X STRATHCLYDE BUSINESS SCHOOL

Digital Twins in Healthcare

Human Digital Twin for Enhancing Occupational Health and Safety

Workshop in the Technology & Innovation Centre

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Agenda

1. Difference between a digital twin and a model
2. Digital twins and simulation modelling
3. Validation of digital twins
4. Digital twins in health care
5. Example: digital twins in cancer diagnosis and treatment
6. Example: digital twins in intraoperative surgery
7. Brief conclusion

Difference between digital twin and a model

- Important parts in the digital twin of an object:
  i. A model of the object
  ii. An evolving set of data relating to the object
  iii. A means of dynamically updating or adjusting the model in accordance with the data
- The model used in a digital twin is not necessarily data-driven, unlike the model updating process that should be data-driven
- A digital twin without a physical twin is a model!
- Digital twins are most useful when an object is changing over time
- Reference: Wright and Davidson, *Adv. Model. and Simul. in Eng. Sci. (2020) 7:13*

Digital twins and simulation modelling (a)

- *"… the core element of a digital twin is the simulation"*

Table 1: Final taxonomy of Digital Twins in simulative applications.

Dimension	Characteristics	
Progress in Time	Continuous (16%)	Discrete (67%)
Probabilities	Deterministic (28%)	Stochastic (72%)
Model Character	Static (17%)	Dynamic (83%)
Usage of a Process Model	Yes (41%)	No (59%)
Model Scope	Single Entity (32%)	System (68%)
Verification and Validation	Conducted (62%)	Not Conducted (38%)
Time Horizon	Terminating (63%)	Non-Terminating (20%)

- Reference: Van Der Valk et al., Digital twins in simulative applications: a taxonomy. *Proceedings of the 2020 Winter Simulation Conference*

Digital twins and simulation modelling (b)

- Important differences between digital twins and conventional simulation:
  i. Simulation uses historical data. Digital twins need real-time data from the physical object
  ii. Simulation typically has a fixed set of parameters. Digital twins can use real-time data to update the parameters
  iii. Using historical data, simulation may not accurately represent the current state of the system under investigation. Using real-time data, digital twins are more responsive to the dynamics of system behaviour
- Reference: Hua et al., Validation of digital twins: challenges and opportunities. *Proceedings of the 2022 Winter Simulation Conference*

Validation of digital twins

- *"The usefulness of a digital twin largely rests on its robustness, captured by the digital twin's ability to closely mirror the current state of its physical counterpart. This is largely reflected by the quality of the underlying simulation model, typically assessed through a validation process."*

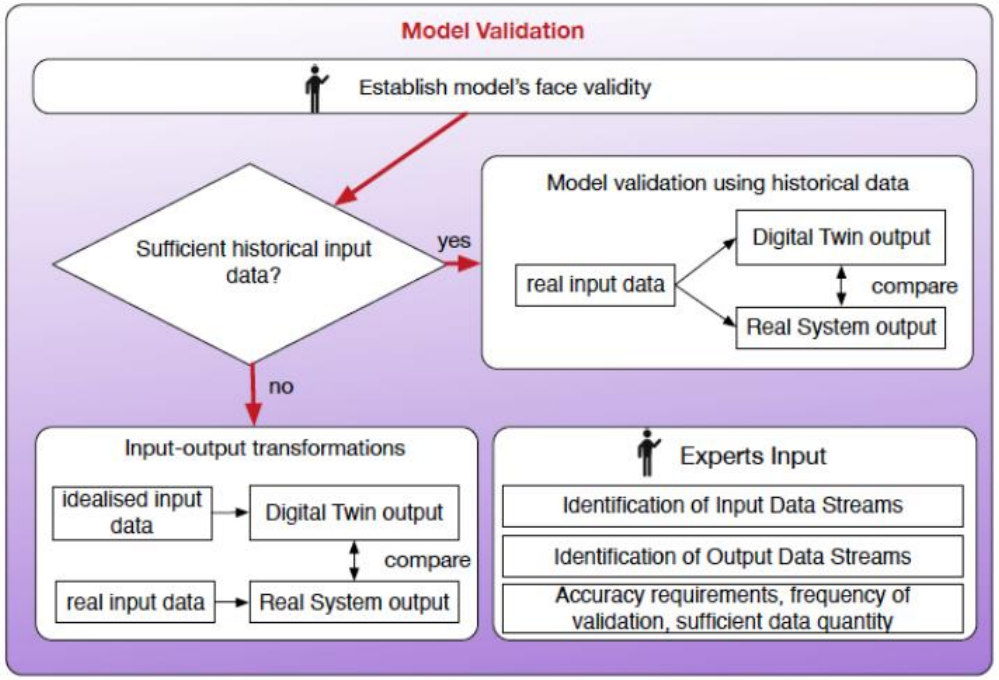

Figure 2: Validation component as part of the framework for data-driven digital twins.

- Reference: Hua et al., Validation of digital twins: challenges and opportunities. *Proceedings of the 2022 Winter Simulation Conference*

Digital twins in healthcare (a)

- *"A digital twin in healthcare (or medicine) is a computational model of the system to be twinned (in our case all or part of a human patient) that is connected to the system in a bidirectional fashion over time, periodically recalibrated with patient data, and provides patient predictions over time."*
- Digital twins are potentially vital for personalised medicine (curative or preventative)
- A key question:

  "… given that biological heterogeneity leads to a wide range of responses to illness and treatments, can computational models, together with the right kinds of data, help the medical team intervene with more effective and better-timed interventions, tailored to an individual patient and resulting in better outcomes?"

- Reference: Laubenbacher et al., Digital twins in medicine. *Nature Computational Science,* 4.3 (2024): 184-191

Digital twins in healthcare (b)

- Challenges for implementing digital twins:
  - Can we apply appropriate modelling technologies?
  - Do we have sufficient medical understanding of biological determinants of health and disease?
  - Are there (national and international) accepted standards for regulatory approval and data sharing?

- Reference: Laubenbacher et al., Digital twins in medicine. *Nature Computational Science,* 4.3 (2024): 184-191

Digital twins in healthcare (c)

- Challenges relating to medical understanding:
  i. For many medical applications, the relevant underlying biology is partially or completely unknown
  ii. The needed data are often not available or are difficult to collect
  iii. The required computational models can be multi-scale, hybrid and stochastic (e.g., agent-based models). However, the theoretical and computational infrastructure to analyse and control such models is not yet developed to a degree that is needed for medical applications.

- Reference: Laubenbacher et al., Digital twins in medicine. *Nature Computational Science,* 4.3 (2024): 184-191

Digital twins in cancer diagnosis and treatment

- *"Cancer digital twins incorporate data about the patient's pre-existing health, cancer type, size and location of tumours, their metabolic activity, and molecular markers expressed by the tumour. The model will then learn and adapt to the evolving patient data (for example, timing and type of chemotherapy, effect on tumour size, development of adverse effects, occurrence of metastases), ensuring that the models remain up to date and reflective of the patient's current condition."*
- Reference: Laubenbacher et al., Digital twins in medicine. *Nature Computational Science,* 4.3 (2024): 184-191
- *"The future direction of research … relies on expanding our view of the multidisciplinary team to include professionals from computing and data science backgrounds with algorithms developed in conjunction with clinicians and viewed as aids, not replacement, to traditional clinical decision-making."*
- Reference: Bradley et al., Personalized pancreatic cancer management: A systematic review of how machine learning is supporting decision making. *Pancreas,* 48.5 (2019): 598-604

Digital twins in intraoperative surgery

- *"The utilisation of artificial intelligence (AI) augments intraoperativesafety, surgical training, and patient outcomes. We introduce the term Surgeon-Machine Interface (SMI) to describe this innovative intersection between surgeons and machine inference. A custom deep computer vision (CV) architecture within a sparse labelling paradigm was developed, specifically tailored to conceptualise the SMI. This platform demonstrates the ability to perform instance segmentation on anatomical landmarks and tools from a single … surgery video dataset."*
- Reference: Park et al., Developing the surgeon-machine interface: using a novel instance-segmentation framework for intraoperative landmark labelling. *Frontiers in Surgery,* 10 (2023):1259756
- Summer 2024 student project for MSc Data Analytics student with Dr Alison Bradley:

  "Development of Artificial Intelligence System through Deep Learning to Identify Key Anatomical Structures and Critical View of Safety During Laparoscopic Cholecystectomy"

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