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# Evaluation and validation of Damage Assessment Tracking Criteria models within the sector of UK automotive remanufacturing

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ABSTRACT

This paper details the specific aims and purposes of the Damage Assessment Tracking Criteria; a series of evaluation tools designed to aid in remanufacturing inspection operations. The background and justification of this model, which is detailed in a separate work, identifies ill definition and an over reliance on opinion as barriers to effective inspection activities. Analysis of this issue led to the building of the Damage Assessment Tracking Criteria; a 4-model foundation that aims to provide a more comprehensive and more structured approach to the inspection stages of the typical remanufacturing process. Through expert opinion this model was evaluated multiple times. One review was used to gauge the level of idea communication within an academic situation, this was followed up by external industrial reviews of the model by those most likely to utilise it during industry practice. After extensive feedback and modification the final model assessment was carried out with an expert panel that were instructed to be as critical as possible with the model in order to ensure that its evaluation was as robust as possible.

The results of these reviews were all on the positive side of the scale. Multiple statements regarding the potential value and suitability of each model aspect and justification for their use was presented in the format of an evaluation form which was used by those involved to present their findings and feedback. Negative feedback was addressed and successful modification yielding more positive results in the next evaluation was achieved.

Though walking the line between specificity and generic was noted to be the most difficult factor to consider when developing the models, the final findings of the evaluation show that significant value was perceived by those operating within industry. The potential benefits of customised variants of the models is acknowledged by all parties as a possible future avenue of research.

## 1. Introduction

This paper aims to examine and discuss the justification and creation of the Damage Assessment Tracking Criteria (DATC); a purpose built inspection tool designed to aid staff within the inspection sector of the remanufacturing process to operate in structured and impartial autonomy. The DATC models are a series of visual and text based aids that can be used, individually or in conjunction, by an automotive remanufacturing operator to more objectively catalogue and assess the inherent level of damage present in incoming 'Core' (Aftermarket automotive components or parts). These aids can therefore allow the user to more effectively plan the necessary tasks required, more objectively make determinations on the inherent economic feasibility of remanufacturing the core, and finally in turn collect and track data regarding the condition and state of select core over a prolonged period.

These benefits are of particular importance due to the level of perceived over-reliance on tacit knowledge in automotive remanufacturing inspection activities, as well as the current uncertainty over the accrued contamination and degradation present in longer term core storage that is often exposed to external environmental conditions.

Remanufacturing is a circular activity vital in many industrial sectors (such as automotive, aerospace, and electronic and electrical

*Abbreviations:* OEM, Original Equipment Manufacturer; DATC, Damage Assessment tracking Criteria; RaPID, Remanufacturing and Processing Inspection Database; PoM, Pyramid of Methods; IICEA, Internal Inspection Comparative Evaluation Analysis.

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equipment) due to diminishing resources and finite material availability. The value and size of the activity across the industrial landscape has seen steady growth throughout the early 2000's and in notably in more recent years as both society and cultural awareness of its value to the larger goal of sustainability has increased (Steinhilper, 1999; Ijomah et al. 2007; ERN, 2016). The typical remanufacturing process involves several stages; theses stages are detailed below in Fig. 1. As can be seen in both Figs. 1 and 2 a key aspect of the process is the inspection stage that occurs several times throughout the standard operation (Errington and Childe, 2013; Ridley 2019).

Inspection is a critical factor within the typical remanufacturing process; it is the assessment of a core/product/parts in order to ascertain its accurate condition (Hammond and Bras, 1998; Fegade and Kale, 2015; Ridley 2019). This assessment allows for suitable 'processing' of the parts later in the process to bring them back to OEM standard and also identifies which parts are too damaged or unsuitable for further remanufacture (leading to scrap or recycling). As such the successful inspection of core (defined as the used product/part for remanufacturing operations) is an essential part of the process and one that requires as accurate and impartial an approach as possible in order to reduce variation in output as much as possible (Errington and Childe, 2013).

## 2. Types of remanufacturer

This section details the different types of remanufacturing businesses operating within the sector, the characteristics of each type vary in relation to factors such as size, resources, and expertise.

Independent.

- *Independent Remanufacturers*; typically operating on a smaller scale, these companies operate without the benefit of the OEM technical specifications, gathering their data from sources such as reverse engineering in-house. As such personal expertise and specialism become highly valued factors due to the lack of available technical data on many incoming cores. Independents undertake a significant amount of the work conducted within the market (Casper and Sundin, 2018; Abdulrahman et al., 2015) often operating with much smaller staff and lower resources.

Contract.

- *Contract remanufacturers*; not directly under the umbrella of an OEM but work closely with OEM's, often operating multiple contracts at once, limited only by the size and capabilities of the facility in question. OEM's can outsource remanufacturing work to these companies, often with ongoing multi-year contracts (European Remanufacturing Network, 2016). This set-up allows the contractor gain access to OEM technical information, and typically a more stable supply of core than Independents, however they must still compete for parts from suppliers with other OEM's and contractors (Guidat et al., 2015).

OEM.

- *OEM*; typically large, these organizations are simply manufacturers that undertake the remanufacture of their own products in house, ensuring that their own EoL products are brought back under the company banner post functional life cycle. Access to greater resources and technical information can put them at an advantage over contract and independents, allowing for a more structured approach to typical processing and reducing the necessary level of individual skill specialisation found within smaller companies (Kapetanopoulou and Tagaras, 2009). OEM's also have access to new designs and parts before they are launched onto the market allowing for 'awareness' of potentially new core that will soon be introduced to the aftermarket (Fang et al., 2019).

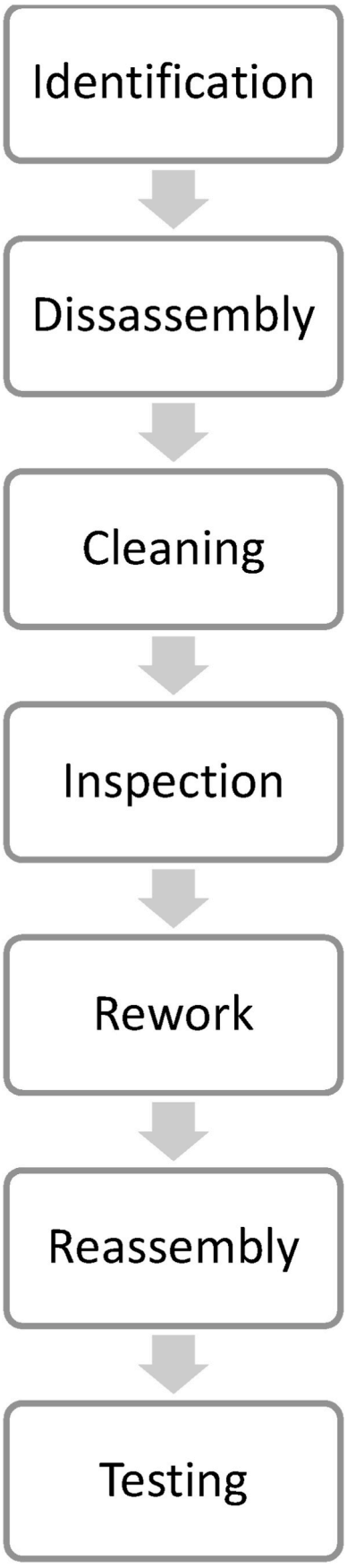


**Fig. 1.** An overview of the key stages of the Remanufacturing Process based on work by authors Steinhilper, Ijomah, and Sundin.


**Fig. 2.** An overview of the key stages within remanufacturing inspection activities as found in the case study primary research.

## 3. Research methodology

The DATC models were developed after multiple industrial case studies, based within the UK automotive remanufacturing sector, displayed a common trend of inspection operators relying on tacit knowledge and subjective experience to analyse core. The potential issues arising from this set-up, including variable interpretations of core condition, difficulties in communicating subtle details, and impartial training methods, all contributed to the observable need for a solution. As the end result of such a solution would be primarily of use to those operating in industry a close relationship with multiple automotive remanufacturers around the UK was required.

The choice of a suitable number of case studies for such research 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, 1989) 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).

The structure of the selected cases chosen for the study are shown below (see Table 1) including features such as the size, type and product focus of each company.

After each case study was completed (based on on-site primary research and interviews with staff) the data was collated and contrasted to note common patterns and trends. Expert academics in the remanufacturing field were consulted regarding their views and opinions on the progression of the DATC models, and their applicability and value to both industry and academic studies. Once fully developed the DATC models had to be evaluated by both academic and industry experts to ensure rigorous validation of the research output.

**Table 1**
A breakdown of the company characteristics selected for Case Study research.

| Company: | Size | Type | Products |
|---|---|---|---|
| Company 1 | Small - Medium | Independent | Gearboxes/Transmissions |
| Company 2 | Small | Contract | Transmissions |
| Company 3 | Medium - Large | OEM | Full Engine |
| Company 4 | Large | Independent | Full Engine |
| Company 5 | Large | OEM/Contract | Steering & Braking systems |

The validation review was broken into 2 key sections; an *Academic Review* and an *Industrial Review*. These workshop reviews would be undertaken at separate times and in separate locations with no cross-over in those undertaking the workshops, so that no influence either positive or negative could carry over.

### 3.1. Academic workshop

Firstly the academic workshop was undertaken, this involved two groups of academics (Group 1 consisting of 3 academics, and Group 2 consisting of 2 academics) all specialising in 'Circular Economy', 'Remanufacturing' and 'Sustainability' to one degree or another. Both workshops took place at within a bookable private research space at the University of Strathclyde.

### 3.2. Industrial workshop

Secondly the industrial workshop was undertaken, this involved multiple key staff operating within the UK automotive remanufacturing landscape. Three separate automotive remanufacturers were selected, each one embodying the perspective and viewpoint of a different area of the remanufacturing industrial set up (Independent/Contract/OEM), Company A & B were first selected, with the feedback and commentary provided aiding in streamlining the DATC for further review with Company C, the largest and most profitable of those involved in the review. These workshops took place at on-site locations at each company in question.

### 3.3. Workshop format

Both workshop types followed the same format, the participants firstly were given an extensive presentation discussing the identified issues arising from the case studies, followed by a general Q&A to answer any areas of uncertainty or necessary clarification. After this point the participants were supplied with an evaluation form designed by the author (Hancock and Algozzine, 2017; Yazan, 2015). The evaluation form listed up to 20 statements that the participant could chose to respond to; first by providing a grading of their view on the statement, ranging from highly positive to completely negative, and second they could also use a commentary section provided after each question to detail the reasoning behind their chosen response. The aim of this type of evaluation format is to allow for a purely data based response (the positive to negative grading system) providing a much more impartial view, and also a more qualitative review of the data through the responses of each operator (Gorard, 2013; Beecham et al., 2005).

The collected responses from the different workshop reviews were used to refine and modify the model in order to best streamline it to the users most successful interaction during usage.

In section 3.1–3.4 a more detailed examination of the different outputs and experiences of these workshops is provided, with key data obtained from the feedback presented in Table formats.

## 4. The DATC model

The DATC is a series of 4 models which act as aids and tools for automotive remanufacturing inspectors based within the UK. Each of the separate models is designed to try and tackle a key issue highlighted

during case study research, including.

- Over-Reliance on tacit knowledge and subjective experience for core evaluation.
- Uncertainty on the potential loss of valuable core to increased damage due to prolonged external storage conditions.
- Ageing workforce.
- Self-Assessment on current areas of potential

Each of the 4 models can be used in isolation, but by using them in conjunction an automotive remanufacturer can assess their own current practices (using the IICEA), make improvements to necessary technology or methods if required (using the PoM), track and evaluate *core* damage in a more objective manner (using the DATC criteria), and finally implement more streamlined and impartial training methods for less experienced staff (using the DATC & RaPID). Please see Fig. 3 below for more details.

The DATC Model contains 4 separate sub-models, these are the.

1. The Damage Assessment Tracking Criteria (*DATC*).
2. The Pyramid of Methods (*PoM*).
3. The Remanufacturing and Processing Inspection Database (*RaPID*).
4. The Internal Inspection Comparative Evaluation Analysis (*IICEA*).

### 4.1. DATC

The DATC sub-model contains a criteria based approach to the identification and the grading of any damage found on a part or component. The model categorises each type of damage to within 1 of 5 distinct categories. In addition to providing a more structured overview of the types of the damage that may be discovered during the typical inspection processes the aim of this model is to allow the grading system inputs to be recorded and then evaluated on a time/damage level plot graph. This system would then illustrate whether certain types of damage are becoming more prevalent within particular subsets of models, types or parts, additionally preparing the operators on what may be expected in terms of 'predictive' damage. Grading is a well suited measure for this type of assessment (Teunter and Flapper, 2011), and can be used to interpret the data into the damage/obsolesce forecasting (Krupp, 1992; Pillai, 2017).

### 4.2. PoM

The PoM (Pyramid of Methods) is a visual model that illustrates the increasing level of both complexity in terms of technology and also accuracy in terms of available output data within the inspection side of the industry methods. The aim of this model is to provide a comprehensive and also easily understood overview of the available methods and each assessment aspect that they are uniquely targeted to relate to. Knowledge of suitable technology to improve remanufacturing inspection activities is not widely available (Andrew-Munot and Ibrahim 2013; Casper and Sundin, 2018; Kerin and Pham 2019).

### 4.3. RaPID

The RaPID (Remanufacturing and Processing Inspection Database) is a step-by-step guide to the overall inspection process. Acting as both a guide and a training tool this model contains the suitable usage of the methods described in the PoM as well as the key benefits and limitations of each approach. The aim is to utilise both the PoM and RaPID simultaneously within a training scenario to carry out the inspection methods with ease and effectiveness, identifying where the discovered damage ranks within the DATC criteria and grading. Structure is essential for the improvement of remanufacturing operations and a key feature of the training aspect of the DATC models (Ijomah et al. 2005a; Sundin, 2004, 2006).

### 4.4. IICEA

The IICEA (Internal Inspection Comparative Evaluation Analysis) is the final aspect of the overall DATC model and can be used by the company in question to review and identify the most and least effective operators working within the inspection field. The IICEA takes the form of akin to a spreadsheet where the values for effectiveness and efficiency can be collected to review against a particular operator (Soto et al., 2016). The effectiveness side of the equation involves a set of criteria regarding the operation of inspection, each stage is noted. While the efficiency side of the equation times how fast each activity in conducted (Ayres and Leynseele, 1997; Ostlin, 2005).

The DATC models are designed to combat the issues faced by remanufacturing inspectors across the several stages of inspection and assessment (part and core), as such the novelty or new knowledge delivered through these models includes.

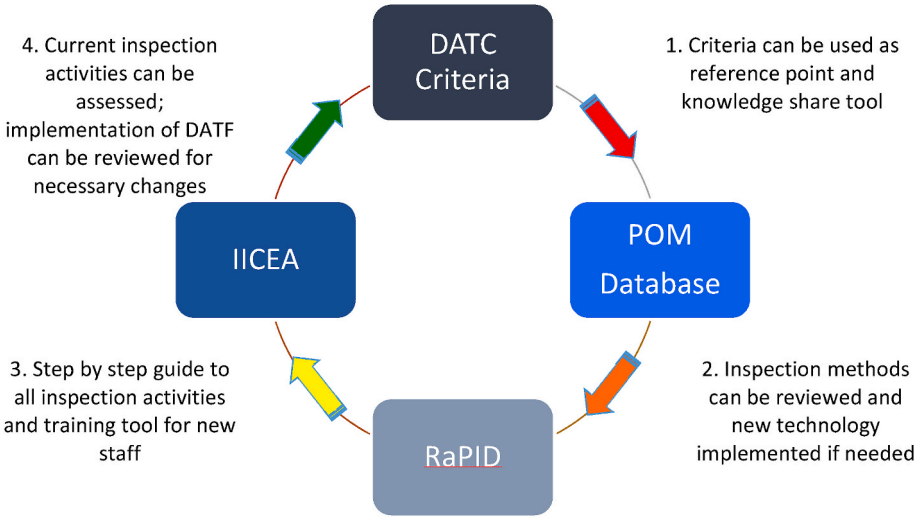


**Fig. 3.** A visual representation of the 4 key elements of the DATC models being used in conjunction together, including the Damage Assessment Tracking Criteria (DATC), the Pyramid of Methods (PoM), the Remanufacturing and Processing Inspection Database (RaPID) & the Internal Inspection Comparative Evaluation Analysis (IICEA).

- 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.
- 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 highly specialized data gathering tool that has several outputs of value.
- A structured breakdown of the available methods and procedures that may be used by the inspector as well as a novel model based ranking system in terms of relevant factors such as "inherent model accuracy", "level of personal experience required".
- 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.
- An analysis model which utilizes data gathered through grading stage to retroactively predict the potential condition of incoming core with the addition of presenting observable trends in part condition due to initial part design or aftermarket handling.

## 5. Model evaluation

This section details the feedback and data provided through review sessions of the DATC models with those operating in the automotive remanufacturing industrial sector as well as the expertise of the remanufacturing research group within Strathclyde University. Firstly the academic feedback will be discussed with the areas of interest noted in the feedback gaining the most focus, the results of the both the industry and academic reviews will then be detailed including the areas where the purposes and key features of the models were communicated most effectively to the proposed audience (both Academic and Industrial) (Kirk and Miller, 1985; Tracy, 2019).

## 6. Academic feedback

Validation could not feasibly be carried out in traditional real world conditions due to the level of expense in terms of structural change in 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 DATC model into their general operation and then recording the result over the course of several weeks or months (Cash and Štorga, 2016; Creswell and Poth, 2016). 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 lead time minimum).

The assessment of the DATC models therefore focuses on validation thorough expert opinion (Beecham et al., 2005). 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 DATC properties including their perceived potential value to both themselves and the industry as a whole. As these validation workshops pulled from the experience of multiple companies the received data gathered for evaluation purposes can be cross-referred to give a much more accurate and robust review of the DATC models potential than any single company. In addition to this the use of academic workshops (see Table 3) also allows for those operating at a research level to provide their open feedback and expert opinion on the model properties.

**Table 2**
The Scoring grades for responses to the workshop questionnaire.

| Answers | Score |
|---|---|
| Strongly Agree | 6 |
| Agree | 5 |
| Mildly Agree | 4 |
| Mildly Disagree | 3 |
| Disagree | 2 |
| Strongly Disagree | 1 |

**Table 3**
The **Academic Workshop** responses from academic groups 1 & 2.

| Question | Response Group: 1 | Response Group: 2 | Average Value |
|---|---|---|---|
| 1. | 6 | 5 | 5.5 |
| 2. | 5 | 3 | 4 |
| 3. | 6 | 6 | 6 |
| 4. | 6 | 5 | 5.5 |
| 5. | 6 | 5 | 5.5 |
| 6. | 6 | 3 | 4.5 |
| 7. | 6 | 6 | 6 |
| 8. | 6 | 1 | 3.5 |
| 9. | 6 | 6 | 6 |
| 10. | 3 | 4 | 3.5 |
| 11. | 6 | 6 | 6 |
| 12. | 5 | 5 | 5 |
| 13. | 6 | 6 | 6 |
| 14. | 4 | 5 | 4.5 |
| 15. | 5 | 6 | 5.5 |
| 16. | 5 | 6 | 5.5 |
| 17. | 6 | 6 | 6 |
| 18. | 5 | 6 | 5.5 |

### 6.1. Academic review responses

Table 3 details the responses across from the academic workshop evaluations of the DATC models. A series of 18 questions were put forth to the reviewers with an aim of ascertaining which were the most successful elements of the research, as the DATC models are designed to aid both industry and enhance academic research avenues it was logical to gain suitable feedback from both expert perspectives. Full list of questions can be found in Appendix A.

All questions were graded on a 1–6 scale with 1 representing how much the participants disagreed or disliked certain elements of the DATC, while 6 represented how strongly participants agreed or supported these DATC elements.

The general consensus of the academic review responses was mainly positive though some outlier grades were noted. In particular the response from Academic Group 2 in relation to question 8 noted a distinct contrast in opinion compared to Academic Group 1, with Group 1 giving it a scoring grade of 6 while Group 2 scored it at a 1.

Further discussion on this point during the feedback session after the workshop included a more detailed response from Group 2 regarding question 8;

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?"

Group 2 noted that they believed that while the Pyramid of Methods would supply additional analysis techniques to the user they also felt that the inherent reliance on personal skill and knowledge in the existing staff would take lead in the final decision regardless of the additional data available.

When using the Pyramid of Methods as part of training new staff without the familiarity of the current set Group 2 did agree that the PoM may provide a more effective aid to objective decision making to those trainees.

### 6.2. Factors noted during academic workshop

#### 6.2.1. Terminology

Previous to this workshop the assigned terminology at use prevalently throughout the research area involved many terms to which a certain degree of uncertainty still exists. Within the remanufacturing field there are a number of terms either detailing key processes or conditions which are known by multiple variations (Ijomah et al. 2005b; BSI, 2009). During this workshop the specified names used to provide categorization to factors such as the damage categories 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.

#### 6.2.2. Categorization

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 provide a highly suitable breakdown of the possible conditions of incoming parts. The categorization 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 (Aras and Verter, 2004; Anityasari and Kaebernick, 2008).

#### 6.2.3. Visual models

The visual aspect of the DATC 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 DATC criteria web, the DATC predictive core form and the RaPID process stages were all reviewed to ensure all key data was easily communicated. Feedback from the academics involved 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 is not as clear with the PoM database. A more detailed visual representation of the PoM including the methods that form each category was then devised as a supplementary addition.

#### 6.2.4. Intended user base

From the outset of the work the aim of the output has always been targeted primarily as a tool designed for industry (Meredith and Burkle, 2008), to be of use to those working at the most 'hands-on' level of the remanufacturing operation. The academics involved with the workshop noted the level of detail and discussion of complex concepts unique to the niche area of remanufacturing. 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 limitation offered by the DATC 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 (Watson, 2008).

From the research area 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.

#### 6.2.5. Applicability to other remanufacturing industrial sectors

During discussion with this workshop the viability of the 'structure' and 'methods' used to build the DATC being applied to other remanufacturing industrial sectors as opposed to purely automotive. Academics involved with this discussion noted that the overall approach displayed by the model of the DATC while focused at the automotive sector could provide a very solid basis from which to adapt from other areas such as Aerospace or EEE (Canada and Sullivan, 1990; Schumacher et al., 2016).

#### 6.2.6. Potential future research

Feedback from the academic workshop included a discussion on the level of 'personal tailoring' that the DATC models could reach for potential users. The categorization 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 work. Future work would utilise the DATC 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 utilized 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.

### 6.3. Level of data communicated successfully

As a whole the Academic Workshop (see Table 3) 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 however 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 of too high an excess rather than a more condensed and focused model feature presentation. Each DATC model has several unique defining points that contribute to the inherent novelty in the overall output and the value of the work, 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.

### 6.4. Company A

The DATC models were reviewed by Company A, an independent automotive remanufacturer within the UK (see Table 4).This company had previously been the subject of a case study by the authors and so was ideally placed to provide review on the assumptions an output of the research that generated the DATC models for inspection and assessment. The supplementary model material was slightly abridged into key features and most 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 paper (Eisenhardt, 1989). 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 (Kirk and Miller, 1985).

The review was conducted across a period of time to allow for full

**Table 4**
An overview of the grading results gathered from Companies A & B, and their averaged combination.

| Question | Company A Response: | Company B Response: | Average Value |
|---|---|---|---|
| 1. | 3 | 5 | 4 |
| 2. | 4 | 5 | 4.5 |
| 3. | 5 | 5 | 5 |
| 4. | 5 | 6 | 5.5 |
| 5. | 6 | 5 | 5.5 |
| 6. | 3 | 6 | 4.5 |
| 7. | 5 | 5 | 5 |
| 8. | 2 | 6 | 4 |
| 9. | 5 | 6 | 5.5 |
| 10. | 5 | 6 | 5.5 |
| 11. | 6 | 6 | 6 |
| 12. | 5 | 5 | 5 |
| 13. | 3 | 5 | 4 |
| 14. | 5 | 6 | 5.5 |
| 15. | 5 | 6 | 5.5 |

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 DATC and its component sub-models present to the industrial sector.

One of the key points included the paths used to build the RaPID model for inspection procedures. There were certain path routes that were identified and then modified to better fit the model and 'real world' operations for inspection based on company experience of the remanufacturing process. These suggested changes were noted for later modification of the DATC models based on the feedback.

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 authors to re-assess the assigned structure within the model, some methods though selected for middle levels were viewed by the external company as more difficult to utilise and implement for the majority of independent and contract remanufacturing organizations due to the availability and expense of the technology involved, specifically NDT (Bergmann and Bauer, 2006; Blitz, 2012).

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 used in the PoM was also addressed with key terms being unknown to the external company or known by different names (Parkinson and Thompson, 2003). 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 utilized 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 A. The DATC data sheet was reviewed well although clarification on the part of the authors was required, in its current state the data sheet is highly 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 (Pyett, 2003; Jiang et al., 2019). This factor was later addressed by the authors, the data sheet is to be used in conjunction with relevant part of the product (such as high value or essential components).

### 6.5. Company B

Company B's feedback has the benefit of being compared to Company A's including key constructive criticism, with suggestions regarding the potential improvement and refinement of the models developed. In addition some relevant points regarding the applicability of the models to the overall automotive remanufacturing industry were made, which allow the authors to debate the point and ensure that the issue is addressed in when discussing these features at later stages (see Table 4).

In particular the applicability of the DATC damage categories to some aspects of the market were discussed during the feedback from Company B; 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 aftermarket 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 (de Bruin and Rosemann, 2005; Creswell and Poth, 2016).

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 (Ridley 2019). 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 aim of the DATC models is to provide value and a solid basis for improvement for as wide a range of companies operating within the automotive remanufacturing sector. With regard to future research the hope is to use the DATC 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 DATC 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 organization the remanufacturing standard and associated technical data used to bring the product or part back to OEM level is developed internally through reverse engineering.

Another key point discussed during feedback was in relation to the viability of the RaPID, PoM and DATC criteria being used to turn unskilled labour into a more skilled workforce. Company B's feedback illustrated that while they felt that it may not turn an completely unskilled labour force into highly skilled operators it did present an 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.

## 7. Industrial review responses

Table 4 details the responses across from the industry workshop evaluation of the DATC models. A series of 18 questions were put forth to the reviewers with an aim of ascertaining which were the most successful elements of the research, as the DATC models are designed to aid both industry and enhance academic research avenues it was logical to gain suitable feedback from both expert perspectives. Full list of questions can be found in Appendix A.

## 8. Company C

Company C assessed the DATC models post modification and

feedback from Companies A & B as well as the Academic feedback. As such this more thorough and extensive validation of the models through expert opinion formed a key foundation of the perceived value of the final output (see Table 5).

The Validation Panel of Company C 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 the field (Koro-Ljungberg, 2008). Following a similar format to the practices utilized 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 DATC 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 DATC Model (DATC, RaPID, PoM and IICEA) in extensive depth ensuring that the reviews would have every chance to provide a fully informed opinion and evaluation (Brink, 1993).

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 30 min presentation was conducted by the lead researcher. The aim of 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.

The workshop then finished up with each member of the validation review 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 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 evaluations were then collected by a liaison at the facility and received by the authors within 14 days of their initial dissemination to the participants. The key results from the reviewers can be observed below in Table 5.

**Table 5**
Overview of Company C evaluation gradings after DATC modification based on Table 3 and 4 feedback.

| Question | Response: 1 | Response: 2 | Response 3 | Response 4 | Average Value |
|---|---|---|---|---|---|
| 1. | 5 | 4 | 5 | 5 | 4.75 |
| 2. | 5 | 5 | 5 | 4 | 4.75 |
| 3. | 5 | 4 | 4 | 3 | 3.75 |
| 4. | 5 | 4 | 4 | 3 | 3.75 |
| 5. | 5 | 4 | 5 | 4 | 4.5 |
| 6. | 5 | 6 | 5 | 3 | 4.75 |
| 7. | 6 | 4 | 5 | 5 | 5 |
| 8. | 5 | 4 | 5 | 6 | 5 |
| 9. | 5 | 4 | 5 | 6 | 5 |
| 10. | 5 | 3 | 4 | 4 | 4 |
| 11. | 5 | 4 | 4 | 4 | 4.25 |
| 12. | 6 | 3 | 4 | 4 | 4.25 |
| 13. | 5 | 3 | 4 | 5 | 4.25 |
| 14. | 5 | 3 | 5 | 5 | 4.5 |
| 15. | 5 | 3 | 4 | 4 | 4 |
| 16. | 5 | 4 | 5 | 4 | 4.5 |
| 17. | 6 | 6 | 4 | 5 | 5.25 |

### 8.1. Discussion

As can be noted the results from Tables 3–5 all display the model within the positive side of the scale (see Table 2). 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. The aim of DATC Models has always been 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.

The remanufacturing field does not share as many similarities 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 that this is likely the work of post-doctoral studies or research projects later in the researchers academic career.

Throughout this validation process it has been strictly stated by the authors 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 authors or the participants be involved. As such no member of the validation Panel had met with the lead author 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.

## 9. Conclusions

The DATC models establish a new format of objective assessment and monitoring of both "Core" and staff practices, They have been designed to aid remanufacturers in enhancing their own internal operations and to provide key tools for self assessment and guidance. The need for such tools in the UK remanufacturing landscape is only rising with obstacles such as an aging workforce, inherent training bias and external factors such as BREXIT.

The workshop feedback has been invaluable in both confirming the assumed potential value of the DATC models to industry but 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 identified and discussed as key points during the feedback sessions, some areas of debate have resulted in the modification or alteration of the existing models in order to incorporate suggested changes or due to new knowledge while in other sections the areas of issue have resulted in a clarification behind the purpose and target user of the model in question.

These models while initially developed with the aim of aiding automotive remanufacturing have the potential to be expanded to include other vital sectors of the aftermarket landscape. As such the next stages for this work may include working with other key sectors such as Aerospace and Nautical remanufacturing in order to create a more comprehensive evolution of the DATC which can be utlised by many remanufacturing areas.

## CRediT authorship contribution statement

**R.S. Harris:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **W.L. Ijomah:** Supervision, Writing – review & editing. **J.F.C. Windmill:** Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.137494.

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