Developing a Consumer Oriented Metric for Measuring Corrosion on Vehicles.

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Developing a Consumer Oriented Metric for Measuring Corrosion on Vehicles

by

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Developing a Consumer Oriented Metric for Measuring Corrosion on Vehicles

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ABSTRACT

New technologies and materials are utilized by the automobile manufacturers to prevent and treat corrosion on vehicles. Vehicle owners can choose a variety of after-market anti-rust products to protect their vehicles from corrosion, such as spray-on rust inhibitor and anti-rust coating. A metric for measuring the corrosion on vehicle is required to effectively benchmark the extent of corrosion, as well as the effectiveness corrosion treatment products. This research develops a metric to measure the corrosion on vehicles and model the corrosion condition against variables such as vehicle age and rust–proofing treatment history.
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LIST OF ABBREVIATIONS/SYMBOLS

SAE ......................................... Society of Automotive Engineers
NACE ........................................ National Association of Corrosion Engineers
EIS ............................................ Electrochemical impedance spectroscopy
ADI ............................................ AnalyzingDigitalImages
SVM ......................................... Support vector machine
k-NN .......................................... k-nearest neighbor
MLP ......................................... Multiplayer perceptrons
RBF .......................................... Radial basis function
ACAP ........................................ Automotive corrosion and prevention
CPAC ........................................ Corrosion prevention and control
DoD ............................................ Department of Defense
A&L ........................................... A&L Auto Recycler
Standard .................................... Standard Auto Wrecker
Wp ............................................. Weighting scale of perforation
Wb ............................................. Weighting scale of blistering
Ws ............................................. Weighting scale of surface rust
1. Introduction

Corrosion is a major concern for vehicles, especially in the regions of southern Canada and northern United States because of the high humidity and the use of deicing chemicals which accelerate the process of corrosion dramatically. A 2001 report prepared for the Federal Highway Administration (Koch et. al. 2001) shows that the cost of corrosion in transportation is $29.7 billion, and 79% ($23.4 billion) contributed by the corrosion of motor vehicles. Corrosion increases the cost of maintenance and manufacturing, and a rusted vehicle could lead to different risks such as: depreciation in value, reduced reliability, safety issues, increased premature repair, and the loss of recoverable and recyclable materials (Shi et al., 2013).

Before the late 1950s, corrosion concerns related to motor vehicles were limited to marine areas, but due to the increasing usage of deicing chemicals, corrosion has become more severe around the snowbelt regions in North America (Johnson 2001). After the 1970s, vehicle manufacturers improved their manufacturing process to increase the corrosion resistance of their vehicles. There are also a number of aftermarket corrosion prevention and treatment products and applications available now to vehicle owners and operators. Now, a vehicle may have less rust than before, but evaluating the effectiveness of an anti-corrosion process, or assessing the degree of corrosion on a vehicle remains an industry-wide challenge. Moreover, there appears to be no single method for evaluating corrosion at the consumer/aftermarket level that has been adopted industry wide.

The objective of this research is to develop a metric for assessing the extent of corrosion on a vehicle that will be readily usable by automotive technicians and sufficiently robust to
serve as a benchmark for comparing the corrosion condition of different vehicles. Such a metric can also be used to evaluate the effectiveness of corrosion prevention and treatment applications.
2. Literature Review

2.1. Corrosion Occurrence and Prevention

Shreir (2010) defines corrosion as: “the undesirable deterioration of a metal or alloy, that is, an interaction of the metal with its environment that adversely affects those properties of the metal that are to be preserved”. The rusting process can be accelerated significantly under certain conditions, such as high humidity and contact with certain chemicals. In snowbelt areas, deicers (e.g., salt) are commonly used in winter. On the vehicle surface, salt absorbs humidity and becomes a salt-bridge between metal and air. The process of rusting occurs more easily in salt water. Different deicers could have different impacts on vehicles (Shi et al., 2013).

Several experiments have been conducted by Xi and Xie (2002) to measure the corrosion rate of metal under different deicing-chemicals. They conducted two different types of tests: 1) the SAE (Society of Automotive Engineers) test; and 2) the NACE (National Association of Corrosion Engineers) test. They tested the corrosion rate with two commonly used deicing-chemicals: NaCl and MgCl₂.

The SAE test is a cyclic test that places a metal specimen in an enclosed chamber and exposes it to an in-service simulated changing environment, including humidity (humid stage), salt-application and evaporation (dry stage). The NACE test consists of applying a chemical deicer solution onto the surface of a coupon. The coupon is cyclically immersed into the chemical deicer solution with 10 minutes exposure in the solution, followed by 50 minutes exposure in the air. The two experiments resulted in two conflicting conclusions. The SAE test showed that MgCl₂ could lead to a higher corrosion rate than NaCl, but the
NACE test showed that the metal is more likely to rust in a NaCl solution. After comparing the two different methods, the researchers considered the SAE method could be a more realistic test method as it simulates the in-service environment of a vehicle, especially for high humidity areas. The reason the MgCl$_2$ tended to have more impact could be because its solution viscosity is higher than that of NaCl so it is more likely to remain on the metal surface and precipitate out as the surface dries. Also MgCl$_2$ has a higher crystallization potential and stronger hydrophilicity, so it can adhere to a surface for a longer period and likely be re-dissolved under suitably wet conditions. This provides perfect conditions for corrosion: electrolyte, oxygen, and water (Xi and Xie 2002). There are of course a variety of other conditions under which corrosion can occur, but the presence of deicing chemicals in adverse weather represents one of the harsher scenarios for vehicles.

2.2. Corrosion Prevention and Treatment

There are several popular products on the market used for corrosion protection. Shi et al. (2013) evaluated the performance of 14 different rust-proofing products on the market, including four coating products, four spray-on inhibitors and six salt removers, and all products were separated into 3 groups by types. A screen test was conducted first using the electrochemical impedance spectroscopy (EIS) method. This test indicated that the following products *Rust Bullet, Lubra-Seal, Krown, Rust Oleum, HoldTight* and *ChlorRid* exhibited good anti-corrosion properties. Then these six products were immersed into a 3% MgCl$_2$ solution for two weeks continuously. The results indicated that a durable protection layer formed on the surface of the coupons by using Rust Bullet, Krown, HoldTight and ChloRid. The HoldTight was selected for the wet-dry test as it was the best performing product through the first two rounds of tests. Coupons were immersed into a 30% MgCl$_2$
solution for 40 minutes and they were dried in the air for 22 hours. After a 30-second power washing with soapy water and HoldTight solution, they were immersed again into the solution. A total of 8 cycles was performed during the third round of tests. The results showed that all four products have significant impacts on protecting carbon steel substrates from corrosion against the MgCl₂ solution. However, power-washing with the salt remover, HoldTight, didn't show a significant benefit for the aluminum alloy substrate, and once the corrosion has occurred, the power-wash could do nothing to stop the corrosion (Shi et al., 2013).

An environmental exposure test was performed by the Southwest Research Institute. The Krown spray-on corrosion inhibitor, performed best to decrease the dry-wet exposure cycle, which is the period when the most severe corrosion usually happens. The periodic use of the Krown spray-on corrosion inhibitor and the one-time application of the Rust Bullet protective coating are both proving effective for corrosion protection, potentially reducing the corrosion rate by as much as 99%. But how long the coatings could last is unknown and would need to be further investigated (Shi et al., 2013).

2.3. Documenting and Assessing Corrosion

The common method for evaluating the corrosion of vehicles is by visual observation. A technician inspects the car and informs the customer which part is rusted and what kind of problems could arise. This method, however, may not be reliable due to: 1) the lack of measurement and performance standards; 2) questionable accuracy and effectiveness, which depend on the technician's experience; and 3) the variability of results as a consequence of different environmental conditions like illumination (Yamana et al., 2005). Even the technician's state of mind could be a factor! Instead, a more accurate and effective
method to detect the corrosion and evaluate its extent should be developed in order to provide vehicle owners an objective assessment of the corroded condition of their vehicle.

There are various materials testing approaches for assessing corrosion. Bardal and Drugli (2004) evaluated several corrosion detection methods including visual inspection, radiography, ultrasonic (manual/auto), and Eddy current. Radiography uses short wave electromagnetic beams generated from radioactive isotopes to detect the thickness of the material (Bardal et. al., 2004). The ultrasonic method is similar to the radiography method but using ultrasonic wave instead of electromagnetic beams. The Eddy current method is based on the measurement of impedance, or the apparent opposition to the flow of an electrical alternating current. The change of impedance causes a measurable electrical signal which is proportional to the distance of the measurement object (the object whose movement, position, dimension or temperature is to be measured) to the sensor (Micro-Epsilon, 2015). Bardal and Drugli (2004) showed that radiography is suitable both for accessible surfaces and non-accessible areas.

Visual inspection is suitable for accessible surfaces but can do nothing for interior areas. The ultrasonic and eddy current methods could be helpful for the inspection of non-accessible areas, but are not applicable for the accessible surfaces. However, given the practical constraints on how to assess consumer vehicles on an efficient and cost effective basis – and the fact that corrosion is often first detected by sight by the owner or an automotive technician – a method based on visual inspection likely offers the most advantages.

There is also a possibility that a higher degree of rust may not extend over a significant area, but may instead result in a reduction of metal thickness, color change and a higher
surface roughness. Data representing these parameters is required in order to determine whether they are suitable indicators or not. Presently, three alternative methods are considered to be valuable for measuring the corrosion on vehicles: 1) thickness analysis process; 2) surface-roughness analysis process; and 3) digital image analysis process.

1) Thickness analysis process

This method focuses on the amount of metal lost due to corrosion. An eddy current instrument has already been utilized for detecting the rust on aircraft (Olympus, 2015). Because corrosion products are not electrically conductive, the thickness could be measured by this test. But in some cases, rust may also expand the metal and form into several thin layers, affecting the accuracy of the thickness gauge. This method is suitable for detecting whether there is rust or cracks on vehicles, but due to the size of its probe, it is not suitable for measuring the total amount of rust on vehicles.

2) Surface-roughness method

Several tests will be required to assess if the surface-roughness method is a reliable method for corrosion assessment before it is utilized for this project. In order to measure the surface roughness of a vehicle part (mainly the bottom of the vehicle), a suitable surface roughness tester is needed which will meet the following requirements:

1) It should be portable - a small tester is preferred.

2) A non-contact, areal-type tester is preferred to avoid actual physical contact with the sample during the measurement. The surface of a vehicle may have
dust, mud or grease on it, which may damage the expensive tester. Also, physical contact may damage the surface of the vehicle. Areal type means the degree of roughness in the surface is measured over an arbitrary rectangular range, giving a more accurate grasp of the state of the surface.

3) The measurement range should be large enough for a rusted metal surface. Some rusted surfaces may have a large surface roughness that may be too rough to be measured by some roughness measurement devices. The roughness test method may only be utilized on the metal surface which is slightly rusted. Since the experiment to measure the actual roughness of a rusted metal surface has yet to be undertaken, some parameters from other metal surfaces can be used as references; for example, a surface made by a circular saw will have a surface roughness in the range Ra(μm)12.5~50 (Gao, 2015).

3) Digital Image Analysis Process

Digital image analysis has been used successfully by prior researchers to study corrosion on different machines and products made of metal; for instance, civil engineers use it to detect the rust on steel bridges; the electrical team use it to make decisions on whether to reuse the rusted crossarms base on their rust conditions. (Sharma, et al., 2013). This method is using the information from a picture (such as: texture, color, size, etc.) taken by a digital camera, to detect and analyze the rusted area with specialized image analysis software. This method was considered as a fast, accurate, convenient and objective way to measure the rust on devices. (Sharma, et al., 2013). For vehicles, a digital imaging process could assess vehicle corrosion using the following general steps:
1. Take pictures of the corroded parts and materials using a digital camera (or iphone/ipad/smart phone/tablet).

2. Analyze the digital images using software to evaluate the corrosion level:
   
   a. Detect the presence of rusted areas in each digital image taken of each vehicle part.
   
   b. Determine the extent of rust and calculate the total rusted area versus non-rusted area within each image.

3. Evaluate the overall corroded condition of the vehicles studied relative to vehicle make, model, model year, history of corrosion treatment, and history of vehicle use and care.

   A key aspect to the success of such an analysis will depend on which suitable software is chosen to analyze the digital images. Two commonly available software packages were reviewed: 1) MATLAB (Matrix Laboratory) and 2) AnalyzingDigitalImages (ADI).

   MATLAB is suitable for numeric computation, data analysis and visualization, programming and algorithm development, application development and deployment. (MathWorks, 2015). Therefore, MATLAB could be programmed to accomplish the digital image analysis work, and to also execute the rust detection and analysis. This, however, requires sophisticated coding and associated coding expertise. In addition, before developing the coding, the programmer needs to learn how to detect the rusted areas, develop mathematical expressions to represent them, and then “teach” the software how to accomplish the rust detection and analysis work. The complexity of a digital image (for example, differences in illumination and colors of the background and the vehicle body)
may influence the accuracy of the rust detection and analysis, and, hence increase the
difficulty to develop an algorithm to model the rust detection and analysis with repeatable
accuracy.

The ADI software is designed for image analysis. It is freeware, and was initially
developed by John Pickle and Jacqueline Kirtley, Museum of Science, Boston (ADI, 2012).
It supports a program called Digital Earth Watch which used to measure the growth of
forests. The software provides several useful tools that can be applied to corrosion detection
and analysis. The Enhance Colors tool and Mask Colors tool can help to isolate the rusted
area with its color features and the Spatial Analysis tool can be used to measure the area.

To be more specific, the Mask Color tool can be used to isolate the color within the
range desired (could be colors representing different degrees of rust), and then the Spatial
Analysis tool measures the areas defined by the isolated colors. However, it would be
difficult to detect the rusting areas accurately if the background contains a variety of colors,
and consequently the estimated area of rust could be inaccurate.

The automatic rust detection based on digital images has been utilized for some
research applications. For example, Yamana, et. al. (2005) developed a digital image
analysis methodology to assess the corroded condition of utility pole crossarms and
evaluate their suitability for direct reuse, reuse after plating, or for retirement. In this
research, digital pictures of utility pole crossarms were taken showing different levels of
rust. The images were input into a computer, compared and classified into three groups,
according to crossarm reusability: reuse, retire, and reuse after plating. This computer
database of inputted pictures was used as a prototype classification and reuse judgment
system based on corroded crossarm condition. To improve the reliability of the reuse
judgement system, four different pattern classification methods - support vector machine (SVM), k-nearest neighbor (kNN), radial basis function (RBF) network, and multilayer perceptrons (MLP) - were used in the reuse judgment system and tested using compressed images of the original pictures. The use of compressed images (e.g. 640×480 pixels compressed to 20x15 pixels) improved the discrimination accuracy of the pattern classification methods used. Based on the testing of the four pattern classification methods, the SVM method provided the highest accuracy and greatest reliability in the researchers’ corrosion-based crossarm reuse judgment system.

2.4. Types of Corrosion

Corrosion in motor vehicles could be present in several forms. The most common and obvious form is the general corrosion of the painted steel body panel (Johnson, 2001). Other types of corrosion include:

1. **Pitting corrosion**, which occurs when metal contacts with chemicals like chlorides, cause a small pit, and could potentially produce cavities and cause leaks;

2. **Galvanic corrosion** occurs in the area between two dissimilar metals, where one is more electrochemically active than the other. This type of corrosion could be prevented by careful design, especially by using different materials; and

3. **Crevice corrosion** occurs in the tight spaces of vehicles (e.g., between a washer and the steel beam) where fluid might be trapped and accelerates the corrosion process (Johnson, 2001).

The next challenge is to classify the degree of rust. A parking lot survey in Detroit area was conducted by The Body Division of the Automotive Corrosion and Prevention (ACAP)
Committee of the Society of Automotive Engineers (SAE) to measure the rusted area on car body panels starting in 1985. In this survey, they classified the rust on vehicle into 3 categories: perforations, blisters, and surface rust. (Bryant, et. al., 1989). A perforation was defined as a visible hole caused by the corrosion, or a complete penetration of the sheet metal on the vehicle body panel. A blister was later defined as any bubbling on the paint. Surface rust was defined as any visible rust on the metal surface in an area where the surface paint had been removed.

The Corrosion Prevention and Control (CPAC) department of the U.S. Department of Defense (DoD) developed a Corrosion Category Code to classify the corrosion degree for ground combat and combat support vehicles of the U.S army. (Wang et. al., 2006). This code is based on the level of maintenance required to return each asset to an operational ready state. A check list of forty questions is provided to be worked through and results in a level between 1 and 5, indicating level of corrosion repair/maintenance required. The five categories are:

- Category 1: Item requires no corrosion repair or preservatives, and has been assessed within the past 6 months. The goal at this level is to maintain the item as a category 1.
- Category 2: Item requires surface preparation, spot paint, and preservation at the operator and/or organizational level. The goal of this effort is to return the item to category 1.
- Category 3: Item requires maintenance performed beyond the operator level. Spot painting has arrested the corrosion, but the item is now in a condition that requires complete repainting and overcoat. The item must be sent to the
“Corrosion Control and Coating” (C3) program for repair. The goal of this effort is to also return the unit to a category 1 condition.

- Category 4: Item requires repair to sheet metal, major frame components, paint, blasting and undercoating (e.g., replacement or repair of components such as doors, fenders, and chassis frame rails, or battery boxes due to corrosion). The goal of this effort is to immediately induct the item into the C3 program so that it will return to the unit in a category 1 condition.

- Category 5: The item is degraded to a degree that requires depot level repair and replacement based on the deterioration caused by corrosion. (Wang, et. al., 2006).

These five categories could serve as reference model for this research. It has the potential to be modified for classifying corrosion in light-duty vehicles, as well as being easier for a technician to apply.

Lastly, ASTM D 610-01 provides a standard method for evaluating corrosion, or in their case, assessing the grade of rust on painted metal surfaces. In brief, this method evaluates corrosion into ten grades of rust, corresponding to percentages of rust appearing within a subject area. There are also four different categories of rust in terms of distribution: spot, general, pinpoint, or hybrid. Finally, it provides illustrated examples of how the rust might appear. Interestingly, this method does not seem to be widely known in the corrosion prevention industry, nor does it seem to have been adapted to vehicle surfaces in any way. There may be several reasons.
- It does not explicitly refer to perforations, which would be critical to protecting the vehicle. Instead, the method states it is for quantifying the amount and distribution of visible surface rust.

- It would require the user to make judgments constantly to compare the percentage of rust against the provided guidelines. Furthermore, there are at least 30 identification combinations because of the ten grades of rust and the variations in the rust patterns. This might be difficult to interpret, and even comparing the rust seen against the examples they provide might be challenging, especially if the area is not well lit.

Nevertheless, the concept of area comparison leading to gradations of rust – as with the CPAC method described earlier - is likely a more useful approach to consider for this research.
3. Methodology

3.1. Sampling and Analysis

In general, the amount of corrosion will be measured from a sampled vehicle in order to develop a metric that shows various states of corrosion. The vehicles that have been treated with corrosion prevention by Krown (or by some other treatment if identifiable) will be classified as *treated*; all other vehicles will be classified as *untreated*.

In reality, practically all modern vehicles when sold have received anti-corrosion treatment at the manufacturing stage. However, such production treatment might vary from manufacturer to manufacturer, and furthermore, such treatments may not be identifiable by the consumer. And of course, many vehicles do exhibit corrosion at some point during their life, depending on the circumstances of their use, and there are a number of anecdotes on how one make or model of vehicle “rusted more” than others; hence the aftermarket products and applications for preventing corrosion. Technically, there are no untreated modern vehicles. However, this research focuses on the aftermarket scenarios and so *treated and untreated refer exclusively to aftermarket applications of corrosion prevention products and/or processes*.

Some of vehicles may have been treated by aftermarket anti-corrosion treatment other than the Krown process (e.g., “black” coatings), but they may be difficult to identify by visual observation alone. A survey was provided to owners to collect their vehicles’ information and included questions about aftermarket treatment. Interestingly, there were no other treatment methods stated by the owners. As a result, all treated vehicles in this research are essentially vehicles that have been treated by Krown. Most of the treated
vehicles will be sampled from Krown’s treatment facilities. In addition, vehicle owners were surveyed to obtain more information of the history of the vehicle and how the vehicle was maintained (see Appendix A: Corrosion Evaluation Questionnaire). This survey was approved by the University of Windsor’s Research Ethics Board. Conversely, data for untreated vehicles come from:

1. Vehicles coming into the Krown’s facility for other treatment rather than anti-rust treatment (e.g., tire change, oil change);
2. Vehicles which are first-time treated by Krown; and
3. Scrapped vehicles in an auto-recycling facility. Although the vehicle history is not known, during the Krown treatment process, holes are drilled on the door seam and then plugged. This plug or hole can be used to identify whether it is a treated vehicle or not (see sample picture in Figure 1). Other corrosion treatment processes also leave behind indicators that the vehicle has undergone some prior application.
Approximately 200 vehicles need to be sampled for this project in order to provide a robust sampling set that covers a variety of vehicle make, models, and possible conditions. 200 vehicles is an achievable number of samples. Some sampling locations are outside of Windsor, and may require extensive travel. Overall, 200 vehicles would be a realistic number for the research.

Image analysis using photos taken for each vehicle’s body panels will be the primary method to measure the corrosion (or lack of corrosion) on vehicles. A stick with scales is used as a reference to determine the area of rust. The angle of taking the picture may influence the accuracy of measurement, so the pictures should be taken as vertical to the target plane as possible to mitigate errors.
Pictures will be taken to provide the evidence of corrosion on different parts of vehicles. Several typical car parts will be isolated during the first and second sampling rounds and will be classified as corrosion prone areas. The amount of rusted area is a measure of the degree of rust. This assumes fundamentally that a larger amount of rusted area indicates a greater degree of rust.

Before taking the pictures of the vehicles, the sample number, car make, model, model year, and treated or untreated condition will be recorded. Pictures will be taken for each body panel, with a T-square ruler used as an established, comparative reference of length. (see Figure. 2). Pictures will also be taken of the hood and the under hood parts (see Figure. 3). If any components are observed to be corroded, more pictures will be taken for those components to observe them in detail.

After the vehicle is hoisted, pictures will be taken of the underbody parts with the T square again as a reference (see Figure. 4). The underbody parts that will be taken into consideration include the cross member, control arm, brake and fuel lines, wheel well, rocker panel and the exhaust system.

Each picture will eventually be analyzed to measure the rusted area for the different categories: perforations, blisters, and surface rust. These data and the results from the vehicle owner’s survey will be both collected and assessed.
Figure 2 - Example of exterior body panel where sampling was conducted.

Figure 3 - Example of under the hood where sampling was conducted.

Figure 4 - Example of under body where sampling was conducted.
3.2 Measuring the Corrosion on Vehicles

The approach in the Corrosion Category Code developed by CPAC (Wang et. al., 2006) is a useful basis to initially begin with. The analysis needs to be done first so that the data could support the classification of each body panel (and other corroded parts and assemblies) of the sampled vehicle into one of the five degrees of corrosion. The area of each category of corrosion (perforations, blisters, surface rust) will be measured for each body panel (and other corroded parts and assemblies). A weight will be assigned for each corrosion category: for example, the weight for perforations, blisters, and surface rust are designated Wp, Wb and Ws, respectively. The overall corrosion index can be calculated as:

\[ P \times Wp + B \times Wb + S \times Ws = \text{Corrosion Index} \]  

\[ P = \text{perforation area}; \ Wp = \text{weighting assigned to perforations} \]

\[ B = \text{blister area}; \ Wb = \text{weighting assigned to blistering} \]

\[ S = \text{surface rust area}; \ Ws = \text{weighting assigned to surface rust} \]

The value of the weights above represent the severity of each corrosion category compared to one another. In general, blistering would be considered the mildest form of corrosion because the paint is still present and offers some protection, although corrosion has started beneath the painted surface. Surface rust would be more severe because the protective coatings have essentially failed, and the metal is now corroding. Perforation is the most severe because the metal has lost part of its integrity and for the perforated area no longer offers any protection. For example, if perforation is considered as twice severe
as surface rust, and blister is considered to be half severe as surface rust, the weighting values will be set as \( W_p = 2, W_s = 1 \) and \( W_b = 0.5 \).

### 3.3 Regression Analysis

Regression analysis is a statistical tool to determine the relationship between variables. (Sykes, 1993). For this case, the regression analysis can help determine a model to quantify the effects of different vehicle information such as vehicle age, anti-corrosion treatment, mileage, etc., and predict the amount of corrosion on the vehicle using the given information. The software that is selected for this project is Microsoft Excel. An add-in was installed into the Excel in order to run the regression analysis.
4. Findings

4.1 First Stage Sampling

The main objective for the first round sampling was to familiarize ourselves with how vehicle rust usually appears, and what would be the practical limitations to sampling vehicles. The first round of sampling was conducted at OK Santing, Windsor, Ontario. This facility runs a business mainly based on servicing and replacing tires, but is also a franchisee of Krown Corporation’s anti-rust treatment. Five to ten vehicles daily undergo the Krown treatment. Most of the vehicles sampled are coming in for the Krown treatment, but a number of vehicles coming for a tire change have also been sampled. The purpose of sampling vehicles not coming in for any sort of corrosion treatment was to build an inventory of how vehicles under a variety of driving conditions would corrode. It was anticipated that vehicles that had undergone some sort of corrosion treatment would not provide a true indicator of how corrosion would otherwise develop under typical circumstances.

Typical car parts which are most likely to have rust were also identified. During the six-day sampling, a total of 26 vehicles were sampled, including 7 treated vehicles and 19 untreated vehicles. From the pictures and consulting with OK Santing’s technician responsible for applying the Krown treatment, six typical vehicle parts were isolated as parts particularly vulnerable to rust. They are: control arm, cross member, rocker panel, wheel well, hood seam and exhaust system.

A comparison between the treated vehicles and untreated vehicles was conducted for the first stage of sampling. The initial analysis shows that a treated vehicle has less
corrosion than an untreated vehicle. Pictures were analyzed using the spatial analysis tool in the ADI software to measure the rusted area on the cross member of a treated (T) 2009 Ford F-150 (Figure 5) and an untreated (UT) 2011 GMC Sierra (Figure 6), and the results are shown in Table 1.

Table 1 - Comparison of rusted area on cross member of two vehicles.

<table>
<thead>
<tr>
<th></th>
<th>T 2009 Ford F150</th>
<th>UT 2011 GMC Sierra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area (cm²)</td>
<td>842</td>
<td>554</td>
</tr>
<tr>
<td>Rusted Area (cm²)</td>
<td>13.2</td>
<td>77.2</td>
</tr>
<tr>
<td>% of area as rust</td>
<td>1.6</td>
<td>13.9</td>
</tr>
</tbody>
</table>

Figure 5 - Treated 2009 Ford F150 Cross member.

Figure 6 - Untreated 2011 GMC Sierra Cross member.
The spatial analysis tool permitted the area of corrosion to be accurately measured. In order to conduct this analysis, a picture must be cropped to isolate the target area and then the ADI software Polygon tool is used to measure the total area of the target part and the rusted area.

A color analysis process was also conducted using the ADI software. A photo of the control arm was selected for this test, as illustrated in Figure 7.

![Color analysis test on the control arm.](image)

In this picture, the color of the rusted areas are mostly within the range of 25~50% of red intensity. Using the mask tool and adjusting the red intensity range to 25~50%, the color of the rusted areas within that range will become black and the remaining areas will
turn white. After the rusted area was isolated within the picture, the spatial analysis tool was used to automatically measure the black area to get the percentage of the rusted area from the picture. For Figure 7, the rusted area occupies 30% of the picture. This method is less time-consuming compared with the spatial analysis method, but also has its weakness: the color analysis requires a picture with uniform lighting brightness, which is hard to achieve in a treatment facility.

Only three to five vehicles came for Krown treatment every day at OK Santing, which is insufficient to meet the 200-vehicles target. Vehicle histories were not collected for the first stage sampling: only the vehicle make, model, model year and treated/untreated were recorded. It would be valuable to collect more detailed information of the vehicles’ history. Manual measurement of the corrosion area using the spatial analysis tool will be used in the research because of its accuracy.

4.2 Second Stage Sampling

The second stage sampling involved collecting data for a larger number of vehicles and much more detailed information of the vehicles’ history. The vehicles were sampled at Krown’s treatment facilities in both north and south London, Ontario. Each facility treats 10 to 15 vehicles daily during the spring. A total of 98 vehicles were sampled and each owner of a sampled vehicle completed a survey to provide the information of the vehicle’s history. All data collected from the survey has been entered into an excel file.

All sampled vehicles were classified into five different car types: Sedan, SUV, Truck, Van and Coupe. The number of each car type is shown in Figure 8:
Due to the similarity of the vehicle structure, SUV will be considered equivalent to a sedan. Figure 9 shows the number of each vehicle brand that was brought into the facilities to be treated using the Krown process.

The corrosion resistance of different vehicles may vary from different vehicle manufacturers. Anecdotally, there often claims that one vehicle make and/or model rusts
more easily or more severely than another. Based on the data availability to date at this point in the research, Ford and Dodge models are selected for initial tests to demonstrate the general trend of vehicle corrosion versus vehicle age from the same manufacturer. The corrosion index is calculated using equally weighted corrosion categories for body panels initially, given that there is no detailed information to justify changing the weights at present. Figures 10 to 11 show the trend for combined data of both Ford and Dodge, and Figures 12 to 15 show the trend for Ford and Dodge separately.

![Ford and Dodge body panels corrosion index chart](image)

*Figure 10 - Ford and Dodge body panels corrosion index.*
Figure 11 - Ford and Dodge underbody parts corrosion index.

Figure 12 - Ford body panels corrosion index.
Figure 13 - Ford underbody parts corrosion index.

Figure 14 - Dodge body panels corrosion index.
All six figures show the treated vehicles tend to have less rust on both body panels and underbody parts. But the poorly clustered data and less fitted trend line show this test cannot provide a definitive conclusion with respect to corrosion versus a particular make or model. It is conceivable that different vehicle makes have different corrosion resistance performances, but 200 vehicle samples do not provide enough data to test the performance of each individual vehicle make or model.

Overall, while the collected data so far was useful, corrosion was rarely found on the vehicle bodies from the first and second stage sampling. More untreated vehicles that exhibited rust were needed for the research. The third stage of sampling involved visiting facilities other than Krown’s to reach the amount of 200 vehicles.

**4.3 Third Stage Sampling**

The vehicle data from the previous samplings provided significant information about treated vehicles from Krown’s facilities. In order to obtain more data for the corrosion of
vehicles, especially from vehicles which have not been treated by rust proof products, a third round of sampling is required. The sampling locations are A&L Auto Recycler (A&L) in Lakeshore, Ontario, and the Standard Auto Wrecker (Standard) in Port Hope, Ontario. The vehicles that were sampled in these two facilities are all end-of-life vehicles (ELV), and they can be classified into two types: the high salvage ELVs and the low salvage ELVs. The high salvage ELVs are relatively newer vehicles involved in collisions. Based on the information provided by the technicians, vehicles are delivered to the facility after the collision, then they are dismantled for usable parts. Most of the vehicles do not remain in the storage yard for more than two weeks; therefore high salvage ELVs remain essentially in the same corrosion conditions as during their operational stage. On the other hand, the low salvage ELV represents vehicles which are relatively old, and often have less reusable and in-demand materials and parts. Low value ELVs may have stayed in the yard for a much longer time after the retirement than the high salvage ELVs. More rust is expected to be found on the low salvage vehicles because the lack of maintenance and older age.

*Table 2 - Vehicle classes from third round sampling.*

<table>
<thead>
<tr>
<th>Location</th>
<th>A&amp;L Auto Recycler</th>
<th>Standard Auto Wrecker</th>
</tr>
</thead>
<tbody>
<tr>
<td>High salvage ELV</td>
<td>3</td>
<td>53</td>
</tr>
<tr>
<td>Low salvage ELV</td>
<td>22</td>
<td>0</td>
</tr>
</tbody>
</table>
4.4 Data Analysis

All pictures are analyzed by the ADI software using the spatial analysis tool. The amount of rusted area from each target vehicle part are entered into a spread sheet. The vehicle parts include the hood, fenders, doors, quarter panels and rocker panels. Three different types of corrosion are recorded for each body panel: perforation, blistering and surface rust. Underbody parts include the control arms, cross members and brake/fuel lines.

A total amount of 202 vehicles were sampled, but only 193 vehicles are included into the analysis. Among them are 115 vehicles from Krown’s facilities, 25 vehicles from A&L Auto Recycler, and 53 vehicles from Standard Auto Wrecker. Of the Krown vehicles, 68 vehicles were actually treated by Krown, and the rest of the sampled vehicles are considered as untreated vehicles. The amount of sampled vehicles for each vehicle maker is shown in Figure 17, and the amount of sampled vehicles for each individual model year are shown in Figure 18.
Figure 16 - Amount of sampled vehicles from 3 locations.

Figure 17 - Count of different vehicle makes
An overall data analysis shows the trend of corrosion on vehicles. All corrosion areas for each vehicle include the body panels and the underbody parts are added up for an overall corrosion area as originally shown in Equation \[1\]. As an initial analysis, the three corrosion types (perforation, blistering and surface rust) are given by the same weighting scale (\(W_p : W_b : W_s = 1 : 1 : 1\)). At this point then, the Corrosion Index is the aggregate of all observed areas exhibiting one of the three types of corrosion. The result is shown in Figure 19:
Figure 19 shows the overall trend of corrosion on vehicles: the amount of rusted area increases with the age of vehicle, and furthermore, treated vehicles tend to have a slower rate of increase of corrosion than untreated vehicles. Based on the sampling to date, it is observed repeatedly that corrosion features between vehicle body panels and underbody parts are quite different. From this point onwards, separate analyses for these two different vehicle parts will be performed. Lastly, the data are highly distributed, resulting in a very low R-square value. Figure 21 and Figure 22 show the corrosion trends for the vehicle body panels and underbody parts separately.

The linear fit is selected initially as a “first cut”; in some cases, it well modeled the general trend of corrosion index vs. vehicle age. The logarithmic, exponential and power fit cannot be selected from the Excel statistical analysis because the data contains zero values. Of course, there are more powerful or alternative statistical analyses available, but at this stage, it was considered important to work with the data using the most straightforward approaches possible. There is relatively little prior research to reference,
and so justifying more elaborate analyses is not warranted. However, the data was also tested with the polynomial fit, and Figure 20 shows the result.

\[ y = -2.2331x^2 + 121.27x - 267.72 \]
\[ R^2 = 0.2076 \]

\[ y = -5.5828x^2 + 242.91x - 413.45 \]
\[ R^2 = 0.3527 \]

*Figure 20 - Overall Corrosion Index vs. vehicles age (polynomial fit)*

From Figure 20, the trend lines show it does not fit the plot better than linear fit, especially for the older vehicles. While the $R^2$ value is slightly improved, the line suggests that older, untreated vehicles will rust less. This does not make sense physically. It could be further argued that the vehicles at ages 25 and 30 should be discarded as outliers. However, at this stage, there is no reason to assume why they differ radically from any other vehicle, and furthermore, they are untreated and so would presumably be subject to the same conditions as any other untreated vehicle. One possible explanation is that such vehicles are collector vehicles and so are better maintained, but this cannot be confirmed with the data provided, and even if they were, would constitute a very small subset. Therefore, at this stage of research, the linear fit is considered as the best choice to demonstrate the corrosion trend on vehicles.
Figure 21 shows a significant difference between the treated and untreated vehicles. The treated vehicles show relatively small amounts of rust on their body panels. Conversely, untreated vehicles start to show rust on their body panels after 5 years, and the data tends to be much less clustered after 15 years old. Corrosion on untreated vehicles therefore seems more widespread in terms of area coverage over time for all sampled vehicles.
Figure 22 shows that corrosion occurs earlier on underbody parts than on body panels. The low salvage vehicles from A&L are not included in this test as some of the underbody parts had already been removed before the sampling. The trend lines for treated and untreated underbody parts show less difference than in Figure 21 which focused only on the body panels, but the untreated vehicles still show greater rust than the treated ones.

The data were also analyzed to compare three different corrosion types on the body panels for the treated and untreated vehicles respectively. Figures 23, 24, 25 show the different trends for three corrosion types on vehicle body panels. All scales on the Y axis are set to the same scale.
Figure 23 - Corrosion trend for perforation.

Figure 24 - Corrosion trend for blistering.
The result from the three figures shows that for blistering (Figure 24), it has the smallest coverage from the sampled vehicles, and that the difference between treated and untreated vehicles appears relatively insignificant. In Figure 25, there again appears to be noticeable differences between treated and untreated vehicle surface rust coverage, and this is consistent with our earlier observations from prior figures. In Figure 23, perforation differences can be seen between treated and untreated vehicles, although this might not be as easily apparent. However, perforation is considered as the most severe rust condition because the vehicle metal has been fully compromised, while blistering is the least severe because the paint is still intact. More differences will be shown between the treated and untreated vehicles in forthcoming analyses.

The vehicles sampled from Krown’s facilities are all operational vehicles: most are expected to be operating for some time yet. However, the vehicles from A&L Auto
Recycler and Standard Auto Wrecker are all ELVs. Furthermore, most of the vehicles from A&L Auto Recycler are low salvage ELVs, only three of them are high salvage ELVs. There could therefore be differences among the vehicles from the three different locations. Figure 26 shows the different trends for the untreated body panels from the three locations, while Figure 27 shows the different trends for the untreated underbody parts from Krown versus the high salvage vehicles from standard and A&L.

![Untreated Corrosion Index from 3 Sampling Locations (Body Panel)](image)

**Figure 26 - Untreated Corrosion Index from 3 sampling locations.**

Figure 26 shows that there are noticeable differences between the untreated body panels from vehicles sampled at Krown’s facilities and the other two locations. The Krown’s untreated vehicle body panels tend to have less corrosion compared with those from the other two locations. Because corrosion treatment cannot actually recover metal from corrosion, it is conceivable that a vehicle owner will not bother to bring in a vehicle that already has significant rust for corrosion treatment. Therefore, the untreated vehicle data from Krown will likely not represent the average corrosion condition of body panels.
found on untreated vehicles in the general vehicle population. In this respect, vehicles sampled at Krown – even if they are untreated – are likely self-selected to be in “better condition” than a typical untreated vehicle of comparable age.

![Untreated Corrosion Index from 3 Sampling Locations (Underbody Parts)](image)

Figure 27 - Untreated Corrosion Index from 3 Sampling Locations (Underbody Parts).

However, Figure 27 shows that the differences in underbody parts from vehicles sampled at Krown and the high salvage ELVs at Standard and A&L are not as significant. This could be for three reasons: 1) customers are usually not aware of the condition of the underbody of their vehicle; 2) most of the routine maintenance (e.g., washing and waxing) cannot access the underbody parts; and 3) it was noticed that even for practically new vehicles coming in for treatment, underbody parts would already have some corrosion present.
Because the untreated body panels from Krown facilities likely do not represent typical corrosion, they are removed from further analysis. Instead, Figure 28 shows the differences between body panels between treated vehicles (from Krown) and the untreated vehicles (from A&L and Standard locations). Based on the trends exhibited, body panels from untreated vehicles display noticeable more corrosion than untreated vehicles, especially in the 8 to 20 year age range. Given the slight increase in the average duration of vehicle ownership to 11.5 years, corrosion will likely be an increasingly important issue to vehicle owners particularly if the longevity of a vehicle continues to rise (IHS Automotive, 2015).

Another set of analyses shows the different corrosion trends for each body panel separately, which are the hood, fenders, doors, quarter panels and rocker panels, in Figures 29 through to 33.
Figure 29 - Corrosion Index for hood.

Figure 30 - Corrosion Index for fenders.
Figure 31 - Corrosion Index for doors.

Figure 32 - Corrosion Index for quarter panels
Figure 33 - Corrosion Index for rocker panels.

All values on the Y axis are again show to the same scale (0 to 3000). From these figures, the rocker panels exhibits the most rust, while the hood exhibits much less. Only 8 out of 193 vehicles were spotted with rust on their hoods. Furthermore, for all five different vehicle body parts, the treated vehicles exhibited less corrosion than the untreated vehicles.

The next analysis focuses on the different state of corrosion for the separate underbody parts, which are: cross members, control arms and fuel/brake lines. The low salvage vehicles sampled from A&L were not included in this test. The results are shown in Figures 34 to 36.
Figure 34 - Corrosion Index for cross members.

Figure 35 - Corrosion Index for control arms.
All three figures show that treated vehicles exhibit less corrosion than the untreated vehicles. Most of the vehicles have some degree of rust on their underbody parts except for the fuel/brake lines; only 12 out of 171 vehicles were spotted to have rust on their fuel/brake lines. Most of the underbody parts, such as cross members and control arms, are usually thick metal. Rust on these parts likely does not pose a significant impact. As the underbody parts are usually not visible, customers may be more concerned about safety issues, such as corrosion on break/fuel lines and electronic parts. For electronic parts, most are inside the vehicle body and cannot be readily seen. The extent of corrosion on the brake/fuel line could therefore be an important predictor for the safety condition of the vehicles. The results for the vehicles which were spotted to have corrosion on their brake/fuel lines are listed in Table 3.
Table 3 - Vehicles with corrosion on their brake/fuel lines.

<table>
<thead>
<tr>
<th>Make</th>
<th>Model</th>
<th>Vehicle age</th>
<th>Brake/fuel line Corrosion Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treated</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oldsmobile</td>
<td>Alero</td>
<td>12</td>
<td>406.78</td>
</tr>
<tr>
<td>Pontiac</td>
<td>Pursuit</td>
<td>10</td>
<td>18.87</td>
</tr>
<tr>
<td>Pontiac</td>
<td>Fiero GT</td>
<td>29</td>
<td>151.16</td>
</tr>
<tr>
<td>Chevrolet</td>
<td>Cavalier</td>
<td>16</td>
<td>1852.44</td>
</tr>
<tr>
<td>Ford</td>
<td>F-150</td>
<td>16</td>
<td>287.31</td>
</tr>
<tr>
<td>Ford</td>
<td>F-150</td>
<td>25</td>
<td>194.4</td>
</tr>
<tr>
<td>Chevrolet</td>
<td>COBALT</td>
<td>7</td>
<td>150.53</td>
</tr>
<tr>
<td>Oldsmobile</td>
<td>Alero</td>
<td>12</td>
<td>82.11</td>
</tr>
<tr>
<td>Chevrolet</td>
<td>IMPALA</td>
<td>8</td>
<td>203.09</td>
</tr>
<tr>
<td>Chevrolet</td>
<td>Cavalier</td>
<td>12</td>
<td>164.88</td>
</tr>
<tr>
<td>Pontiac</td>
<td>Sunfire</td>
<td>12</td>
<td>15.7</td>
</tr>
<tr>
<td>Pontiac</td>
<td>Montana</td>
<td>8</td>
<td>97.9</td>
</tr>
</tbody>
</table>

Among the treated vehicles, only 2 out of 67 (3.0%) vehicles exhibit corrosion on their brake/fuel line, and both of them are older than 10 years. On the other hand, 10 out of 104 (9.6%) untreated vehicles are found to have corrosion on their brake/fuel lines. The youngest vehicle with corrosion on the brake/fuel line is 7 years old.

### 4.5 Linear Regression Analysis

Linear regression analysis was used to establish a relationship between the extent of corrosion on a vehicle and its age. Both treated and untreated vehicles are analyzed for the body panels and underbody parts separately.

1. **Body panels**

   Vehicles younger than 6 years old are excluded from the analysis. In almost all instances, no rust was spotted. After multiple observations, vehicles which are less than 6 years old can be essentially considered as “rust from rust” for their body panels. In addition, vehicles older than 15 years old are not included either because:
a) According to a report published by Desrosiers Automotive (2005), the overall lifetime of a typical customer vehicle is approximately 15 years.

b) Most of the sampled vehicles that are older than 15 years old had been either treated very well by the customer (e.g., classic car), or dumped in the junk yard as a low salvage vehicle. Either case represents more of an unusual circumstance, rather than the active corrosion period a typical car might undergo.

c) Only 3 treated vehicles and 13 untreated vehicles (most of them are low salvage vehicles sampled from A&L) sampled are older than 15 years old. This lack of robust data could also bias the analysis.

This analysis therefore only includes vehicles between 6 to 15 years old. The weighting scale for the perforation, blistering and surface rust are again set as 1:1:1.

1.1. Body panel on Krown treated vehicles.

44 vehicles from Krown’s facilities were selected in this analysis. The linear regression results for the body panels of the Krown treated vehicles within 6 to 15 years old are shown in Figure 37:
Figure 37 - Treated vehicles (6 - 15 years old) corrosion line fit plot.

Figure 38 - Treated vehicles (6 - 15 years old) corrosion residual plot.
Table 4 - Regression statistics for treated vehicles (16 - 15 years old) Corrosion Index.

Regression Statistics

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.379357819</td>
</tr>
<tr>
<td>R Square</td>
<td>0.143912354</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.123529315</td>
</tr>
<tr>
<td>Standard Error</td>
<td>91.19614071</td>
</tr>
<tr>
<td>Observations</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 5 - ANOVA test result for treated vehicles (16 - 15 years old) Corrosion Index 1.

ANOVA

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>58719.461</td>
<td>58719.461</td>
<td>7.060</td>
<td>0.011</td>
</tr>
<tr>
<td>Residual</td>
<td>42</td>
<td>349302.92</td>
<td>8316.736</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>408022.38</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 - ANOVA test result for treated vehicles (16 - 15 years old) Corrosion Index 2.

<table>
<thead>
<tr>
<th></th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
<th>95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle age</td>
<td>13.579</td>
<td>5.111</td>
<td>2.657</td>
<td>0.011</td>
<td>3.266</td>
<td>23.893</td>
<td>3.266</td>
<td>23.893</td>
<td>23.893</td>
</tr>
</tbody>
</table>

The following is a summary of the key test variables:

- **R Square Value**: The coefficient of determination. This value ranges from 0 to 1. It indicates how well the data fit the model. Multiple R is the root of R Square.

- **Adjusted R Square**: This number is a more conservative number and is usually smaller than R Square. It adjusts for the number of predictors. This number should be used instead of R Square when multiple predictors (x) are used.

- **Significant F**: The probability that the model does not explain the variation; indicates the probability that the Regression output could have been obtained
by chance. A small F Significance confirms the validity of the Regression output. The commonly acceptable largest value is 0.05.

- **P–Value**: Similar to the Significant F, it indicates the probability of the result occurs as a chance for each predictor. The commonly acceptable largest value is 0.05.

- **Residual Plot**: A plot of residuals versus predictor. An ideal residual plot should be centered on zero throughout the range of fitted values, with no values being systematically too high or too low.

According to the equation given by this test, Corrosion Index = 13.579 * vehicle age - 88.391, which means in general, between 6 and 15 years old, one treated vehicle is expected to increase 13.6 cm² rust area on their body panels every year (including all three types of corrosion). According to the result from Table 4, the R Square value is approximately 0.144, which means only about 14.4% of variations as indicated via the Corrosion Index can be explained by the equation.

For some types of studies, the R Square values can be expected to be very low, such as when predicting human activities. Conceivably, measuring the corrosion on vehicles can also result in a very low R Square value because many factors other than vehicle age can also affect the condition of the vehicle body, such as road conditions, vehicle make and model, temperature, driving habits, and so on. According to the significant F value given in Table 5, the significant F value is 0.011, which is smaller than the commonly accepted largest value 0.05. Furthermore, the residual plot in Figure 38 shows most of the residuals are centered on zero throughout the range of fitted values, with no values systematically too high or too low. As a result, this equation describes reliably the general relationship.
between vehicle age and Corrosion Index for the treated vehicle within the ages of 6 – 15 years old. However, it may not be suitable for precise predictions.

The treated vehicles selected for this test are defined as any vehicles that have been treated by Krown before the sampling. The frequency of the treatment however was not considered in Figure 37. According to Krown’s recommendation, to obtain the best performance from corrosion protection, vehicles should be treated annually. The question then is if there is any additional significance if the analysis focused on vehicles with repeated treatment. Based on the survey sampling, less than 10 vehicles were claimed to have undergone such treatment every year. It was not possible to sample vehicles that received annual treatment based on Krown’s customer records because to do so would have necessitated contacting specific vehicle owners in advance, rather than the random (and less biased) sampling that was undertaken. As a reasonable approximation, any vehicles with five or more treatments were selected for analysis. Doing so means using only a limited number of sample points (17) compared to the overall data set. The results are shown as follows.
Figure 39 - Treated vehicle (with 5+ treatments) corrosion line fit plot.

Figure 40 - Treated vehicle (with 5+ treatments) corrosion residual plot.
Table 7 - Regression statistics for treated vehicle (with 5+ treatments).

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.002884285</td>
</tr>
<tr>
<td>R Square</td>
<td>8.3191E-06</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.066657793</td>
</tr>
<tr>
<td>Standard Error</td>
<td>69.29072765</td>
</tr>
<tr>
<td>Observations</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 8 - ANOVA test result 1 for treated vehicles (with 5+ treatments).

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>0.599</td>
<td>0.599</td>
<td>0.00125</td>
<td>0.991</td>
</tr>
<tr>
<td>Residual</td>
<td>15</td>
<td>72018.074</td>
<td>4801.205</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>72018.673</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9 - ANOVA test result 2 for treated vehicles (with 5+ treatments).

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>41.121</td>
<td>40.042</td>
<td>0.32</td>
<td>-44.225</td>
<td>126.469</td>
<td>-44.225</td>
<td>126.469</td>
</tr>
<tr>
<td>VEHICLE</td>
<td>0.0354</td>
<td>3.169</td>
<td>11.12</td>
<td>-6.718</td>
<td>6.789</td>
<td>-6.718</td>
<td>6.789</td>
</tr>
</tbody>
</table>

According to the result of this test, the R Square value is extremely low which is only 8.32*10^-6, and the significant F value is 0.991 which means 99.1% of this regression output is merely a chance occurrence. Furthermore, the residual plot shows that more data appears under the zero line, and the spots above the line are too high compared with the data below. The output of this test is not reliable: assessing the relationship between vehicle age and corrosion for repeatedly treated vehicles is therefore not currently supported in this research.
1.2. Body panel on untreated vehicles.

For this situation, 55 vehicles are assessed, including 42 vehicles from Standard and 13 vehicles from A&L. Figures 41 and 42 and Tables 10 to 12 outline the results for body panels of untreated vehicles between 6 to 15 years of age.

Figure 41 - Untreated vehicles from Standard and A&L (6 - 15 years old) corrosion line fit plot.
Figure 42 - Untreated vehicles from Standard and A&L (6 - 15 years old) residual plot.

Table 10 - Regression Statistics for untreated vehicles from Standard and A&L (6 – 15 years old) Corrosion Index.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.661189431</td>
</tr>
<tr>
<td>R Square</td>
<td>0.437171463</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.426552057</td>
</tr>
<tr>
<td>Standard Error</td>
<td>514.2923474</td>
</tr>
<tr>
<td>Observations</td>
<td>55</td>
</tr>
</tbody>
</table>

Table 11 - ANOVA test result 1 for untreated vehicles from Standard and A&L (6 – 15 years old) Corrosion Index.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>10888591.13</td>
<td>10888591.1</td>
<td>41.167</td>
<td>3.91512E-08</td>
</tr>
<tr>
<td>Residual</td>
<td>53</td>
<td>14018320.79</td>
<td>264496.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54</td>
<td>24906911.92</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
According to the equation given by this test, Corrosion Index = 173.103 * vehicle age – 1386.05, which means that in general, an untreated vehicle between 6 to 15 years is expected to increase 173.1 cm² of rust area on its body panel every year, which includes all three types of corrosion. This is much higher than a treated vehicle of 13.579 cm² per year. The R Square value for the test is approximately 0.437, which means 43.7% variations (Corrosion Index) can be explained by the equation. This value is much higher than the fitted linear equation for treated vehicles from Krown. Several reasons may cause the fitting of treated vehicles to have a much lower R Square value than the fitting of untreated vehicles:

1. The number of samples included in the test. The test for the untreated vehicles has 55 observations and the test for the treated vehicles has 44 observations.

2. Although all treated vehicles are claimed to have been treated by Krown at least once, the frequency of treatment has not been included. Presumably, a vehicle which is treated every year will not exhibit the same corrosion as a vehicle which is treated every 3 years. According to the information provided by Krown, a once-every year treatment is recommended for the customers. Untreated vehicles of course do not have this problem of treatment repeatability.
also according to the result of Residual Plot (Figure 42), most of the residuals are centered on zero throughout the range of fitted values, with no apparent values systematically too high or too low. As a result, although a 43.7% R Square value cannot justify precise predictions, the equation does explain the general relationship between the amount of corrosion and the vehicle age within the 6 to 15 year range.

2. Underbody parts

According to the previous observation, corrosion can occur on the underbody parts of vehicles at a very early age. Furthermore, owner actions such as car washing and other regular maintenance cannot readily access the underbody parts. Therefore, unlike the body panel assessments, vehicles of all ages (not just those between 6 and 15 years) are selected for the test. The low salvage vehicles from A&L are not included as some parts had already been removed before the sampling. Therefore, 171 vehicles are assessed here, including 67 treated vehicles and 104 untreated vehicles.

2.1. Underbody parts on Krown treated vehicles.

In total 67 vehicles are included in this test, and all of these vehicles are from Krown’s facilities. Figures 43 and 44 and Tables 13 through 15 show the results for underbody parts on Krown treated vehicles:
Figure 43 - Treated vehicle underbody corrosion line fit plot.

Figure 44 - Treated vehicle underbody corrosion residual plot.
Table 13 - Regression statistics for treated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.443441048</td>
</tr>
<tr>
<td>R Square</td>
<td>0.196639963</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.184280578</td>
</tr>
<tr>
<td>Standard Error</td>
<td>718.0945893</td>
</tr>
<tr>
<td>Observations</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 14 - ANOVA test result 1 for treated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>df</td>
<td>1</td>
</tr>
<tr>
<td>SS</td>
<td>8204237.539</td>
</tr>
<tr>
<td>MS</td>
<td>8204237.539</td>
</tr>
<tr>
<td>F</td>
<td>15.910</td>
</tr>
<tr>
<td>Significance F</td>
<td>0.000171</td>
</tr>
</tbody>
</table>

Table 15 - ANOVA test result 2 for treated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th>Coefficient s</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-71.077</td>
<td>175.641</td>
<td>0.405</td>
<td>-421.857</td>
<td>279.703</td>
<td>-421.857</td>
<td>279.703</td>
</tr>
</tbody>
</table>

According to the result, the fitted linear equation given for the treated underbody corrosion fitting is: Corrosion Index = 72.876 * vehicle age – 71.077, which means, in general, from the first year, a Krown treated vehicle is expected to increase 72.9 cm² area of corrosion every year. The R Square value given by the regression statistics is (Table 13) 0.197, which means approximately 19.7% of the variations (Corrosion Index) can be explained by this equation.

From Table 14, the result shows that the Significant F value is 0.000171, which is much lower than the largest commonly acceptable value 0.05, and also Figure 44 shows most residuals are centered on zero throughout the range of fitted values, with nothing systematically too high or too low. As a result, the relationship between the underbody
Corrosion Index and vehicle age for treated vehicles can be described by the resulting equation.

2.2. Underbody parts on untreated vehicles.

104 vehicles are included in this assessment, including the vehicles coming for the first time treatment from Krown’s facilities (47) and the high salvage ELVs from Standard (53) and A&L (4). Figures 45 and 46 and tables 16 to 18 show the results.

Untreated Vehicle Underbody Corrosion Line Fit Plot

\[ y = 127.17x - 15.945 \]

\[ R^2 = 0.2999 \]

Figure 45 - Untreated vehicle underbody corrosion line fit plot.
Figure 46 - Untreated vehicle underbody corrosion residual plot.

Table 16 - Regression statistics for untreated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.54762669</td>
</tr>
<tr>
<td>R Square</td>
<td>0.299894991</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.293031217</td>
</tr>
<tr>
<td>Standard Error</td>
<td>1034.939002</td>
</tr>
<tr>
<td>Observations</td>
<td>104</td>
</tr>
</tbody>
</table>

Table 17 - ANOVA test result 1 for untreated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>46798906.68</td>
<td>46798906.68</td>
<td>43.692</td>
<td>1.7871E-09</td>
</tr>
<tr>
<td>Residual</td>
<td>102</td>
<td>109252071.3</td>
<td>1071098.738</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>103</td>
<td>156050977.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 18 - ANOVA test result 2 for untreated vehicle underbody Corrosion Index.

<table>
<thead>
<tr>
<th></th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>127.166</td>
<td>19.238</td>
<td>6.6100</td>
<td>1.787E-09</td>
<td>89.007</td>
<td>165.325</td>
<td>89.007</td>
<td>165.325</td>
</tr>
</tbody>
</table>

According to the results, the fitted linear equation given from the plot for the underbody parts of the untreated vehicles is: Corrosion Index = 127.17 * vehicle age – 15.945. As a result, in general, an untreated vehicle will increase on average 127.2 cm² of corrosion on its underbody parts every year from the first year. The R Square value given by the regression statistics (Table 16) is approximately 0.3, which means that 30% of the variations (Corrosion Index) can be explained by this equation, which is higher than the R Square value of the fitted linear equation for the underbody parts of the treated vehicles (19.7%). The significant F value given by ANOVA test (Table 17) is 1.787 * 10⁻⁹, which is extremely small, and also the Residual Plot Figure 46 shows that the residuals are centered on zero throughout the range of fitted values, and no values are systematically too high or too low. As a result, the equation provided by this test is not suitable for precise prediction but does in general describe the relationship between the corrosion and vehicle age.

3. Other potential factors affecting corrosion

Many factors may affect the corrosion condition of a vehicle, such as the road conditions, regular maintenance, and driver behavior. A survey was provided to Krown customers prior to sampling to obtain such information (Appendix A). Of all the information gathered, two factors are considered to be more valuable than others: 1) mileage; and 2) how many time was the vehicle protected against corrosion. These variables from the survey were chosen because:
a) These two factors are quantifiable as actual numbers are given by the customers;

b) Some customers do not have a very clear idea of the condition of their vehicles, so the veracity of the answers for some questions is doubtful, such as asking the owner to comment on typical road conditions or the frequency of washing the car. If the police force is active, the mileage can be read directly from the odometer, and the amount of time a vehicle was protected against the corrosion can be confirmed with Krown records if it can be verified that the vehicle was treated in the same facility.

Vehicle age – as general as it is – appears to be an important factor, and this appears to be borne out by the prior analysis. The greater the time or length of ownership of a vehicle is a proxy for increasing exposure to the elements and various conditions that contribute to corrosion. Because of this, vehicle age will be kept as a key variable. The analyses are only conducted for the body panels in order to determine if the two above factors have a significant impact on vehicle corrosion or not. Again, only the vehicles within 6 – 15 years old are selected for assessment since the vehicles within this range exhibit a more significant relationship between the age and corrosion condition. Two sets of data are tested by the regression analysis. The first set focuses on mileage and the vehicle age – presumably, the more mileage a vehicle has, the more exposure it would have had to increase corrosion. The second set includes the number of times a vehicle was treated to against corrosion (number of treatments) and vehicle age. Only treated vehicles are selected for this test.

3.1. Mileage and vehicle age vs. Corrosion Index
49 vehicles are selected in this test. The results are shown in Tables 19, 20, and 21.

*Table 19 - Regression statistics for mileage & vehicle age test.*

<table>
<thead>
<tr>
<th>Regression Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
</tr>
<tr>
<td>R Square</td>
</tr>
<tr>
<td>Adjusted R Square</td>
</tr>
<tr>
<td>Standard Error</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>

*Table 20 - ANOVA test result 1 for mileage & vehicle age test.*

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>2</td>
<td>17449.241</td>
<td>8724.620</td>
<td>2.887</td>
<td>0.0703</td>
</tr>
<tr>
<td>Residual</td>
<td>32</td>
<td>96689.059</td>
<td>3021.533</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>114138.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 21 - ANOVA test result 2 for mileage & vehicle age test.*

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-44.742</td>
<td>35.667</td>
<td>1.254</td>
<td>0.219</td>
<td>-117.392</td>
<td>27.909</td>
<td>-117.392</td>
</tr>
<tr>
<td>Mileage</td>
<td>-1.114E-05</td>
<td>0.000</td>
<td>0.946</td>
<td>0.916</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>VEHICLE AGE</td>
<td>8.259</td>
<td>3.605</td>
<td>2.291</td>
<td>0.916</td>
<td>15.602</td>
<td>0.916</td>
<td>15.602</td>
</tr>
</tbody>
</table>

According to Table 21, the fitted linear equation for this test is: Corrosion Index = -1.114*10^-5 * Mileage + 8.259 * Vehicle age – 44.742, which means for every 10,000 kilometres of mileage, the potential corrosion area decreases by 0.1114 cm², plus every year a vehicle is expected to increase by 8.26 cm² corrosion area due to aging on its body panels for vehicles between 6 years old to 15 years old.

This suggests increasing mileage may decrease corrosion area on the vehicle body, which seems improbable and counterintuitive. In addition, the impact is very small, which means the mileage does not have a significant impact on vehicle body panel corrosion. And also, the adjusted R Square value for this test is extremely low at 0.1, which means only
10% of the variations (Corrosion Index) can be explained by this equation. The significant F value (0.0703) and P – values for mileage (0.946) are higher than the commonly acceptable largest value (0.05), which means the addition of a new predictor variable - mileage - lowers the correlation between the predictor variables and the response variable. Thus, this equation cannot explain this set of circumstances and should not be used.

3.2. Numbers of treatment & vehicle age vs. Corrosion Index

41 vehicles are selected for this test. The results are shown in Tables 22, 23, and 24.

Table 22 - Regression Statistics for amount number of treatments & vehicle age test.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.430922524</td>
</tr>
<tr>
<td>R Square</td>
<td>0.185694221</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.142836022</td>
</tr>
<tr>
<td>Standard Error</td>
<td>92.54876527</td>
</tr>
<tr>
<td>Observations</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 23 - ANOVA test result 1 for amount number of treatments & vehicle age test.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>df</td>
<td>2</td>
</tr>
<tr>
<td>SS</td>
<td>74222.525</td>
</tr>
<tr>
<td>MS</td>
<td>37111.263</td>
</tr>
<tr>
<td>F</td>
<td>4.333</td>
</tr>
<tr>
<td>Significance F</td>
<td>0.0202</td>
</tr>
</tbody>
</table>

Table 24 - ANOVA test result 2 for amount number of treatments & vehicle age test.

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Lower 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-106.234</td>
<td>55.127</td>
<td>1.927</td>
<td>0.0615</td>
<td>-217.833</td>
<td>-217.833</td>
<td>5.365</td>
</tr>
<tr>
<td>Vehicle age</td>
<td>17.519</td>
<td>5.967</td>
<td>2.935</td>
<td>0.0056</td>
<td>5.438</td>
<td>29.599</td>
<td>29.599</td>
</tr>
<tr>
<td>number of</td>
<td></td>
<td>0.730</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatments</td>
<td>-5.058</td>
<td>6.922</td>
<td>0.4694</td>
<td>-19.072</td>
<td>8.956</td>
<td>-19.072</td>
<td>8.956</td>
</tr>
</tbody>
</table>

According to table 24, the fitted linear equation for this test is: Corrosion Index = 17.519 * vehicle age – 5.058 * number of treatments – 106.234. If a vehicle between 6 to
15 years old is treated every year, it is expected to increase \((17.519*1 - 5.058*1) = 12.461\) cm\(^2\) corrosion area every year. The negative coefficient of the number of treatments (-5.508) indicates that treatment is mitigating the amount of corrosion. The Significant F value (0.0202) satisfies the limit value (0.05). However, the p–value (0.47) for the number of treatments is larger than the commonly acceptable largest value 0.05, which means the treatment amount is not strongly related with the Corrosion Index. However, the vehicle age still has a strong relationship with the Corrosion Index as its p – value is 0.00562. The weak relationship between treatment and the mitigation of corrosion seems counterintuitive when compared to the prior, overall analysis of the data. Given that the data collected could not verify the number, or type, of treatments (it was largely based on owner recollection and/or observation of the vehicle), further analysis is recommended to thoroughly test this aspect.

4. Regression analysis summary

The key parameters from the regression tests are shown in Table 25.
Table 25 - Regression analysis conclusion.

<table>
<thead>
<tr>
<th>Predictor variable(s)</th>
<th>Vehicle part</th>
<th>T or UT</th>
<th>Samples</th>
<th>observations</th>
<th>Interce pt</th>
<th>Coefficients</th>
<th>(Adjusted R²)</th>
<th>Significant F</th>
<th>P - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single predictor (vehicle age)</strong></td>
<td>Body panels</td>
<td>Treated</td>
<td>6 - 15 years old vehicles from Krown</td>
<td>44</td>
<td>-</td>
<td>13.579</td>
<td>0.144</td>
<td>0.011</td>
<td>0.0110</td>
</tr>
<tr>
<td></td>
<td>Untreated</td>
<td>6 - 15 years old vehicles from A&amp;L and Standard</td>
<td>55</td>
<td>1386.0</td>
<td>5</td>
<td>173.103</td>
<td>0.437</td>
<td>3.92E-08</td>
<td>3.915E-08</td>
</tr>
<tr>
<td>Underbody parts</td>
<td>Treated</td>
<td>Krown</td>
<td>67</td>
<td>71.077</td>
<td>-</td>
<td>72.876</td>
<td>0.197</td>
<td>0.000171</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Untreated</td>
<td>Krown and high salvage vehicles from A&amp;L and Standard</td>
<td>104</td>
<td>15.945</td>
<td>-</td>
<td>127.166</td>
<td>0.300</td>
<td>1.79E-09</td>
<td>1.787E-09</td>
</tr>
<tr>
<td><strong>Vehicle age &amp; Mileage</strong></td>
<td>Body panels</td>
<td>Treated</td>
<td>6 - 15 years old vehicles from Krown</td>
<td>35</td>
<td>-</td>
<td>44.742 -1.114E-05</td>
<td>0.10 0.070 0.946</td>
<td>0.946</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mileage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vehicle age</td>
<td>8.259</td>
<td>0</td>
<td></td>
<td>0.029</td>
</tr>
<tr>
<td><strong>Vehicle age &amp; number of treatments</strong></td>
<td>Body panels</td>
<td>Treated</td>
<td>6 - 15 years old vehicles from Krown</td>
<td>41</td>
<td>-</td>
<td>106.23 -5.058</td>
<td>0.14 0.020 0.469</td>
<td>0.469</td>
<td>0.00562</td>
</tr>
</tbody>
</table>
1. Body panels: the treated vehicles tend to have less rust every year for vehicles between 6 to 15 years old. A treated vehicle will reduce the potential rusted area on its body panel by $173.103 - 13.579 = 159.5\text{cm}^2$ every year, which is a 92% reduction. The R-Square values for both treated and untreated vehicles are small, and both of the significant F values are in the acceptable range.

2. The “Vehicle age & mileage” test shows there is no significant relationship between the mileage and body panel corrosion condition since the adjusted R Square value is extremely low, and both the significant F value and p–value are higher than the limit.

3. For the “Vehicle age & number of treatments” test, the adjusted R Square value is only 14.3%, and the p–value for “number of treatments” is 0.469 which is much higher than 0.05 but the significant F value is 0.0202 which is lower than 0.05. There are several possible reasons that may result in the high p–value. First, some vehicles are preowned vehicles, which means the customer who participated in the test may not know the treatment history of the vehicle. Records can be found from Krown’s facilities, but treatment records are only kept at individual facilities: if a vehicle was treated in different facilities, the record will not be accurate. Second, the survey provided for the customer only asks them to select the range of number of treatments, such as 2 to 3 times or 6 or more times. Clearly, more research with improved data is necessary for this test. Further sampling is recommended for the “vehicle age & number of treatments” test with a more accurate number of treatments.
4. Underbody parts: based on the data, a treated vehicle tends to reduce potential rusted area on its underbody panel by $127.166 - 72.876 = 54.29 \text{ cm}^2$, which is a 43% reduction. Both of treated and untreated vehicles have a low R Square value but the significant F value meets the limit.

From this table, for both body panel and underbody parts, the R Square values for untreated vehicles are higher than the treated ones, which implies the untreated vehicles are more predictable in terms of developing corrosion than treated vehicles. To some degree, this makes sense given that corrosion can be expected after a significant period of vehicle operation. Conversely, how much corrosion can be prevented by treatment will vary by the type and number of treatments. Out of necessity, for this initial research, any vehicle with at least one treatment will be classified as a treated vehicle. Different frequencies of treatment may result in less predictable corrosion development. In future research, the sampling should target treated vehicles with more identifiable treatment records and reliable data.

**4.6 Corrosion Levels**

So far, the research has identified that there are distinct trends between the development of corrosion for increasing vehicle ages for both untreated and treated vehicles. Untreated vehicles do corrode more than treated ones, particularly within the 6 to 15 year age range. However, as shown in the linear regression results, the predictability of the equations is low. There are several possible reasons:

1. Although nearly 200 vehicles were sampled, this data set might be insufficient to represent enough variations in vehicle operation.
2. The data gathered might be inaccurate (e.g., relying on owner recollection) or biased (e.g., vehicles coming in for treatment might be self-selected to have less corrosion).

3. There may be some other factors (e.g., undisclosed driver behavior) that impacts the vehicle exposure and which ultimately affects corrosion but which was not discovered.

4. The relationship between corrosion and vehicle age is assumed to be linear, but may not be.

The initial intent was to formulate the Corrosion Index as closely as possible to quantitative measures; in particular, the observable area of corrosion. However, in doing so, a greater level of detail may have been deemed possible when assessing corrosion than is warranted. Although great care was taken in the visual measurement of corroded parts, there is a degree of subjectivity in each observation. In addition, it should be questioned if there is a significant difference between, say, 500 cm$^2$ of surface corrosion versus 550 cm$^2$. In addition, some types of corrosion, such as if the metal is perforated, are arguably more serious, but do not cover much area – this implies that for some instances, the corrosion area observed is not linearly related to its severity. Overall then, the prior analysis may presume levels of precision and accuracy that are not necessarily warranted. Interestingly, some of the other approaches to corrosion evaluation reviewed previously in the literature adopt coarser descriptions that are more understandable and even more workable in some respects. The difference is that the classification presented here was developed from quantitative measures that should match practical observations.
As an alternative, using the data already collected and the insights from the prior analyses, three types of observable corrosion are instead considered: blistering, surface rust, and perforation. Based on observations and the literature, corrosion on vehicle body panel surfaces usually start with blistering on the surface and is visible under the paint (if any). As the corrosion expands, the damaged paint starts to peel off, and rusted metal sheet surface is exposed, leading to surface rust. Corrosion can also reduce the thickness of the metal sheet, which may eventually create a visible hole on the metal sheet, and this is defined as a perforation. Therefore, a Corrosion Index based solely on the observable areas of corrosion may be inadequate. Instead, levels of corrosion will be defined. Different levels will be set for both vehicle body panel and underbody parts separately.

1. Body panel corrosion level

Five levels of corrosion are assigned to categorize the corrosion on vehicle body panels. Because perforation means the metal has been penetrated through, the only effective repair is to replace the panel. At the other end, any amount of perforation on body panels means it will be classified as level 5, irrespective of the observed area of rust. For level 2, 50cm$^2$ was considered the cutoff: areas of corrosion less than 50cm$^2$ could be covered with small “touch up” paint applications. Levels 3 and 4 lie in-between in terms of reparability and would require more extensive equipment and actions to repair any corrosion. A decision was made to separate the two at the 250cm$^2$ mark.

In terms of weighting, because blistering is considered the initial stage of corrosion, half of the blistering area will be considered to contribute to the level of corrosion, which means the weighting for blistering is “0.5”. Surface rust is assessed between perforation and blistering and is weighted as “1”. Overall, a vehicle with no rust on its
body panels will be classified as level 1, with classifications for level 2 to level 5 as shown in Table 26.

Table 26 - Corrosion level classification for body panels.

<table>
<thead>
<tr>
<th>Level</th>
<th>Corrosion Index (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1 - 50</td>
</tr>
<tr>
<td>3</td>
<td>51 - 250</td>
</tr>
<tr>
<td>4</td>
<td>251 - 1000</td>
</tr>
<tr>
<td>5</td>
<td>&gt;1001 or Perforation</td>
</tr>
</tbody>
</table>

Some typical pictures are given as examples of the corrosion levels. Figure 47 shows Level 2 corrosion with body panels having 8.7 cm² corrosion index. Figures 48, 49, 50 show Level 4 corrosion with body panels having a combined 308 cm² corrosion index. Figure 51 shows a perforation area of 32.6 cm², which is classified as level 5.

Figure 47 - Level 2, corrosion index=8.7 cm²
Figure 48 - Level 4, corrosion index=12.8 cm² on the hood.

Figure 49 - Level 4, corrosion index=53.9 cm² on the doors.
Each vehicle from the sampling will be assessed a corrosion level for its body panel. In order to find the relationship between the corrosion level and vehicle age, a mean value of corrosion for each year is calculated. Based on the total amount of sampling, the amount of vehicles for each year is insufficient to perform an ideal analysis: even though nearly
200 vehicles were sampled, because each vehicle age varies from 1 to 28 years old, there are actually few data points within each age range. Instead, it may be more illustrative to aggregate vehicle data into, for example, three year bands for vehicles ranging from 1 year old to 15 years old, while vehicles older than 15 years old are aggregated into one larger set because of the drop off in data points beyond the 15 year mark. The mean age of each set will be used. The percentage of the amount of vehicles within each body panel corrosion level for each set of vehicle age is calculated in order to find the mean level for each vehicle age set. The calculation of mean corrosion level can be represented by Equation [2].

\[
\text{Mean Corrosion Level} = \sum_{i=1}^{5} X_i P_i \quad \text{Eq. 2}
\]

\(X = \) Body panel corrosion level

\(P = \) Percentage of vehicles falling into that level

For example, in Table 27, the mean level of corrosion for the treated body panels at mean age 11 is calculated as: “Level 1” * 38% + 2 * 23% + 3 * 15% + 4 *0% + 5 * 23% = 2.461. This suggests that an 11 year old vehicle can develop a mean corrosion level of 2.5.

The results for treated and untreated vehicle body panels can be shown in Table 27 and Table 28 respectively:

<table>
<thead>
<tr>
<th>Mean Age</th>
<th>Level 1</th>
<th>%</th>
<th>Level 2</th>
<th>%</th>
<th>Level 3</th>
<th>%</th>
<th>Level 4</th>
<th>%</th>
<th>Level 5</th>
<th>%</th>
<th>Total</th>
<th>Mean level</th>
</tr>
</thead>
</table>

Table 27 - Vehicle age and mean body corrosion level for treated vehicles.
<table>
<thead>
<tr>
<th>Mean Age</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
<th>Total</th>
<th>Mean level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1~3</td>
<td>7</td>
<td>100%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td>4~6</td>
<td>17</td>
<td>94%</td>
<td>1</td>
<td>6%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>8</td>
<td>7~9</td>
<td>13</td>
<td>72%</td>
<td>5</td>
<td>28%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>5</td>
<td>38%</td>
<td>3</td>
<td>23%</td>
<td>2</td>
<td>15%</td>
</tr>
<tr>
<td>14</td>
<td>5</td>
<td>2</td>
<td>22%</td>
<td>4</td>
<td>44%</td>
<td>1</td>
<td>22%</td>
</tr>
<tr>
<td>16</td>
<td>&gt;15</td>
<td>2</td>
<td>67%</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>33%</td>
</tr>
<tr>
<td>Sum</td>
<td>46</td>
<td>13</td>
<td>4</td>
<td>0</td>
<td>0%</td>
<td>5</td>
<td>13%</td>
</tr>
</tbody>
</table>

Table 28 - Vehicle age and mean body corrosion level for untreated vehicles.

Plotting the mean body panel corrosion levels against the mean vehicle age sets results in more meaningful results as shown in Figure 47. Because there are only three treated vehicles older than 15 years old, they will not be included into this test. The corrosion levels more aptly fit an exponential fit, and the trend is much more clearly seen. This is also in keeping with Categories 1 through 5 now used for classification in which the amount of corrosion increases with each step. While it could be that the accuracy has been reduced because of the aggregation of data, it appears that the reduction of data complexity better reflects how corrosion can be more practically observed, measured, and interpreted.
2. Underbody parts corrosion level

Only surface rust is considered in this analysis. For the untreated vehicles, the low salvage vehicles are not included into the test. Five levels are assigned to each vehicle age set. New scales are set for the underbody parts instead of using the same scale for body panels because:

a) Only surface rust is measured for the underbody parts because most of them are bare metal. Although during the sampling, some vehicles were found to have a layer of rubber paint on some of their underbody parts, in order to provide the uniformity for all underbody parts, only the observable rust is measured.

b) Underbody body parts start to rust at a very early age, and tend to have much more rust than the body panels.
c) Most of the underbody parts are significantly thicker than body panels. As a result, rust on them does not have as much significant impacts as the rust on body panels. Furthermore, they are usually not accessible for observation during daily operation.

The classification for Levels 1 through 5 for underbody parts are shown in Table 29:

<table>
<thead>
<tr>
<th>Level</th>
<th>Corrosion Index (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1 - 1000</td>
</tr>
<tr>
<td>3</td>
<td>1001-2000</td>
</tr>
<tr>
<td>4</td>
<td>2001-3000</td>
</tr>
<tr>
<td>5</td>
<td>&gt;3000</td>
</tr>
</tbody>
</table>

The mean corrosion level is again calculated by Equation 1. The result for treated and untreated vehicle underbody parts can be shown in Table 30 and Table 31 respectively:

<table>
<thead>
<tr>
<th>Mean age</th>
<th>AGE</th>
<th>lev 1 %</th>
<th>lev 2 %</th>
<th>lev 3 %</th>
<th>lev 4 %</th>
<th>lev 5 %</th>
<th>% Total</th>
<th>Mean level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1~3</td>
<td>4</td>
<td>57%</td>
<td>3</td>
<td>43%</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td>4~6</td>
<td>2</td>
<td>11%</td>
<td>16</td>
<td>89%</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>8</td>
<td>7~9</td>
<td>0</td>
<td>0%</td>
<td>15</td>
<td>88%</td>
<td>2</td>
<td>12%</td>
<td>0%</td>
</tr>
<tr>
<td>11</td>
<td>10~12</td>
<td>1</td>
<td>8%</td>
<td>10</td>
<td>77%</td>
<td>2</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>14</td>
<td>13~15</td>
<td>0</td>
<td>0%</td>
<td>5</td>
<td>56%</td>
<td>2</td>
<td>22%</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>&gt;15</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>67%</td>
<td>1</td>
<td>33%</td>
<td>0%</td>
</tr>
<tr>
<td>Sum</td>
<td>7</td>
<td>51</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 31 - Vehicle age and mean underbody corrosion level for untreated vehicles.

<table>
<thead>
<tr>
<th>Mean age</th>
<th>AGE</th>
<th>level 1</th>
<th>%</th>
<th>level 2</th>
<th>%</th>
<th>level 3</th>
<th>%</th>
<th>level 4</th>
<th>%</th>
<th>level 5</th>
<th>%</th>
<th>TOTA L</th>
<th>%</th>
<th>MEAN LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1~3</td>
<td>13</td>
<td>52%</td>
<td>12</td>
<td>48%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>25</td>
<td>0%</td>
<td>1.48</td>
</tr>
<tr>
<td>5</td>
<td>4~6</td>
<td>2</td>
<td>13%</td>
<td>13</td>
<td>87%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>15</td>
<td>0%</td>
<td>1.867</td>
</tr>
<tr>
<td>8</td>
<td>7~9</td>
<td>2</td>
<td>6%</td>
<td>19</td>
<td>56%</td>
<td>9</td>
<td>26%</td>
<td>2</td>
<td>6%</td>
<td>2</td>
<td>6%</td>
<td>34</td>
<td>2%</td>
<td>2.5</td>
</tr>
<tr>
<td>11</td>
<td>10~1</td>
<td>2</td>
<td>0%</td>
<td>9</td>
<td>53%</td>
<td>6</td>
<td>35%</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>12%</td>
<td>17</td>
<td>12%</td>
<td>2.706</td>
</tr>
<tr>
<td>14</td>
<td>13~1</td>
<td>5</td>
<td>0%</td>
<td>4</td>
<td>67%</td>
<td>1</td>
<td>17%</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>17%</td>
<td>6</td>
<td>17%</td>
<td>2.667</td>
</tr>
<tr>
<td>16</td>
<td>&gt;15</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>14%</td>
<td>2</td>
<td>29%</td>
<td>2</td>
<td>29%</td>
<td>2</td>
<td>29%</td>
<td>7</td>
<td>29%</td>
<td>3.714</td>
</tr>
<tr>
<td>Sum</td>
<td>17</td>
<td>58</td>
<td>18%</td>
<td>18</td>
<td>29%</td>
<td>16</td>
<td>29%</td>
<td>16</td>
<td>29%</td>
<td>16</td>
<td>29%</td>
<td>104</td>
<td>17%</td>
<td>3.714</td>
</tr>
</tbody>
</table>

Plotting the mean body panel corrosion levels against the mean vehicle age sets results in more meaningful results as shown in Figure 47. Because there are only three treated vehicles older than 15 years old, they will not be included into this test.

Plotting the mean underbody parts corrosion levels against the mean vehicle age sets again results in more meaningful results as shown in Figure 48. Treated vehicles older than 15 years are not included in the test given that only three such vehicles were sampled. As with the revised body panel regression analysis, there is significantly improved fit although there is less difference between treated and untreated underbody parts. This result is still consistent with the prior Corrosion Index analysis.
3. Corrosion level test summary

Compared to the prior Corrosion Index analysis which focused on using detailed assessments of observable corrosion, this analysis aggregated the data to develop a broader classification of corrosion that potentially better represents the relationship between the level of corrosion and vehicle age. Based on Figures 47 and 48, treated vehicles exhibit markedly less corrosion on both body panels and underbody parts. Compared with the underbody parts, body panels exhibit more corrosion differences between the treated and untreated vehicles. These results can be used to show the differences between treated and untreated vehicles, and produces a more understandable and potentially more applicable method for modeling the development of corrosion in categorical terms. The tradeoff is that it may no longer be possible to model and then later predict the amount of corrosion precisely. However, this level of detail may be unwarranted regardless.
There are some notable issues with this analysis. In particular, so long as the vehicle had been treated before sampling, it is considered as a treated is vehicle, regardless of the actual number of treatments it has had. And of course, changes to the category scales could alter the outcome of the analyses.
5. Conclusions and Recommendations

The objective of this research was to develop a metric for assessing the extent of corrosion on a vehicle that will be readily usable by automotive technicians and sufficiently robust to serve as a benchmark for comparing the corrosion condition of different vehicles. Such a metric can also be used to evaluate the effectiveness of corrosion prevention and treatment applications. While there are several systems currently for classifying corrosion, there is no industry-wide accepted metric or approach that is based on empirical data that potentially describes the relationship between key vehicle variables (e.g., vehicle age) and the degree of corrosion expected. This research has succeeded in developing such a description and furthermore, has also evaluated the potential benefits offered by corrosion prevention measures.

In this research, it was affirmed that measuring the corrosion area on vehicles through visual observation and recording (digital images) is the most effective means to do so based on practical limitations. The accuracy for the measurement may be influenced by the shape of vehicle parts and the angle of view when observing and taking photographs, but all sampling were taken in similar set ups under controlled conditions in either Krown’s treatment facilities or vehicle recycler’s plants. Approximately 200 vehicles were sampled, including treated and untreated vehicles, with treated being defined as any vehicle that was visually observed or stated to have had prior treatments, regardless of the treatment frequency. Photographs were only taken for selected exterior body panels and underbody; other vehicle components such as electronic parts and inside panels are not sampled since they are not accessible for observation.
AnalyzingDigitalImages (ADI) software was used to measure the amount of corrosion using its spatial analysis tool. By using a ruler with known length as a reference, all pictures were analyzed by this tool manually. Other features of the software such as Enhance Colors tool and Mask tool can be used to isolate the color in a certain range, and so this software has the potential to automatically detect the corrosion area detection if there is uniform brightness and a background that is distinguishable from the corrosion area. Alternatively, sophisticated coding could account for less ideal conditions. In the end, only the spatial analysis tool is used to manually measure the corrosion area for this research.

Finally, a survey was developed and distributed to vehicle owners to obtain the vehicle history, general driving conditions, and if and how the vehicle was stored or cleaned. The information collected proved helpful, but did not establish definitive descriptions between vehicle corrosion and such additional variables. A more focused survey could help in future research to refine the conclusions reached.

All corrosion measurements for observed vehicle parts and the survey information were entered into an Excel spreadsheet and analyzed using the statistical functions within Excel. For the vehicle body panels, only vehicles older than 6 years exhibited corrosion. On the other hand, corrosion was observed on underbody parts even for new vehicles. In the first portion of the assessment, the regression analysis reveals that when comparing the Corrosion Index (comprised of measured corrosion areas (cm\(^2\)) against vehicle age for vehicles between 6 to 15 years of age:

- For body panels, treatment of the vehicle can potentially reduce the area by 92% every year, compared to an untreated vehicle.
• For underbody panels, treatment of the vehicle can potentially reduce the corrosion area by 43% every year from the first year.

• The output statistics by the linear regression analysis shows although the R Square values are relatively low both for body panels and underbody parts, the significant F value and residual plots indicate a strong relationship between vehicle age and amount of corrosion. However, the output equation may not sufficiently model corrosion due to the low R Square values.

• The treated vehicles selected in this research are defined as any vehicle that had been treated through observation or owner claim, but the frequency of treatment or other factors that may have impacts on vehicle corrosion are not considered.

Vehicle mileage and the number of corrosion treatments were then included in the analysis. Based on the regression analysis results, the mileage of a vehicle has a very limited impact on vehicle corrosion, and the low R Square value, high significant F and P–value indicates that the relationship modeled is not reliable. With respect to the effect of the number of corrosion treatments on the regression results, the significant F value is within the acceptable range, but the p–value is larger than the limit. The questionable accuracy of the data from survey may have contributed to an inaccurate regression test, as well as the broad definition for what constitutes corrosion treatment. More vehicles with well known treatment history should be sampled for further analysis.

As an alternative for measuring corrosion, a five level Corrosion Index was developed to classify corrosion, with Level 1 indicating no or very low corrosion, and Level 5 indicating high levels of corrosion. These were based on the measured corrosion areas already obtained, and separate scales were developed for body panels and for underbody
parts. The vehicle corrosion data were aggregated into three year intervals by vehicle age. A mean level of corrosion is calculated for each vehicle age set, and curves of mean vehicle level corrosion versus vehicle age sets were plotted for both body panel and underbody parts for both treated and untreated vehicles. This alternative analysis revealed that treated vehicles exhibit less corrosion than untreated vehicles, and the differences between treated and untreated vehicles of the body panels is more significant than the underbody parts. More importantly, the model regression improved significantly. This improved fit could be because the initial analysis using the measured areas of rust might have been at too fine of a resolution given the subjectivity of visually measuring corrosion, and the range of potential variables at play. The coarser level-of-corrosion measure is consistent with other corrosion evaluation approaches, and in this research, was developed from extensive measurements and field observations.

**Recommendations for Future Research**

1. **Collecting more vehicle data.**

   200 vehicles were sufficient samples for a general assessment. However, if a filter is added to examine specific targeted samples - for example, assessing the corrosion for each model year - the amount of data within that filter may not satisfy the assessment. By expanding the data set, it better represents more variations in vehicle operations. New data can be added to the existing assessments to test if it will lead to a significant change of the result, such as the fitted linear equations, R-Square values and Significant F values. For the corrosion levels assessment test, by adding more data, the average corrosion level for each individual vehicle model year can
be achieved. Lastly, the developed equations and process can be validated and refined with a greater data set.

2. **Collecting treated vehicles with definitive vehicle treatment history.**

   This activity would require the cooperation of Krown. Krown’s treatment record can be used to confirm the accuracy of vehicle treatment history provided by customers. Krown could select past, loyal customers who have definitive treatment history to participate the research. Rerunning the *vehicle age and number of treatment test* with new vehicle treatment history information would help determine if treatment frequency does have a significant impact on vehicle corrosion.

3. **Selecting key underbody parts that may represent underbody corrosion conditions.**

   Unlike the body panels, the vehicle undercarriage tends to be more complicated and without a hoist, be more difficult to examine easily and effectively. The structure and shape of each part may vary dramatically between different vehicle models. Also, parts like cross members and control arms are thick pieces of metal, and tend to rust at a very early stage. However, rust on these parts may not be a pressing concern of the vehicle owners. If a single underbody part can represent the overall underbody condition as a proxy, it would simplify the underbody analysis. Conversely, another part, such as the brake line or fuel line can be examined more closely. Such lines represent significant safety concerns if they fail due to corrosion. While only 12 vehicles were found to have rust on their brake/fuel lines, more data are needed to determine if such a scenario poses a risk.

4. **Automating the scanning and analysis.**
Automating the analysis could speed up the overall process of classifying the corrosion on a vehicle. Sophisticated coding would be needed to program the computer to accomplish such a job. For example, color may be a valuable aspect for rust detection, but it is affected by the illumination and background color. How to eliminate these influences is key to achieving automatic rust detection and measurement, as well as speeding up the entire analysis. As a stretch goal, this research could be refined into an application software for a portable device that would allow a technician to quickly photograph, assess the area of corrosion, and then provide feedback to the technician and vehicle owner what level of corrosion that is present, and how corrosion treatment could present or arrest further corrosion.
REFERENCES


APPENDICES
Appendix A - Corrosion evaluation questionnaire

Corrosion Evaluation Questionnaire and Study Participation

In our continuing effort to better understand the effects of corrosion on vehicles and how it can be assessed, Krown Corporation and the University of Windsor, Faculty of Engineering, are documenting, measuring, and evaluating corrosion on vehicles at various known treatment locations. This research is being undertaken by Dehua Hu as part of his Master of Applied Science in Environmental Engineering degree. We would like your permission and participation to: [1] examine your vehicle for corrosion. Your vehicle will not be damaged or altered. We will be documenting and recording the extent and type of corrosion on your vehicle through photography, videography, and/or surface measurements. [2] Complete the following survey.

This information will not be shared with any third party company and is for this research study only. We would greatly appreciate your cooperation in participating in this study. However, should you decline to participate, your vehicle will not be examined. Should you elect to withdraw your survey response and the vehicle information collected within 15 days of participating, or if you have any concerns or comments, please contact the University of Windsor’s Dr. Edwin Tam, PhD, P.Eng., ettam@uwindsor.ca; 509-228-6000, x1300.

This research activity and survey has been approved by the University of Windsor Research Ethics Board.

**************************** DETACH QUESTIONNAIRE HERE ****************************

Name: ____________________________ City: ____________________________ Signature: ____________________________ Date: ____________________________

I give Krown/University of Windsor permission to examine my vehicle identified below, and to use the information collected in this survey.

Vehicle Year: ___________ Vehicle Make: ___________ Vehicle Model: ___________

Mileage/Odometer: _______ km

1. How long have you owned this vehicle? ___________ Years / Months (Please circle applicable)

2. On average, how many kilometres per year do you drive? ___________ km per year.

3. Do you drive this vehicle all year round? Yes ☐ No ☐ Mainly in fair weather ☐ Mainly in poor weather ☐

4. What percentage (%) of total time do you estimate the vehicle is driven in the following situations?

<table>
<thead>
<tr>
<th>Urban/city:</th>
<th>Rural/country:</th>
<th>Offroad:</th>
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5. In your estimation, is your vehicle exposed to any of the following scenarios, and if so, on what basis?

During the winter, to road salt: All the time ☐ Frequently ☐ Moderately ☐ Infrequently ☐ Never ☐
During the winter, to road sand: All the time ☐ Frequently ☐ Moderately ☐ Infrequently ☐ Never ☐
Unpaved/gravel roads: All the time ☐ Frequently ☐ Moderately ☐ Infrequently ☐ Never ☐
Water environments (e.g., marina): All the time ☐ Frequently ☐ Moderately ☐ Infrequently ☐ Never ☐
Other (please specify): All the time ☐ Frequently ☐ Moderately ☐ Infrequently ☐ Never ☐

6. When this vehicle is not being driven, do you keep it in a garage? Yes ☐ No ☐ 4 or more times/week ☐ 3 or less times/week ☐

7. How often is this vehicle washed? Weekly ☐ Monthly ☐ 6 to 11 times per year ☐ 1 to 5 times per year ☐ Never ☐

8. To your knowledge, has this vehicle ever been protected against corrosion in the past? Yes ☐ No ☐ Unknown ☐

9. If you answered yes to the previous question, complete the following.

How many times was this vehicle protected against corrosion before today?

1 time ☐ 4-5 times ☐ Unknown ☐
2-3 times ☐ 6+ times ☐

Which company protected this vehicle from corrosion in previous years? Please check all that apply.

Krown ☐ Zabart ☐ Unknown ☐
Rust Check ☐ Dealership ☐

10. In your opinion, regardless of any corrosion treatment or prevention, do you think your vehicle has unusual or unexpected corrosion issues (for example, rust in unexpected areas despite driving it only in fair weather conditions)? Yes ☐ No ☐

11. If you have any other comments regarding your vehicle and corrosion, please write them on the back of this sheet.

Thank you for your participation in this questionnaire. If you would like to be entered into our monthly prize draw for a $100 gift card for gas, please provide us with a valid email address where we can reach you if your submission is selected. This information is optional and is recorded to select a winning selection each month as our way of saying thank you to you, our participants.

Email address: ____________________________
Please enter any additional comments in this space.
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