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OPTIMIZING EQUIPMENT MAINTENANCE VIA AUTOMATED MONITORING

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AIM

1. The aim of this service paper is to examine the use of integral monitoring systems in the Canadian Army's fleets of vehicles as a tool for predicting the lifespan of various components on the vehicle. This paper will explore the theory of these systems, options for adding after-market monitoring systems to fleets, examine the cost versus benefit of adding these systems, and conclude with a recommendation for fleet based analysis the Canadian Army should take in order to decide whether to implement the system in that fleet.

INTRODUCTION

2. Preventative maintenance (PM) is considered an essential element in ensuring a vehicle fleet maximizes its serviceability rate while minimizing overall maintenance time and reducing vehicle failures while conducting operational tasks.[1] For a military force, the costs of having vehicles fail during operations are far more significant than budgetary considerations. Critical equipment failures can cause mission failure, lead to loss of life or seriously impact the outcome of an operation. Additionally, the corrective maintenance required to repair a failed component or sub-system in a vehicle will typically require more resources than the PM done to prematurely correct a predicted fault. For example, replacing engine oil is a relatively minor maintenance activity, which is necessary to maintain the lifespan of an engine. Failure to change the oil can eventually result in excessive wear on the engine and ultimately could cause the engine to overheat, seizing pistons within the engine block and requiring the replacement of the entire engine. If the vehicle was engaged in a

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[1] Sreeja Rajesh and Benjamin Francis, "A Study of Condition Based Maintenance for Land Force Vehicles" (Edinburgh, South Australia: Land Operations Division, Defense Science and Technology Organisation, 2012), 4–5.

combat operation, the immobilized vehicle would be vulnerable to attack or unable to conduct its own attack.

3. PM on land-based vehicles has typically relied upon a combination of a time-based construct whereby at routine intervals specific inspections are performed along with preventative component replacements.[2] This time-based approach aims at identifying issues and replacing components before failures occurs. The approach is based on predicting the failure of a component or sub-system in a vehicle based on historical usage rather than actual indications that a failure is imminent. Time based inspections rely on the experience of the technician to identify failure indicators. If maintenance schedules are adhered to, this can be an effective way to prevent vehicle failures from occurring and minimize costs. Downsides to this approach are that it requires active intervention to determine if a failure may occur and inspections can be delayed dependent on the workload of a maintenance organization. Aircraft are more vulnerable to catastrophic failure when a component fails as compared to land-based vehicles. For example, the inflight failure of an engine could lead to the airframe crashing into a mountain and complete loss of crew. In a ground vehicle, the operators can bring the vehicle to a safe stop and focus on remedying the issue. As a result, the air environment has used a conditions-based monitoring (CBM) system rather than a time-based monitoring solution for maintenance.[3] Health and Usage Monitoring Systems (HUMS) are an on-board diagnostic systems that have been employed in aircrafts for decades. These systems can both measure the overall usage of a vehicle as well as perform diagnostics to find

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[2] Rajesh and Francis, iii.
[3] *Ibid.*

components that have failed or are failing in the system prior to catastrophic failure.[4] Advances over the last decade in artificial intelligence (AI) and machine learning (ML) have increased the potential accuracy of the HUMS. The increasing complexity of land-based vehicles requires that changes to their maintenance strategy are re-evaluated as well.[5]

DISCUSSION

4. HUMS is an example of a CBM system that can range in capability from limited to networked and sophisticated whereby the majority of mission-critical components are monitored and linked to networked sustainment systems.[6] The benefits of the CBM system over the time-based PM system are most significant on operations. Platforms can be relocated to rear areas for maintenance and replacement components can be ordered on a just-in-time basis, reducing the required holdings of theatre stocks of spare parts.[7] HUMS, which are geared to CBM focus on the health of the vehicle rather than the usage. The HUMS works by leveraging the historical information gained from usage and diagnostics of the vehicle platform in order to enable prediction of failures.[8] Usage-based prognostics are focused on considering the historical, present and future use of the system or component and then predicting what future life remains.[9] These systems will be able to more accurately predict the impending failure of a component as opposed to a simple time used based system. A simple example of this is the oil life indicator available on newer vehicles. The systems

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[4] E. Rabeno and M. Bounds, "Condition Based Maintenance of Military Ground Vehicles," in *2009 IEEE Aerospace Conference*, 2009, 1, https://doi.org/10.1109/AERO.2009.4839683; R. Rhoads and L. M. Keeney, "Embedded Diagnostics and Prognostics Synchronization for Army Transformation," in *2004 IEEE Aerospace Conference Proceedings (IEEE Cat. No.04TH8720)*, vol. 6, 2004, 3, https://doi.org/10.1109/AERO.2004.1368191.
[5] Rajesh and Francis, "A Study of Condition Based Maintenance for Land Force Vehicles," 1.
[6] Rhoads and Keeney, "Embedded Diagnostics," 6.
[7] *Ibid*.
[8] Rabeno an Bounds, "Condition Based Maintenance," 1.
[9] Tomas Turo, Vlastimil Neumann, and Zdenek Krobot, "Health and Usage Monitoring System Assessment" (International Conference on Military Technologies (ICMT) 2019, Brno, Czech Republic, 2019), 1.

approximate the useful remaining lifespan of the oil based on factors such as distance driven, oil temperature and engine RPM. This enables more useful life to be extracted from the oil rather than simply changing the oil based on distance driven. A CBM would take this further and not only utilize the historical usage of the oil but measure the current condition of the oil in order to predict the useful life remaining. A CBM oil life system may measure the viscosity of the oil compared to its temperature, the rate that the oil temperature changes, and detect impurities within the oil thus predicting with high accuracy, the remaining useful life of the oil.

5. HUMS can be added as an aftermarket item to land vehicles, tying together the existing data generated by the various vehicle sub-systems, adding additional sensors and using modern algorithms to predict component failure with high accuracy. Acerta is an Automotive Intelligence company that uses artificial Intelligence (AI), and Machine Learning (ML) to correlate data captured from vehicle sub-systems with component failures. The company was hired by a "leading OEM" to develop predictive vehicle maintenance solutions using a software they had developed. The company was able to train their AI algorithm using ML techniques based on normal data generated solely from normal vehicle operation. The company claimed that they could then predict an impending engine failure approximately 400 km before it actually occurred.[10] Commercial products designed for industrial use may not be sufficient for a military environment requiring adaptation. Military grade connectors must employ electromagnetic interference (EMI) shielding to control the EMI both to and from military communications gear in the vehicles. The HUMS must also be

[10] "On-Road Failure Prediction," Acerta, n.d., https://acerta.ai/case-studies/on-road-failure-prediction/.

robust enough to handle environmental factors such as temperature, vibration and varying power levels that will be experienced on a military vehicle.[11]

6. Prognostic algorithms for prediction of impending failures rely on historical information of vehicle performance as well as maintenance records. The historical data allows for a steady state history to be created which shows which sensor readings are expected during expected usage of a vehicle fleet, and also allows for correlation of sensor readings with failures.[12] Normal vehicle usage is subjective and highly dependant on the operating environment. Baseline testing needs to be conducted in a wide range of operating conditions, varying temperatures, terrains, and speeds in order to simulate the conditions expected over a vehicle's lifetime.[13] Baseline testing can also include induced failures in order to replicate the sensor readings expected in the "How To" program, and identify the faults that we want to predict.

7. CBM Systems are not a panacea to solve all of our maintenance problems and poorly implemented solutions may cause more problems than they solve. CBM is dependant on integrated sensors and a smart hub capable of collating and analyzing data on the fly. They are not plug and play systems and their selection, integration and usage may require significant expenditure as well as well as personnel resources to implement the systems and develop processes to make use of the data.[14] The ability to aggregate the data from a fleet

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[11] Rabeno an Bounds, "Condition Based Maintenance," 2.
[12] *Ibid*, 4.
[13] *Ibid*, 5.
[14] S. Das et al., "An Open Architecture for Enabling CBM/PHM Capabilities in Ground Vehicles," in *2012 IEEE Conference on Prognostics and Health Management*, 2012, 1, https://doi.org/10.1109/ICPHM.2012.6299529.

into a central point is another significant challenge requiring established data standards, networks and secure processes.[15] Modern systems from companies like Acerta or nCode are aimed at OEMs looking to solve design issues based on user profiles and geographic employment.[16] Systems that come integral with some platforms such as the Canadian Army's TAPV HUMS may produce limited usage data and fault recording rather than providing useful life estimation or component failure prediction.[17]

8. HUMS must also be capable of accurately predicting failures and not unnecessarily limit the operation of the platform. A system prone to false positives will lead to operators ignoring the system or unnecessarily impact operational effectiveness and increase maintenance costs as unnecessary repair actions are carried out.[18] Warnings should be unambiguous and not require the operator to second-guess the system. The Sea King fleet of maritime helicopters had a chip indicator for its main gearbox that indicated that a potentially catastrophic situation had occurred which required the pilot to perform an emergency landing. Anecdotal reports from pilots indicated that at times the system would be triggered by metallic shavings of inconsequential size as the sensor wasn't able to discriminate based on size. Overly risk-adverse warnings are necessary on a helicopter as a failure could be catastrophic for the platform. On land vehicles, they could become nuisance warnings reducing the systems overall effectiveness.

[15] *Ibid*.
[16] "Big Data Analytics in Engineering Applications" (HBM Prenscia, 2019); "On-Road Failure Prediction."
[17] LCol (ret) David Beyea, Health and Usage Monitoring System (HUMS) on the Tactical Armoured Patrol Vehicle (TAPV), Phone Call, February 3, 2021.
[18] Das et al., "An Open Architecture," 1.

CONCLUSION

9. Conditions based maintenance systems have the potential to improve the efficiency and effectiveness of land equipment maintenance within the Canadian Army. The implementation of prognostic Health and Usage Monitoring systems will enable maintainers to focus their efforts replacing failing components based on accurate predictions. This will decrease maintenance costs while improving operational effectiveness of our ground fleets of vehicles. Implementation of HUMS will require a coordinated effort involving the analysis and design of open-systems, integration with future networks, creation and adoption of new business practices and a cultural shift for operators, maintainers and commanders. The Canadian Army should adopt these systems by first performing a proof-of-concept using the WLAV fleet of vehicles and integrating the system with the incoming MISL software. Once the system is fully deployed, it should be implemented across the army's other fleets of land vehicles.

RECOMMENDATIONS

10. DGLEPM should begin using HUMS in order to capitalize on improved efficiencies, increased operational effectiveness and as a means of mitigating the maintenance challenges of increasingly complex vehicle systems. The implementation should begin with a proof-of-concept (POC) project of a modern HUMS in order to set the stage for future systems. This test case should mirror efforts that the US Army undertook with their Stryker fleet by capitalizing on the ongoing work that the DAVPM 2 Systems Engineering Management team is currently conducting on data capture.[19] The POC demonstration should be developed to address technical challenges associated with these systems, develop a framework for

[19] Rhoads and Keeney, "Embedded Diagnostics," 2; LCol Jay Van Dyk, HUMS on the LAV6, Phone Call, 20 Jan 21.

assessing implementation on future fleets and address institutional changes required to modernize the maintenance processes for ground vehicles.

11. The POC system should be selected and designed based on the requirements for the WLAV fleet while ensuring that it can be implemented on other Canadian Army Ground Fleets. Initial analysis should identify the critical sub-systems of interest in the fleet that are to be monitored. This analysis should be based on historical failure data for the fleet and expert knowledge from operators, technicians and manufacturers. Sensors can then be identified, and will either already be integral to the system or need to be procured and installed. The selection of a HUMS processor and software algorithms should ensure that they sufficiently abstract the analytics and algorithms from the system so that it is extendible to other fleets.[20]

12. The POC should seek to develop or adopt open data standards that can be utilized across the CAF maintenance and logistics fields as well as by vendors. This will ensure that information can be moved efficiently between all stakeholders that are involved in the sustainment of land-based vehicle fleets.[21] The development of data standards should be nested within the development of the upcoming Modernization and Integration of Sustainment and Logistics (MISL) project that will replace DRMIS. The POC should also align with the VCDS' direction with respect to a data strategy for the CAF. Data created should be platform agnostic and not tied to any particular vendor. We should retain the freedom to use our in-house expertise to analyze our data or contract it out to industry. Future

[20] Das et al., "An Open Architecture," 2.
[21] Rhoads and Keeney, "Embedded Diagnostics," 5.

technology trends, driven by machine learning and artificial intelligence, are dependant on large datasets or big data. Big data will be invaluable to our defence scientists and engineers though it is impossible to predict exactly how the data will be used yet, thus we must protect our freedom of action in this field.

13. The POC should also lead to the development of new business practices. If current maintenance and logistics processes are unchanged, it will eliminate the value of integrating a HUMS on a vehicle fleet. The institution must aim to institute cultural change in how it values, collects and analyzes data. The conduct of these new business practices will eventually need to be applied across all of our land systems rather than bespoke processes, applied on a fleet-by-fleet basis. Standardized processes will lead to efficiency, improved effectiveness and enable the integration of new team members. For example, the same process used to order a replacement component in garrison should be mirrored in a theatre of operations. Our networks must therefore not be tied to geography but be portable and take advantage of space and satellite technology. Secure data transfer protocols must be implemented to network our fleets to MISL in order to minimize operator and maintainer action required. We must avoid the errors of DRMIS, where excessive manual data entry coupled with an abysmal user interface led to slow adoption of the system and questionable data quality generation. We also must be capable of operating at the speed of our computing power and not add unnecessary bottlenecks in business practices. The value of the HUMS is in the automated notifications that it provides to operators, commanders and the logistics systems. Human-in-the-loop processes should only be implemented where it is required due to ethical or practical reasons. For example, the HUMS on several vehicles of a deployed

fleet may indicate that their engines will likely fail within 2-4 weeks of future usage. This shouldn’t automate the ordering of several power packs, but should automatically notify vehicle operators, maintenance personnel, the commander’s staff, and EMT staff and in turn enable them to make appropriate decisions on sustainment and operations.

BIBLIOGRAPHY

"Big Data Analytics in Engineering Applications." HBM Prenscia, 2019.

E. Rabeno and M. Bounds. "Condition Based Maintenance of Military Ground Vehicles." In *2009 IEEE Aerospace Conference*, 1–6, 2009. https://doi.org/10.1109/AERO.2009.4839683.

LCol Jay Van Dyk. HUMS on the LAV6. Phone Call, 20 Jan 21.

LCol (ret) David Beyea. Health and Usage Monitoring System (HUMS) on the Tactical Armoured Patrol Vehicle (TAPV). Phone Call, February 3, 2021.

Acerta. "On-Road Failure Prediction," n.d. https://acerta.ai/case-studies/on-road-failure-prediction/.

R. Rhoads and L. M. Keeney. "Embedded Diagnostics and Prognostics Synchronization for Army Transformation." In *2004 IEEE Aerospace Conference Proceedings (IEEE Cat. No.04TH8720)*, 6:3733-3741 Vol.6, 2004. https://doi.org/10.1109/AERO.2004.1368191.

Rajesh, Sreeja, and Benjamin Francis. "A Study of Condition Based Maintenance for Land Force Vehicles." Edinburgh, South Australia: Land Operations Division, Defense Science and Technology Organisation, 2012.

S. Das, R. Hall, A. Patel, S. McNamara, and J. Todd. "An Open Architecture for Enabling CBM/PHM Capabilities in Ground Vehicles." In *2012 IEEE Conference on Prognostics and Health Management*, 1–8, 2012. https://doi.org/10.1109/ICPHM.2012.6299529.

Tomas Turo, Vlastimil Neumann, and Zdenek Krobot. "Health and Usage Monitoring System Assessment." Brno, Czech Republic, 2019.