.

8. Q. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that the level of personal judgement on the final assessment decision decreases due to the benefit of additional more objective data?

   Grade:

   A.

9. Q. Do you agree with the assumption that as the user progresses up the different "Levels" of the POM that this level of additional data (gained through various methods beyond visual inspection and judgement) can only produce a positive impact on the final pass/fail decision for the part/core in question?

   Grade:

   A.

10. Q. Do you find that the POM Database (which details the various methods described in the visual model level) conveys appropriate and suitable information to the user?

    Grade:

    A.

11. Q. Do you agree that the 'Steps' detailing the actions to be taken in each method of the POM Database provide a detailed and comprehensive breakdown of the necessary steps for the user to follow?

    Grade:

    A.

12. Q. Does the RaPID guide present a potentially useful and valuable tool to less developed Remanufacturing Companies?

Grade:

A.

13. Q. Do the RaPID guide steps to successful "Inspection" cover the key factors and provide a suitably comprehensive overview of the requirements of this process?

    Grade:

    A.

14. Q. Do you believe that the RaPID model in conjunction with the criteria discussed in the DATF model & POM could be used as a valuable training tool in turning unskilled labour into more skilled labour?

    Grade:

    A.

15. Q. Does the IICAE (Internal Inspection Comparison Assessment Evaluation) present a potentially valuable tool allowing for the company in question to self-assess the efficacy of its operators in this area?

    Grade:

    A.

16. Q. Do the methods stated within the IICAE to assess the operator allow for a relatively unbiased and objective result?

    Grade:

    A.

17. Q. Do you find that each Model may be used independently or in conjunction to the benefit of the user?

    Grade:

    A.

18. Q. Do you agree with the placement of the DATF models within the inspection overview as described in the initial point?

    Grade:

    A.

Thank you for your valuable contribution to this research project. Please note that all forms will remain anonymous when used in review.