Institution: Bournemouth University

Unit of Assessment: 12

Title of case study: Preserving historically important battle tanks and developing best practice in the heritage vehicle museum sector

Period when the underpinning research was undertaken: 2009 – 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Zulfiqar Khan	Professor of Design, Engineering and Computing	2005-current
Dr Adil Saeed	Lecturer in Engineering	2018-current
Dr Hammad Nazir	Postdoctoral Researcher	2013-2018

Period when the claimed impact occurred: September 2013 – 31 December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Military vehicles are important heritage assets and the Tank Museum in Dorset houses one of the world's most significant collections. It attracts 200,000 visitors and generates approximately GBP2,000,000 each year – contributing to England's GBP31,000,000,000 heritage sector.

The museum applied Bournemouth University's (BU) mechanical corrosion and wear research to increase vehicle lifespan. The research data secured GBP2,500,000 to fund a vehicle conservation centre, established optimal preservation and operating conditions, and defined best practice for museums worldwide.

The research has been pivotal in bringing cultural enrichment and economic value via the museum, as well as mass media – the collaboration between BU and the museum to restore the Tiger 131 led to its inclusion in the 2014 Brad Pitt film *Fury*.

2. Underpinning research (indicative maximum 500 words)

Large engineering structures require regular, expensive inspections to avoid mechanical failure. Existing methods to detect damage cannot accurately predict safe operating windows because the structure's specific properties and its environment make it difficult to construct reliable models.

BU's Condition Monitoring, Analysis and Prediction model (CMAP) closes the gap between the model and the real system. It develops reliable estimates of the performance and vulnerability of structural systems, by using improved simulations based on experimental observations and data [R1, R2, R3].

Research began in collaboration with the Tank Museum in 2009. The aim was to implement a framework that could monitor and, ultimately, slow down structural deterioration. Initial experimental investigations analysed tanks' corrosion and wear failures. This data was supported by meteorological data from NASA's Corrosion Technology Lab, which used its satellites to monitor the local atmospheric conditions. This resulted in publication of a joint paper

with NASA [R4]. BAE Systems also provided in-kind support with access to its labs, testing, and knowledge-share.

The experimental research provided valuable data to develop precision-based mathematical models (in collaboration with the Defence Science & Technology Laboratory) to predict and prognose failures in military vehicles. The first prototype was commissioned by the Tank Museum and installed on two historically important battle tanks – the Valentine Mark II and the Mark III. Compared to other structural health monitoring methods, the device allowed faster structural analysis with greater reliability – saving money, labour costs, and time.

This work led to a patented novel sensor design and the development of a framework of remote sensing techniques. Since 2009, a suite of numerical models has been developed, [R3, R5], as well as published algorithms and methodologies that enable other researchers to reproduce the methods. These were used to predict failures such as corrosion, deterioration, cracking, chipping, coating and significant wear and erosion [R6, R7]. Combined with novel maintenance-scheduling algorithms, this enabled identification of the best time to perform maintenance, in terms of safety and cost.

The models were later extended to include nanocomposite materials, and to allow for sea-water conditions in order to address failures in marine applications. Alongside these predictive models, a complete maintenance-scheduling model was developed to encompass both predictions and maintenance. This programme was integrated with novel corrosion, strain, temperature, and humidity microsensors, along with GSM-based (Global System for Mobile) remote sensing methods, to develop a complete CMAP device for remote monitoring, prediction, and maintenance of large mobile structures.

Since 2016, CMAP has also enabled the monitoring and prediction of the effects of refrigerants as lubricants for interacting moving parts, as well as the effects of deep-zone residual stresses within nanomaterials. The latest version is a holistic condition-monitoring and maintenance-scheduling unit, with a range of applications from heritage to defence, naval, automotive, and aerospace [R7].

The research has received grants totalling approximately GBP180,000, from a range of funders, including the Tank Museum, BAE Systems, the Defence Science and Technology Laboratory, Schaeffler, Analatom and Pakistan's National University of Science and Technology.

3. References to the research (indicative maximum of six references)

R1-6 were all subject to rigorous peer review.

R1: Nazir, M.H., Khan, Z.A. and Saeed, A. (2017), "A Novel Non-Destructive Sensing Technology for On-Site Corrosion Failure Evaluation of Coatings," *IEEE Access*, vol. 6, pp.1042-1054. DOI: 10.1109/ACCESS.2017.2777532

R2: Nazir, M. H., Khan, Z. A., Saeed, A. and Stokes, K. (2016), "Modelling the Effect of Residual and Diffusion-Induced Stresses on Corrosion at the Interface of Coating and Substrate," *Corrosion,* vol. 72, pp.500-517. DOI: 10.5006/1804

R3: Nazir, M. H., Khan, Z. A., Saeed, A. and Stokes, K. (2016), "A predictive model for life assessment of automotive exhaust mufflers subject to internal corrosion failure due to exhaust gas condensation," *Engineering Failure Analysis,* vol. 63, pp.43-60. DOI: 10.1016/j.engfailanal.2016.02.014

R4: Khan, Z. A., Saeed, A. and Montgomery, E. (2013), 'Corrosion Damage Analysis and Material Characterization of Sherman and Centaur – the Historic Military Tanks', *Materials Performance and Characterization,* 2 (1), pp1-16.

https://www.researchgate.net/publication/236960217_Corrosion_Damage_Analysis_and_Material_Characterization_of_Sherman_and_Centaur_-_The_Historic_Military_Tanks

R5: Nazir, M. H., Khan, Z. A. and Stokes, K. (2015), "Optimisation of interface roughness and coating thickness to maximise coating–substrate adhesion: a failure prediction and reliability assessment modelling," *Journal of Adhesion Science and Technology,* vol. 29, pp.1415-1445. DOI: 10.1080/01694243.2015.1026870

R6: Nazir, M. H., Khan, Z. A. and Saeed, A. (2018), "Experimental analysis and modelling of c-crack propagation in silicon nitride ball bearing element under rolling contact fatigue," *Tribology International,* vol. 126, pp.386-401. DOI: 10.1016/j.triboint.2018.04.030

R7: Nazir, M. H., Saeed, A. and Khan, Z. A. (2018), "Electrochemical corrosion failure analysis of large complex engineering structures by using micro-LPR sensors," *Sensors and Actuators B: Chemical,* vol. 268, pp. 232-244. DOI: 10.1016/j.snb.2018.02.191

4. Details of the impact (indicative maximum 750 words)

In stable times, the heritage sector brings a wealth of social and economic richness to our society. It supports jobs, skills, tourism, economic prosperity, and wellbeing, according to Museums & Heritage Advisor (2020). Heritage experiences enrich our lives, helping shape who we are as individuals and as a community (Royal Society for the encouragement of Arts, Manufactures and Commerce, 2020) and – as the Heritage Fund states - museums tell stories of our cultural heritage, giving a sense of place and identity.

Research carried out by Historic England shows that in 2019 in England alone the sector generated GBP31,000,000,000 in gross value- added and 464,000 jobs (Heritage & the Economy, 2019). While heritage organisations have been hit hard by the Covid-19 pandemic, it is widely acknowledged that the sector is an important vehicle to support economic recovery, which is one of the reasons the UK government has committed GBP1,570,000,000 to cultural, art and heritage institutions (£1.57 billion investment to protect Britain's world-class cultural, arts and heritage institutions.)

The Tank Museum

The Tank Museum houses one of the most important collections of its kind in the world. It has the largest collection of tanks and third largest collection of armoured vehicles: almost 300 from 26 countries, including the world's first ever tank. This draws 200,000 visitors annually from around the world, generating approximately GBP2,000,000 annual turnover (Charity Commission Register of Charities, 2019, p. 25).

BU's research has enabled the Tank Museum to preserve these artefacts, so they continue to deliver cultural and economic benefits for many years to come. It was critical in establishing the Vehicle Conservation Centre, opened in September 2013, which – without BU's data – would "probably not have been built" [E1]. The data was presented in a Heritage Lottery Fund bid, securing GBP2,500,000 to build the 3,700m² facility, which now houses most of the tanks. "As well as protecting against environmental damage, [the centre] provides an opportunity for the ongoing volunteer-led conservation and preservation programme aimed at diminishing corrosion failures in a non-invasive and cost-effective way." [E1]

Preserving historic military vehicles

Applying BU's novel condition-monitoring method – now patented [E2] – has significantly increased the lifespan of the vehicles. Upon learning that operating vehicles led to a tenfold increase in rates of degradation, the museum reduced the number of vehicles in operation from 50 in 2012 to 35 in 2019 – and reduced running time by 30% [E1].

"Without the evidence we gained from the work with BU, we would not have known that we were over-using the vehicles. If we had continued, we would have severely, and possibly irreparably,

damaged them, losing examples of real cultural and historical significance." [E1]

Some important examples of preserved heritage assets include reduced structural failure in the Tiger 1 tank engine, and the Valentine Mark II and Mark III tanks, employed in World War II. The Tiger 131 is one of only seven Tiger 1 tanks surviving worldwide and – as a result of the BU-Tank Museum collaboration – is currently the only one restored to running order.

Cultural enrichment

Following the Tiger 131's improved performance, it was featured in the 2014 Brad Pitt film *Fury,* which grossed USD211,000,000 worldwide (Nash Information Services, 2021). The film was widely praised for its realistic, unglamourised depiction of World War II. ITV's *Meridian Tonight* news programme, which has an average audience reach of 193,360, covered the story on 22 October 2014 [E3].

Figure 1: Tiger Tank 131 in action at the Tank Museum 2012 © Copyright Peter Trimming (licensed for reuse under this Creative Commons Licence.)

Increased public interest prompted the museum to hold special 'Tiger Days', which have taken place on a biannual basis since 2013. Thousands of spectators come to see the Tiger 131 and other iconic tanks [E4], enhancing their understanding of armoured warfare. A YouTube video [E5] from the event currently has 4,800,000 views (as of 16 December 2020), with comments illustrating the value of bringing military heritage to life [E5]:

- "Seeing this Tiger in person is really a shock… If anyone seeing this video gets a chance to visit Bovington… it's worth the trip, these old tanks are very impressive."
- "Thank you to the museum and everyone involved for restoration on this piece of history."

Commercial benefits

The increased visitor numbers have brought commercial benefits to the museum, contributing to the annual turnover of more than GBP2,000,000. The remote-sensing technology is helping to reduce inspection and maintenance costs [E1].

Global knowledge share

The Tank Museum's successful vehicle preservation prompted a sector steering committee to be established. Members from 25 heritage vehicle museums in Europe and North America now meet annually to share best practice for preservation and operating conditions. "With the input

from BU, this has helped professionalise the sector, moving from a 'trial-and-error' approach to data-driven decision making" [E1].

In conclusion, these heritage assets bring significant cultural, historical, and economic value. "Now, we are able to think about how we can use the vehicles for the World War II centenaries in 2039 and 2045 because of our improved conservation." [E1] Benefits are reaped directly through museum visits and events and indirectly through film. Where society has been deprived of heritage experiences for much of 2020, the Tank Museum, and organisations like it, play an important role in the economic recovery from the Covid-19 pandemic.

5. Sources to corroborate the impact (indicative maximum of 10 references)

E1: Tank Museum, (2020). Letter, November.

E2: Bournemouth University Higher Education Corporation, (2019). *Corrosion Measurement Device*. GB2568702.

E3: ITV News. (2014). *Brad Pitt on his Dorset co-star; a World War Two tank | ITV News*. [online] Available at: https://www.itv.com/news/westcountry/2014-10-22/brad-pitt-on-his-dorset-co-star-a-world-war-two-tank [Accessed 28 January 2021].

E4: Cartlidge, S., (2019). PICTURES: Thousands flock for Tiger Day 12 at the Tank Museum. *Bournemouth Echo*, [online] Available at: https://bit.ly/2Lu0ArE [Accessed 13 January 2021].

E5: YouTube. (2014). *Tiger Tank 131 Sounding Great In The Mud And Rain*. [online] Available at: https://www.youtube.com/watch?v=dXP0QhbBDC8 [Accessed 13 January 2021].