# Automation of Heavy Machinery

– Development using hardware- and model-in-loop verification



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DTU High-Tech Summit
October 11th 2018

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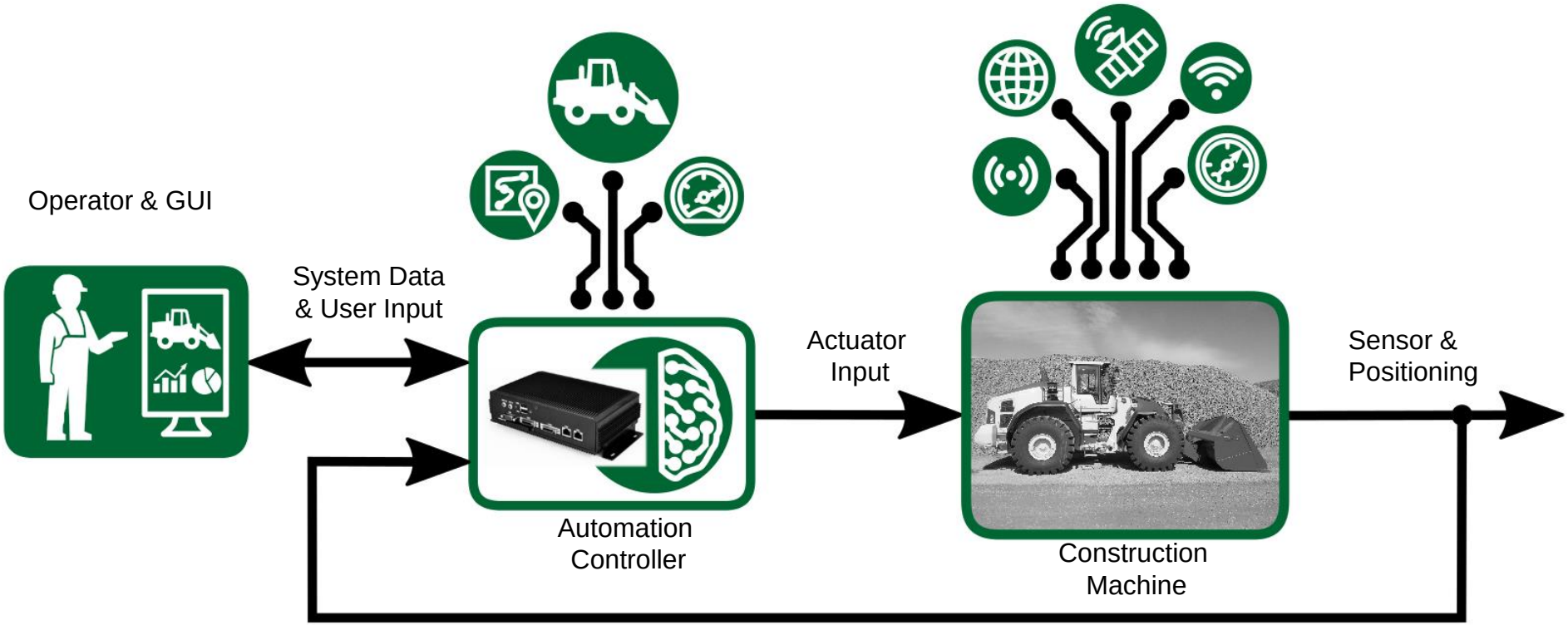
# Project Overview (Confidential)

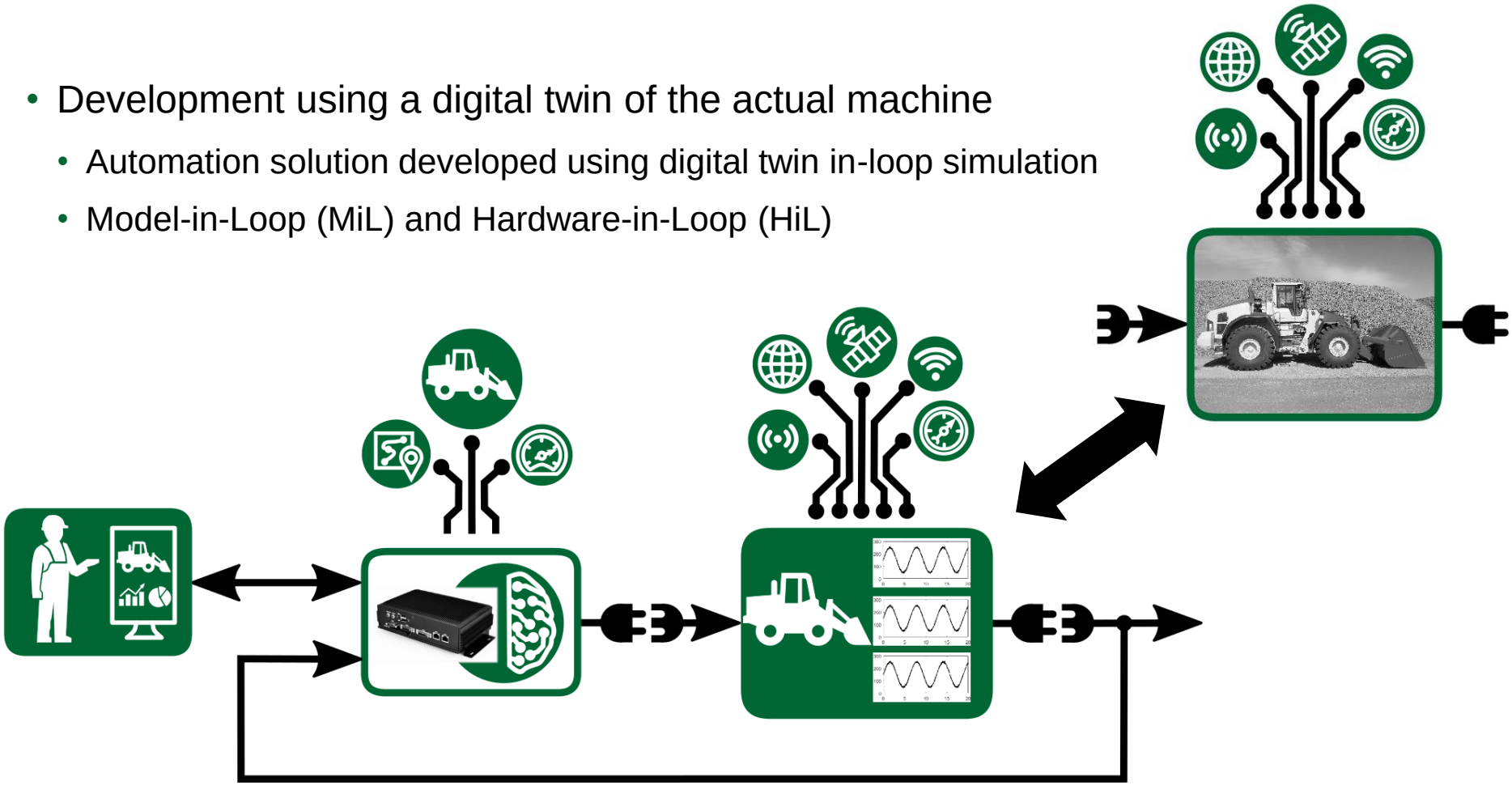
- Automation project of heavy duty construction machinery **(confidential)**
  - Automation solution for existing construction machine.
  - Retrofit with new hardware, develop automation controller and user interface



# Development using Digital Twin

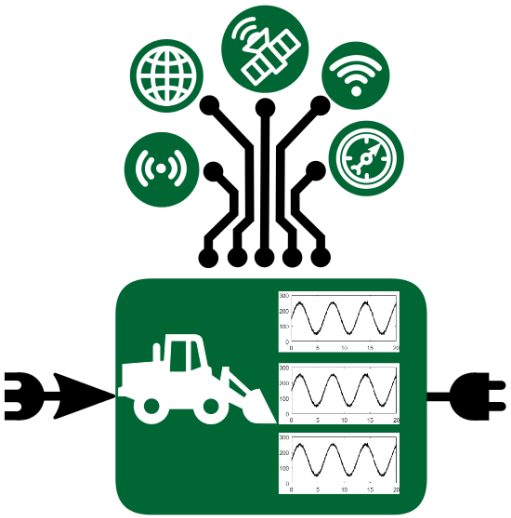
- Limited tests on actual machine during development → Expensive to take out of production.

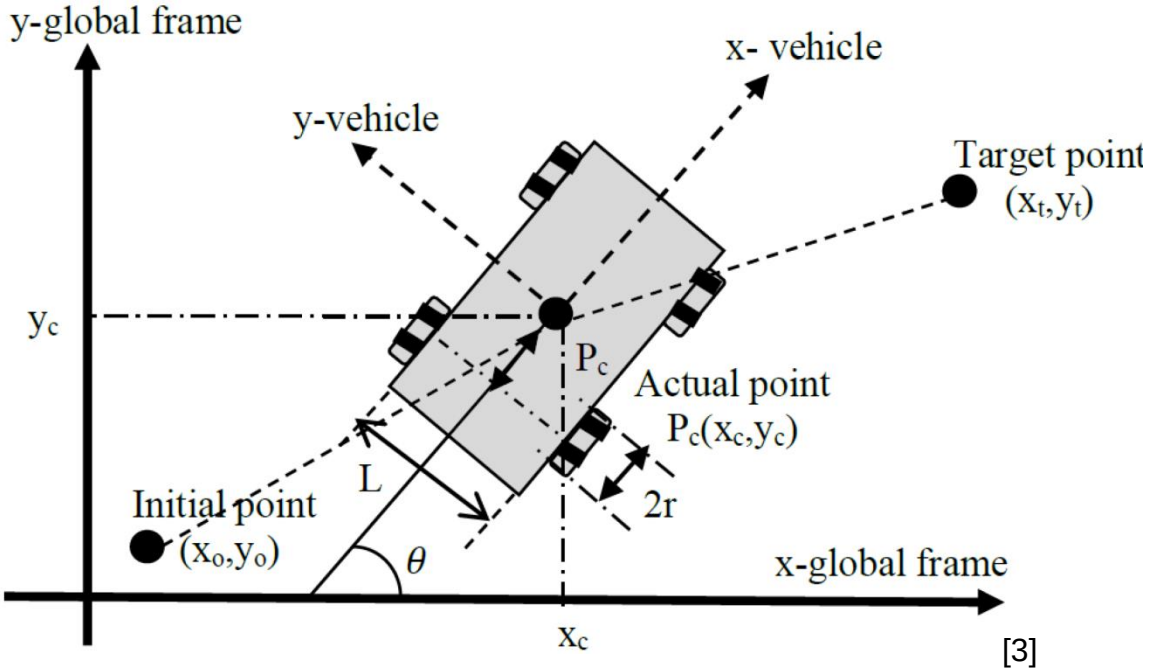
- Development using a digital twin of the actual machine
  - Automation solution developed using digital twin in-loop simulation
  - Model-in-Loop (MiL) and Hardware-in-Loop (HiL)



# Developing the Digital Twin I

- Digital Twin Must represent the actual system
- Cyber-physical modelling.
  - Hydraulic actuation system
  - Robotics and vehicle dynamics / kinematics
  - Sensor modeling



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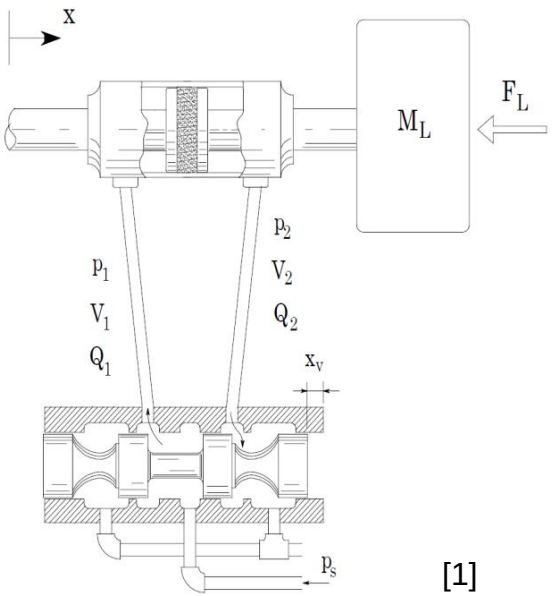


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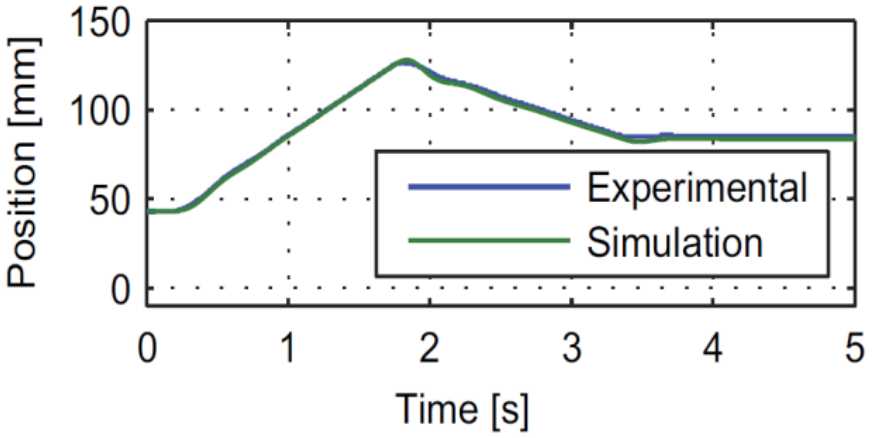
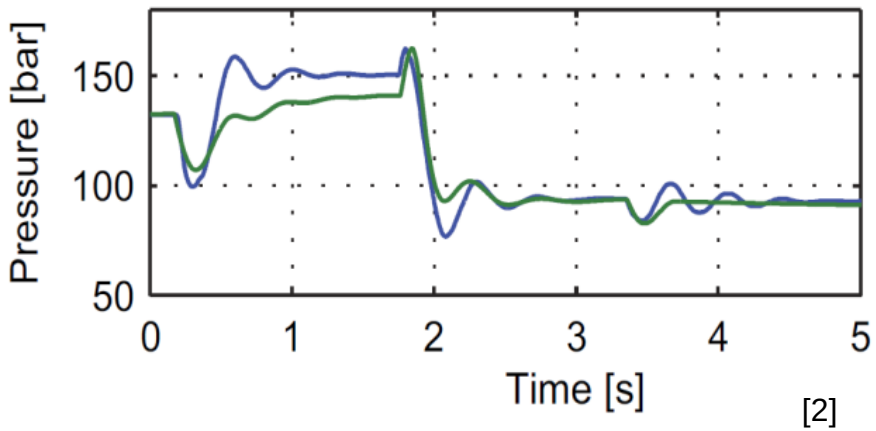
# Developing the Digital Twin II

- Certain components may be modelled in hardware – electronics of sensor, valve dynamics, etc.

- Digital twin will never match actual system 100%.
- Sufficient accuracy with engineering intuition and system understanding.
  - Accuracy of system vs. modelling effort vs. simulation time should always be considered.

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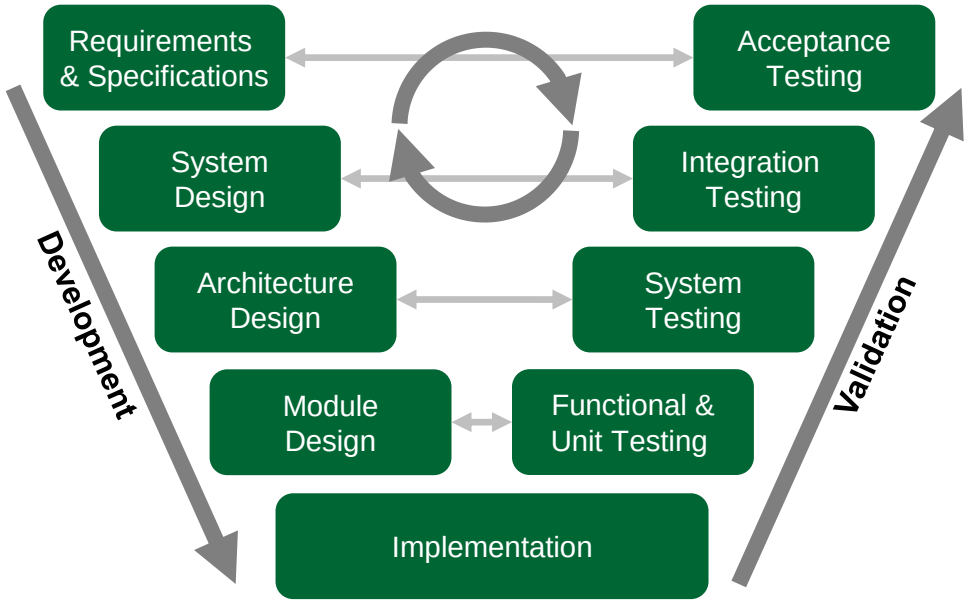
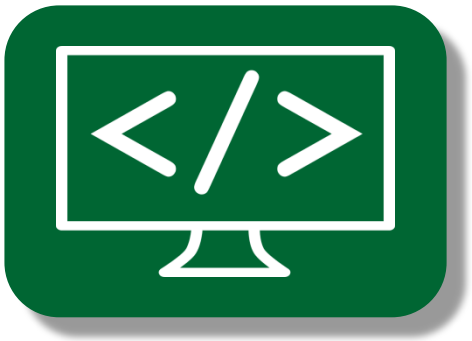
# Development Methodology and Workflow

- Development approach using V-cycle.
  - Traceability between requirements, implementation and validation.
- System and integration testing very fast when developing on digital twin
- High confidence of solution with continuous HiL and MiL simulations.

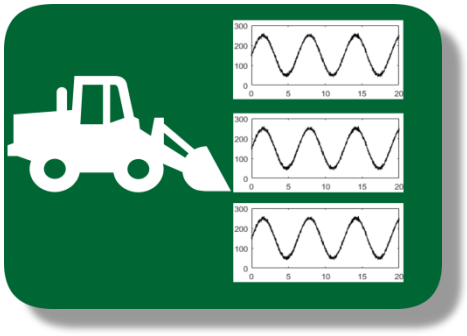



Implementation according to specification

Unit and functional testing

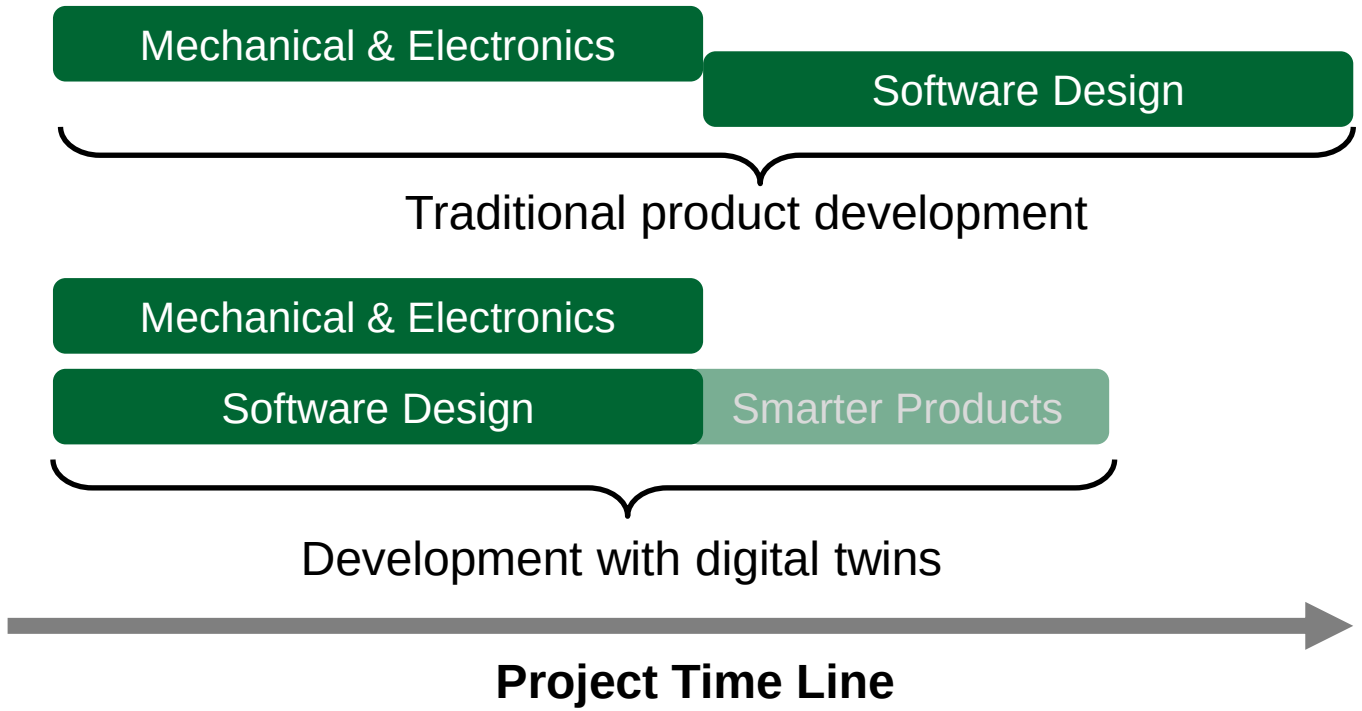


System & integration testing



# Take-Away and Advantages of R&D with a Digital Twins II

- Much faster development time, and high confidence in developed solution

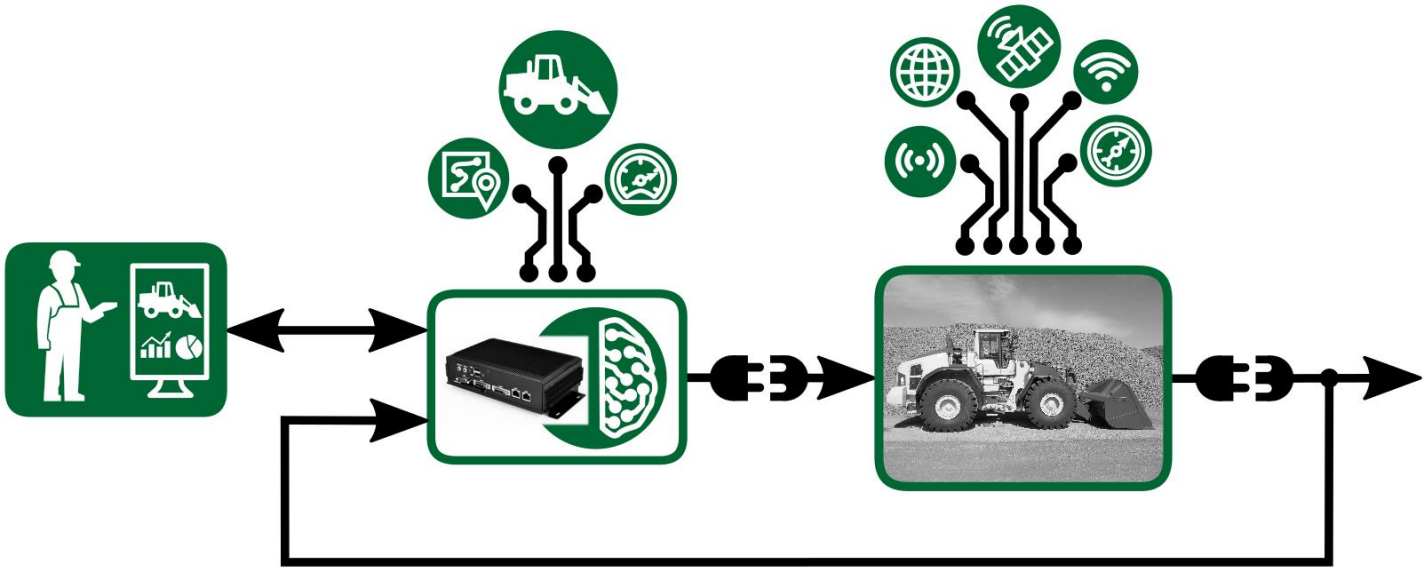



- With digital twin, testing for failure modes and fault handling becomes easy (Typically expensive tests requiring damaged hardware by design)

# Take-Away and Advantages of R&D with a Digital Twins II

- Possible to perform  product / system analysis though batch simulations.
  - Sensitivity analysis and parameter sweeps – typically expensive in hardware.

- Digital twin will never match physical system 100%
  - Software and control strategies developed up against a digital twin, will require online tuning and adjustments on the actual system.
  - Integration and system test should be performed on physical system in parallel with development on digital twin (effective V-cycle development).



# Reference

[1] Fluid Power Systems – Modelling and Analysis, T. O Andersen, Department of Energy Technology Lecture Notes, Aalborg University, 2nd Edition, 2003.

[2] Robust Control of Industrial Hydraulic Cylinder Drives - with Special Reference to Sliding Mode- & Finite-Time Control, L. Schmidt, PhD Dissertation, Department of Energy Technology, Aalborg University, 2014

[3] Adaptive Neuro-Fuzzy Technique for Autonomous Ground Vehicle Navigation, A. Al-Mayyahi, W. Wang and P. Birch, Robotics 2014, 3(4), 349-370, 2014.