Impact case study (REF3)

Institution: Middlesex University	
Unit of Assessment: UoA 11	

Title of case study: **Digital Twin Specification, Design and Application**

The research reported in [R6] addressed the issue of inherent high dimensionality of measured structure data in raw time series sensory signals for SHM using different deep learning techniques to assess the reliability as well as the trade-off between accuracy and of different deep learning models, assisting the relevant stakeholders to make informed decision in maintenance and operation of bridges.

The work in [R7] makes use of physical features embedded in raw data and an elaborated hybrid deep learning model, featuring two algorithms—convolutional neural network (CNN) and long-short term memory (LSTM). Building on advances in algorithms for health monitoring uniting machine learning, structural mechanics and signal processing Nguyen developed a novel hybrid approach that delivered highly accurate results in detecting damage and its severity even for multiple damage scenarios. The resulting method has been a practical end-to-end data-driven framework used for defining a Digital Twin for automatically monitoring the operational state of structures. This framework is reported in the *IEEE Transactions on Automation Science and Engineering* [R7]. These works were integrated in a Cloud based Digital Twin platform (http://3.140.199.12/) that was critical to the repair plan development of the Th ng Long bridge in Hanoi, Vietnam by the Ministry of Transport resulting in savings of £1.5 million on repair costs and benefits of £7.6 million in economy [S12].

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

[R1] Clark, T., Barn, B.S. and Oussena, S., 2011, February. LEAP: a precise lightweight framework for enterprise architecture. In Proceedings of the 4th India Software Engineering Conference (pp. 85-94). ACM. (doi:10.1145/1953355.1953366)

[R2] Clark, T., Kulkarni, V., Barn, B., France, R., Frank, U. and Turk, D., 2014, January. Towards the model driven organization. In 2014 47th Hawaii International Conference on System Sciences (pp. 4817-4826). IEEE. (doi:10.1109/HICSS.2014.591)

[R3] Kulkarni, V., Barat, S., Clark, T. and Barn, B., 2015, September. Toward overcoming accidental complexity in organisational decision-making. In 2015 ACM/IEEE 18th International Conference on Model Driven Engineering Languages and Systems (MODELS) (pp. 368-377). IEEE. (doi: 10.1109/MODELS.2015.7338268)

[R4] Clark, T., Kulkarni, V., Barat, S. and Barn, B., 2017, June. ESL: an actor-based platform for developing emergent behaviour organisation simulations. In International Conference on Practical Applications of Agents and Multi-Agent Systems (pp. 311-315). Springer, Cham. (doi: https://doi.org/10.1007/978-3-319-59930-4_27)

[R5] Barat, S., Kulkarni, V., Clark, T., Barn, B. (2019) An Actor Based Simulation Driven Did

Impact case study (REF3)

TCS Research is a pioneer in core technology infrastructure to support Model Driven Engineering (MDE) and has delivered several large business critical software systems using this infrastructure for almost 20 years. They recognized that MDE could be applied to address all aspects of an enterprise such as vision, mission, goal, strategies and operational processes. These research questions were congruent with the LEAP research conducted by Barn and Clark [R1] and it is this that shaped the collaboration. The [S1] letter from the Executive Vice President and Chief Technology Officer of TCS confirms the basis of the collaboration, the ongoing work and the benefit of contributions of Barn and Clark to TCS a…