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Intersection of corrosion prevention strategy and practice

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Abstract

Purpose – The purpose of this paper is to objectively evaluate the cost benefit of applying corrosion prevention coatings throughout a mid-life logistics fleet supporting the Canadian Army.
Design/methodology/approach – A database of maintenance records for an Army logistics vehicle throughout a four-year study period is mined. Statistical analysis (primarily ANOVA) accounting for the frequency of treatment and geographic region is executed.
Findings – Statistical analysis indicates counter-intuitive results. Vehicles that are most frequently treated to prevent corrosion incur the highest maintenance costs. Consultation with operational units suggests that a strategic approach to corrosion prevention is largely absent. Instead, vehicles are treated on an *ad hoc* basis, or – equivalently – on an as available basis.
Practical implications – Among high tempo organizations, vehicles most readily available to maintenance support are those that are in the greatest state of disrepair. Vehicles that are in better condition are preferred by operators for daily operations and are not available. Consequently, the vehicles that are subject to preventative maintenance most often are those near their end-of-life or are in disrepair and therefore gain little through further investments in corrosion prevention initiatives.
Originality/value – Clearly, having corrosion prevention compounds applied to a fleet on an *ad hoc* basis suffers from the natural bias occurring among operators to retain vehicles in best condition for operational purposes. Corrosion prevention requires a more strategic approach including disciplined maintenance operations in order to provide dividends on a fleet-wide basis.

Keywords Maintenance strategies, Maintenance policy, Maintainability, Maintenance planning, Maintenance analytics

Paper type Case study

1. Introduction

At the strategic level, National Association of Corrosion Engineers International produced a study of International Measures of Prevention, Application and Economics of Corrosion Technologies, in 2016, which investigated how applying various methods of corrosion technologies could lead to cost saving and increased productivity. This study emphasized the need for corrosion management strategies and the “buy-in” that is required from top to bottom of an organization, in both civilian and military sectors. One particular case study of the US Department of Defence corrosion management processes revealed that the Integrated Product and Process Development approach is effective at addressing the problem of corrosion from a strategic perspective by integrating corrosion management into the conceptual design phase of a project (Koch *et al.*, 2016).

Corrosion can also be handled through high-level strategy and policy. As an example, the US Congress passed an act in 2003, which mandated that all Department of Defence purchases valued over $10,000 must have a strategic corrosion control plan. This act was implemented after a study on corrosion costs, done in 2002, by the US Federal Highway Administration,

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revealed the substantial cost of corrosion (Defence Research and Development, 2006). In contrast, the Government of Canada does not have a comparable program mandating the Department of National Defence to have a corrosion management program.

In the Canadian Army, support vehicles routinely succumb to corrosion effects after protective coatings and paints deteriorate, often prematurely ending the service life of the vehicle. Upon vehicle failure, fleet-wide inspections are sometimes undertaken, leading to major structural repairs throughout a swath of the fleet. Corrosion is especially problematic in the Canadian Army due to environmentally hostile surroundings, an aged vehicle fleet and rigorous vehicle use. The Army has engaged a private contractor to treat vehicle fleets in hopes of reducing the maintenance burden and prolong the vehicle life. This paper reviews the impacts of vehicle treatment on downstream maintenance requirements to assess whether the benefit has provided dividends worthy of the initial investment in treatment. The analysis illustrates that, notwithstanding a strategic-level investment in corrosion prevention at the national level, the impacts of unit-level practice are profound and, in this case, to the detriment of the national strategy.

1.1 Background

Several studies have demonstrated the value of preventive maintenance strategies. Given theoretical models of failure probability, Erdem *et al.* (2014) examine the positive influence on system life or mean time to failure. Khalil *et al.* (2009) identify a minimum-cost solution to balancing preventive and corrective maintenance procedures by leveraging industrial case studies. Empirical maintenance data from a bus fleet are used by Zhou *et al.* (2015) demonstrating the positive impact of preventive maintenance while also accounting for environmental variables. The importance of a robust strategy including preventive maintenance is demonstrated by Salonen and Deleryd (2011) through its impact on firm financial performance within the manufacturing sector. Stenström *et al.* (2016) demonstrate, also using empirical evidence – from a rail network, that sections of track having the lowest total cost are the same as those having the highest proportion of preventive maintenance (accounting for upwards of 30 percent of the sections' total maintenance costs). The general virtues of preventive maintenance in reducing the total maintenance costs are reiterated by Velmurugan and Dhingra (2015). These studies would suggest that preventive maintenance through corrosion prevention spray coatings yield a net reduction in total maintenance costs.

Prior to undertaking any empirical study leveraging data held by a Computerized Maintenance Management System, Hodkiewicz and Ho (2016) recommend using a rules-based approach to data cleaning rather than using an automated machine-learning approach. This is due to the large proportion of unique records resulting from the customized nature of most work orders. Not only is this data useful in analyzing historical performance but also in establishing long-term maintenance plans, policies and strategies (Answell *et al.*, 2003). More specifically, Zhou *et al.* (2015) propose a balanced scorecard to support strategic and operational-level maintenance decisions.

Kumar *et al.* (2013) caution against using a multitude of potential indicators on a scorecard, "Scorecards with large numbers of indicators that do not define the users or responsible personnel actually hinder the work for which they are developed". Parida *et al.* (2015) agree, suggesting that numerous measures on a scorecard serve only to confuse – rather than inform – managers. The authors go further to suggest that maintenance data often yields very limited knowledge growth due to poorly developed strategic plans, thereby limiting the potential of maintenance data to influence strategic-level decisions. A case study demonstrating this within the textile industry is aptly described by Maletič *et al.* (2014) where a relationship between maintenance policies and firm profitability is established.

Clearly, the successful implementation of a scorecard depends largely on the quality and suitability of the key performance indicators (KPIs) contained therein. A survey of manufacturing sector managers undertaken by Muchiri *et al.* (2010) suggests that few organizations leverage maintenance KPIs in making strategic decisions and, perhaps unsurprisingly, few are satisfied with the KPIs used by their organizations. It is critical that the relationships between maintenance functions and firm performance be characterized by the chosen metrics by including the various manners in which maintenance can impede or support organizational processes (Muchiri *et al.*, 2011). Notwithstanding the broad failure of maintenance KPIs and absent of the development of high-performing maintenance strategies, it is widely understood that maintenance policies have a profound impact on firm performance. Velmurugan and Dhingra (2015) articulate the issue well, "performance measures must be aligned with the operational measures which are derived from overall strategic goals of the organization". Otherwise, their value in strategic decision- making remains dubious.

Corrosion prevention figures prominently within many preventive maintenance strategies. Assuming the spray coating behaves as expected and impedes the corrosion of metal surfaces, a vehicle could be assumed to experience lower corrective maintenance. This is the premise of Klassen and Roberge (2008) who identify an aircraft wash interval to minimize costs. It should be noted that their study includes a Canadian Air Force Base – the same climate included in the present work. Corrosion is estimated to cost the US economy $276bn annually (Koch *et al.*, 2002). It is estimated the corrosion costs the US Department of Defence $22.4bn annually (Koch, 2012). The US Army alone has estimated the cost of corrosion control measures to be approximately $2bn per year for ground vehicles alone (Defence Research and Development Canada, 2006). Although the cost of corrosion is not known in the Canadian Army, it is relatively certain that the cost is substantial.

Recognizing the significant and damaging effects of corrosion, the Army's Quality Engineering Test Establishing conducted a study on corrosion inhibiting compounds in order to support the Army's decision to initiate a corrosion prevention program in 2000. The study provided a critical review of seven different Corrosion Prevention Compounds (CPCs) of which the current contractor's compound proved superior to its competitors in a salt fog test. The current standing offer with the contractor identifies nine different vehicle and trailer types within the "B Fleet" (logistics vehicles) for corrosion prevention treatment and is valued at CDN$6.78m (Public Works and Government Services Canada, 2015).

The office of the Director General Land Equipment Program Management (2016) recognizes that "corrosion is the leading cause of vehicle attrition, affecting the B fleet". This realization drives the decision to treat selected vehicle and trailers on an annual basis. Compliance with this schedule is "mandated" although not enforced. Tracking and reporting is possible using the Defence Resource Management Information System (DRMIS) – a custom enterprise resource planning software used throughout the Canadian Armed Forces. Maintainers are notified, through DRMIS, when a vehicle is due for its annual treatment, and when the treatment takes place, the data are entered into DRMIS, satisfying the notification. However, as was discovered through the course of this study, the above strategy represents an idealistic perspective. Due to the operational commitments of a unit, vehicles routinely miss scheduled treatment.

Once vehicles reach the contractor for treatment, the vehicles are washed. Access holes are then drilled into the body to enable spaying in the enclosed sections of the vehicles. As mandated by the contract, the CPC product is sprayed on the underbody, fenders and cargo box, seams, weld points, hinges, structural members, battery terminals and other areas which can be subject to corrosion. Parts, such as the radiator, belts, high temperature areas, cab interior, brake friction areas and wheel assemblies are avoided to ensure that no product is wasted and the safety of the vehicle is not compromised. Additionally, the contract mandates that CPC must not be sprayed over flaking undercoating, loose rust or mud and water buildup. Upon completion of the treatment process, the vehicles are left to drip off excess fluid, the drilled holes are capped off, a sticker, indicating the date of the treatment is affixed to the inside of the driver door and the vehicle is driven back to its origin.

1.2 Study scope

This study will only consider the Light Support Vehicle Wheeled (LSVW) fleet as a case study, shown in Plate 1. The Canadian Army procured a fleet of 2,800 LSVW vehicles in 1993 in order to augment its logistical capabilities (Poulter, 2012). The LSVW vehicles were produced mainly as cargo variants; however, some vehicles were produced as command post, maintenance and special equipment variants. Data mining DRMIS yields the LSVW fleet information illustrated in Table I. In this table, Level I refers to vehicles treated only in 2013, Level II vehicles were treated in both 2013 and 2014, Level III vehicles were treated in 2013, 2014, 2015 and finally, Level IV vehicles were treated annually within the four-year study period (2013–2016).

Despite the introduction of the corrosion control program in 2000 for the LSVW, corrosion is currently present and continues to degrade the life of these vehicles. This indicates the need for a thorough review of the corrosion management strategy.

2. Statistical analysis

Initial statistical analysis indicated that the frequency of treatment varied throughout the fleet. Some vehicles were treated only once or twice through the study period while others were treated annually or even more frequently. This served as the first indication that the national corrosion prevention strategy was not being adhered to as, initially conceived. Therefore, treatment frequency was included in the analysis to account for potential performance differences as a function of treatment frequency. Given the environmental differences throughout Canada's geography, this was also thought to potentially contribute to the deterioration rate and therefore, any statistical model should account for this factor as well.

Plate 1. The Light Support Vehicle Wheeled (LSVW)

			Treatment frequency				
Region	Mixed	Level 0	Level 1	Level 2	Level 3	Level 4	Total
AB	392	11	98	28	4	49	582
BC	33	0	0	0	0	4	37
MN and SK	120	2	62	13	2	3	202
Maritimes	202	13	44	14	10	16	299
ON	478	9	102	22	7	26	644
QC	254	11	42	12	30	41	390
Total	1,479	46	348	89	53	139	2,154

Table I. LSVW fleet by region and frequency of corrosion prevention treatments

Before establishing these factors as influential in predicting maintenance costs, each factor within the model is tested to confirm its significance as an explanatory variable. This is undertaken in the following sections. Although mileage might also be expected to influence the maintenance costs of a vehicle, statistical analysis (not presented here) indicated this was not the case. Conceivably, this is due to the advanced age of the LSVW fleet and extensive maintenance throughout the fleet prior to the study period.

2.1 By region

Canada's geography is very diverse and, as illustrated in Figure 1, Army bases are dispersed throughout the nation. Each Canadian Forces Base (CFB) supporting the Army is noted in Figure 1. In addition Land Force Central Area Training Centre in Meaford, Ontario; and Land Force Atlantic Area Training Centre (LFAATC) in Aldershot, Nova Scotia – both significant users of the LSVW – are also indicated in Figure 1. The dispersion of vehicles throughout the country is illustrated in Table I.

Vehicle susceptibility to corrosion is expected to be most extreme in humid and saline maritime regions or where road salts are used extensively throughout the winter period. This corresponds primarily to the Maritime Provinces and to a lesser degree the vicinity of the St Lawrence Seaway through Quebec and Great Lakes regions of Ontario. Conversely, arid Prairie Provinces (Alberta, Manitoba and Saskatchewan) receive markedly less precipitation throughout the year – and consequently use less road salt, and are considerably distant from water bodies having high degrees of salinity. The annual maintenance costs of the LSVW fleet, by region, are illustrated in Figure 2.

A statistical test of regional influence on annualized maintenance costs may be framed using the following set of hypotheses:

$$H_0\colon \mu_i = \mu_j \; \forall i,\; j \,|\, i \neq j$$

$$H_a\colon \exists\, i,j \,|\, \mu_i \neq \mu_j,$$

where μ_i represents the mean annual maintenance cost for the vehicle fleet in region i. The results of the corresponding ANOVA tests are provided in Table II. The results indicate, rather conclusively, that region does play a role in predicting the maintenance costs of an LSVW.

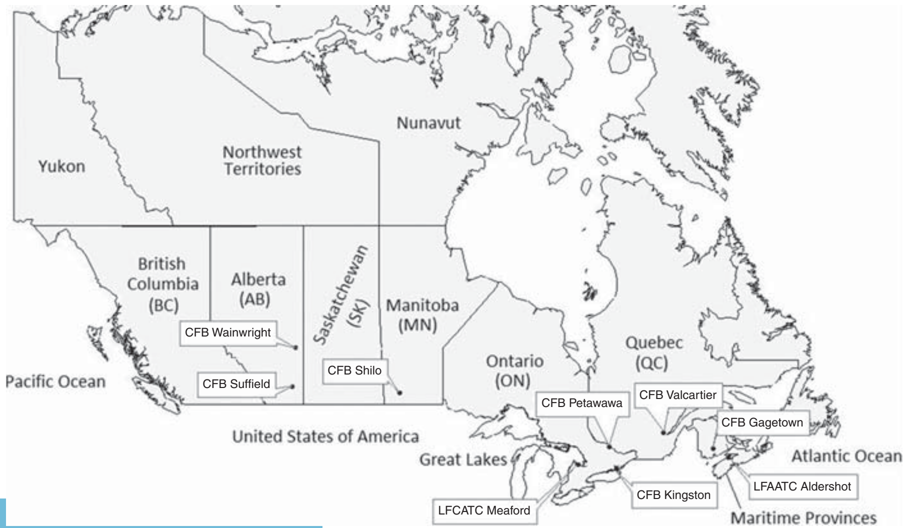

Figure 1.
A map of Canada showing locations of Army bases having significant volumes of LSVWs

A *post hoc* test must be used to indicate where, among the six regions, significant differences exist. Due to the unbalanced nature of the statistical experiment (see Table I), a Sheffé test is used. The findings demonstrate that vehicles in Quebec (QC) and the Maritime Provinces incur similar maintenance costs but this group of vehicles is significantly different from the maintenance demands of vehicles in all other regions.

2.2 By treatment frequency

Naturally, one might also hypothesize that more frequent treatment of corrosion prevention coatings would have a positive impact on the maintenance burden by retarding vehicle deterioration and consequently reducing the annual maintenance burden. Yet, the opposite is observed in the data records – as illustrated in Figure 3.

Whether the differences illustrated in Figure 3 are statistically significant or not can be evaluated using the following hypotheses:

$$H_0 \colon \mu_m = \mu_n \; \forall m, \;\; n \,|\, m \neq n$$

$$H_a \colon \exists \; m, n \,|\, \mu_m \neq \mu_n$$

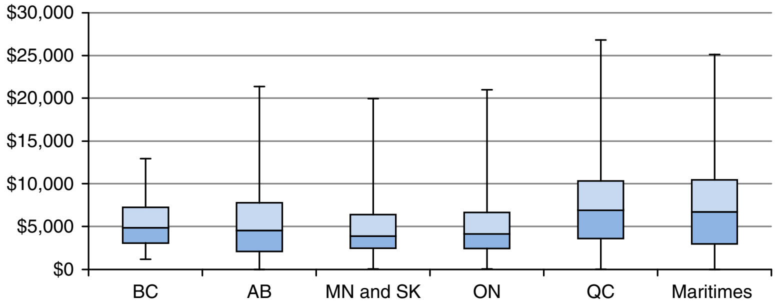

Figure 2. Boxplots of mean annual maintenance costs for the LSVW fleet, by region

Table II. ANOVA results testing regional differences among maintenance costs of LSVWs pooled by region

Source of variation	SS	df	MS	*F*	*p*-value	*F* crit.
Between groups	2.36E+09	5	4.72E+08	24.22481	8.9E−24	2.218332
Within groups	4.12E+10	2,113	19,493,852			
Total	4.36E+10	2,118				

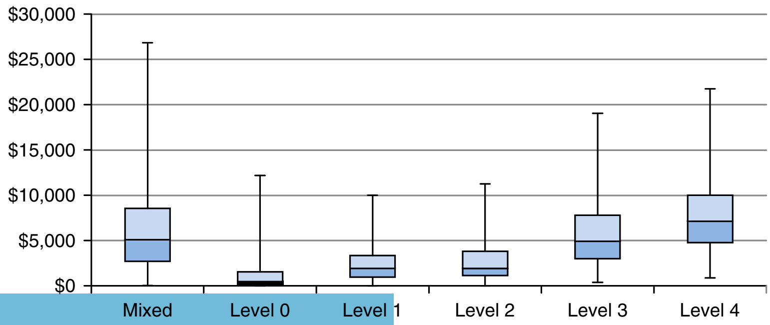

Figure 3. Boxplots of mean annual maintenance costs of the LSVW by frequency of treatment with corrosion prevention coatings

where μ_m represents the mean annual maintenance cost for the vehicle fleet treated with frequency level *m*.

Vehicles that were removed from service at some point during the study period were eliminated from the data set to reduce potential bias from underestimating the annual maintenance costs for those vehicles. Otherwise, a vehicle that was treated only in 2013 and soon after removed from service would appear to have low maintenance costs as only a single year of maintenance would be amortized over the course of the four-year study period. Dates of vehicle disposal were not available and therefore, filtering the data to include only vehicles having maintenance records throughout all four years of study remains the only way to ensure the data set remains representative.

The ensuing ANOVA results are provided in Table III. These results strongly suggest that a significant difference does indeed exist (as evidenced by the extremely low *p*-value). Again, precisely where among the six factor levels those differences exist are the subject of a *post hoc* Scheffé test. This test demonstrates that the differences lies between Levels 0, 1, 2 (as a common group) and Levels 3, 4, and Mixed (as a second common group).

2.3 Interaction

The final possibility is that some interaction exists between treatment level and region. Select regions (specifically BC, AB, and MN and SK) were excluded from this test as the sample sizes were too small corresponding to some treatment levels. Among the remaining three regions (ON, QC and the Maritime Provinces), the number of observations varies (i.e. unbalanced). A balanced design is possible but is limited to the smallest set of observations in any specific Block, in this case, 7. Bootstrapping is used to generate a balanced data set having seven observations in each block prior to executing multi-factor ANOVA. The following table illustrates the ANOVA results on a bootstrapped data set (Table IV).

Naturally, the risk of a bootstrapped sample is whether the sample is bias or truly representative. For this reason, an automated procedure was written in Visual Basic for Applications, embedded into Excel that executed ANOVA on an independently generated bootstrapped sample 5,000 times. Treatment level was found to be significant in all of the 5,000 trials. The region was found to be significant in 2,318 of the 5,000 trials and the interaction terms were significant in only 1,416 of the trials. The larger data set including the western half of the country convincingly demonstrated that region plays a role in predicting annualized maintenance costs, as described in Section 2.1 – consequently, the results here are somewhat moot. Finally, the results for the interaction terms are somewhat ambiguous.

Table III. ANOVA results testing difference in CPC treatment frequency among pooled samples

Source of variation	SS	df	MS	*F*	*p*-value	*F* crit.
Between groups	5.97E+09	5	1.19E+09	73.83022	1.97E−71	2.218332
Within groups	3.41E+10	2,113	16,161,513			
Total	4.01E+10	2,118				

Table IV. ANOVA results testing the interaction of region and treatment frequency

Source of variation	SS	df	MS	*F*	*p*-value	*F* crit.
Region	36,225,069.9	2	18,112,535	1.493967	0.229082151	3.080387
Level	1,030,420,443	5	2.06E+08	16.99833	2.27179E−12	2.298431
Interaction	177,742,203	10	17,774,220	1.466062	0.162039875	1.919467
Within	1,309,368,565	108	12,123,783			
Total		125				

3. In practice

Concurrent with the statistical analysis of maintenance records, focus group studies were undertaken with maintenance staff at two Service Battalion (CFB Petawawa). These maintainers supported the notion that badly corroded vehicles require more maintenance and receive more attention from the maintainers in the form of repairs, inspections and yearly corrosion prevention treatments. Why deteriorated vehicles were subject to more frequent preventative maintenance that vehicles in better condition became readily apparent – simply because deteriorated vehicles spent more time in the hands of the maintainers, i.e. these vehicles were readily available to maintenance facilities to allocate for corrosion prevention treatments. Vehicles that were in better condition were favored by operational unites and consequently, spent less time awaiting maintenance and less time accessible by maintenance staff. This is supported by the statistical evidence described in this paper.

Central to this study is the quality of data contained within DRMIS. Throughout the study, it was also noted that maintenance operations are described by an "open" text field – meaning that maintainers are unrestricted in how they describe the work done during any maintenance request. This naturally presents numerous challenges in data analysis from not only the many ways in which a maintainer might describe a corrosion prevention procedure but also spelling errors, abbreviations, etc. Rather than using an open text field, drop-down lists are preferred within ERPs to standardize these descriptions thereby better accommodating analysis.

4. Conclusions and recommendations

The results of this study serve as a potent reminder that an *ad hoc* preventative maintenance strategy risks falling victim to bias representing near – term operational priorities – at the expense of the long-term health of a vehicle fleet. Rather than permitting operational units to unilaterally manage fleet maintenance, a strategic approach and disciplined preventative maintenance measures are required to leverage investments made in that regard. Maintenance managers must be empowered to acquire vehicles from operational units to undertake routine preventative maintenance procedures – notwithstanding the fact that the officer commanding of a maintenance depot is typically outranked by the commanding officer of an operational unit. Otherwise, leveraging contracted preventative maintenance resources is unlikely to yield dividends to the longer term health of a vehicle fleet but will indeed incur a financial cost. Maintenance requirements are also influenced by environmental factors, and, consequently, the allocation of maintenance resources throughout a geographically diverse nation, such as Canada, should be sensitive to this.

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