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Data-driven Manufacturing (DDM) at NMIS

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Data Analytics Theme Lead

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nmis.scot

University of Strathclyde Glasgow

What is the National Manufacturing Institute Scotland?

The National Manufacturing Institute Scotland is a group of industry-led manufacturing research and development facilities where research, industry and the public sector **work together to transform skills, productivity and innovation** to attract investment and make Scotland **a global leader in advanced manufacturing.**

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NMIS: One Scotland Team

Operated by

University of Strathclyde Glasgow

Supported by

The Scottish Government
Riaghaltas na h-Alba

Scottish Enterprise

HIE
Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

CATAPULT
High Value Manufacturing

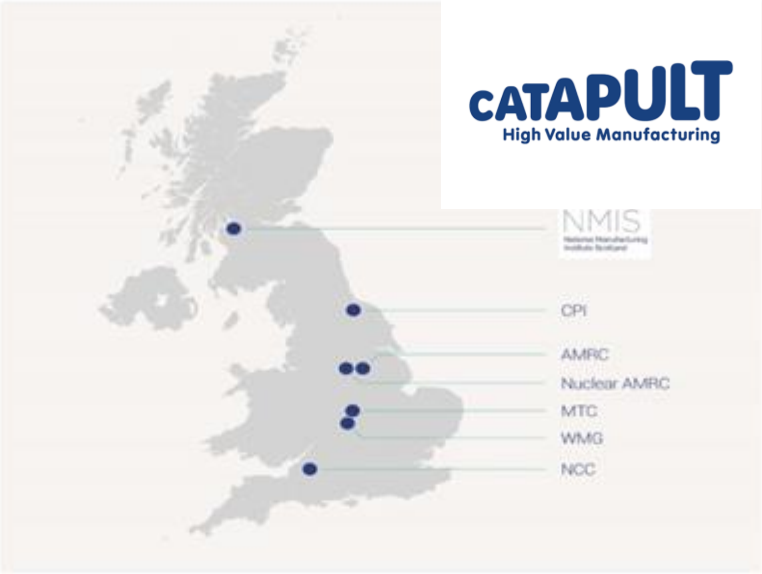
Skills Development Scotland

Renfrewshire Council

Scottish Funding Council
Promoting further and higher education

NMIS: Innovation Ecosystem

University of Aberdeen
University of Dundee
The University of Edinburgh
Edinburgh Napier University
University of Glasgow
GCU Glasgow Caledonian University
Heriot Watt University
RGU Robert Gordon University Aberdeen
University of Strathclyde
UWS University of the West of Scotland



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NMIS: Strategic Innovation Priorities

Digital Transformation
Smart connectivity, intelligent robotics & automation, systems integration across and beyond the enterprise...

Post Covid Regeneration

Net Zero: Hydrogen
Production, storage, distribution and use

Net Zero: Electrification
Automotive, Aerospace, Oil & Gas, Subsea, Rail.....

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Innovation Priorities

Skills

Resilient UK manufacturing

Net Zero: Energy Generation
Renewables, Nuclear, Oil & Gas, Heat Pumps

Lightweighting for mobility
Manufacturing capability focussed on composites, metallics, and hybrid material systems

Net Zero: Resource Efficient Manufacturing
Remanufacturing, Remake, Recycle

NMIS: Current Facilities

Advanced Manufacturing District Scotland

NMIS HQ

- Digital Factory
- Manufacturing Skills Academy (MSA)

Metallics Research Centre (MRC)

In partnership with Boeing

Medicines Manufacturing Innovation Centre (MMIC)

Part of AMIDS only

Advanced Forming Research Centre (AFRC)

Digital Process Manufacturing Centre (DPMC)

In partnership with CPI

Lightweight Manufacturing Centre (LMC)

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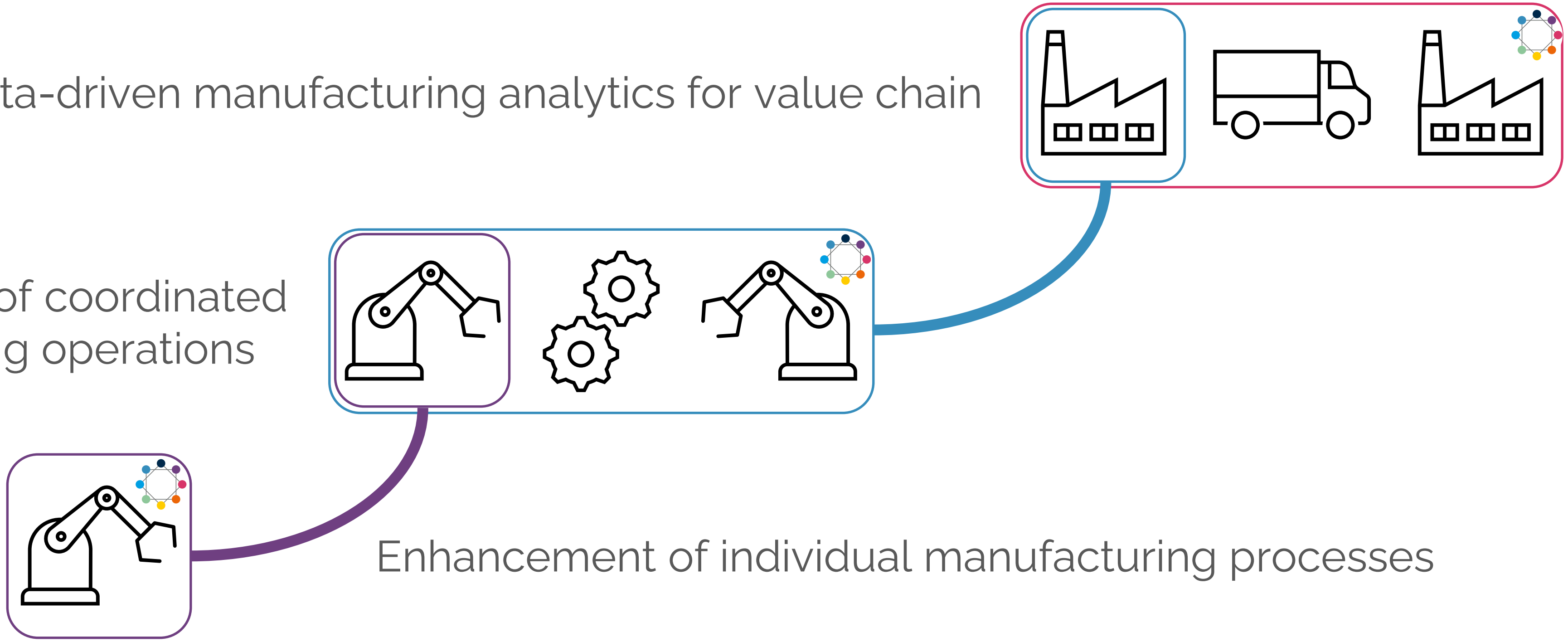
DDM@NMIS: Manufacturing Stack

Data-driven manufacturing analytics for value chain

Enablement of coordinated manufacturing operations



Enhancement of individual manufacturing processes

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DDM@NMIS: Manufacturing Data Problems

Volume

- Machines with dozens of sensors with 10kHz sampling operating continuously over months
- Multiple machines or process monitoring systems within single factory zone

Manufacturing Data

Diversity & Domain Knowledge

- Temperature data, pressure data, imaging data, localisation data
- Sensors connected via PROFINET, Modbus TCP, ad hoc networks, etc.

Specificity

- Comparison between similar processes is not immediately transferrable
- Analysis needs the ability for domain knowledge to be incorporated

Implementing data-driven solutions for manufacturing data is challenging

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DDM@NMIS: Manufacturing Data Science

- **Data science** will be **transformational** to Scottish **manufacturing productivity** and attainment of **net-zero** targets
- Scottish manufacturers are responding to this opportunity by **upskilling** engineers and **recruiting** data scientists
- Even large OEMs tell us they **struggle to recruit**, **retain** and **effectively support** data science teams with sufficient critical mass required to maintain world class capabilities when competing with other sectors
- The situation for **SMEs** is even more difficult

*NMIS is uniquely positioned with its **Data-driven Manufacturing (DDM) Team** which supports …*

*… **DDM _colab**, an open approach to industrial engagement, augmenting and upskilling Scottish manufacturers' in-house data science capability*

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DDM@NMIS: Overview

Combining the best practices of **data science**, **data infrastructure** and **manufacturing domain expertise** to support translational manufacturing research:

- DDM _colab for internal/external data-driven engagement
- Data-driven Manufacturing Team to support and drive DDM _colab
- Data science infrastructure for internal/external projects
- Software engineering processes and best practices
- Manufacturing sandboxes for de-risking digital transformation

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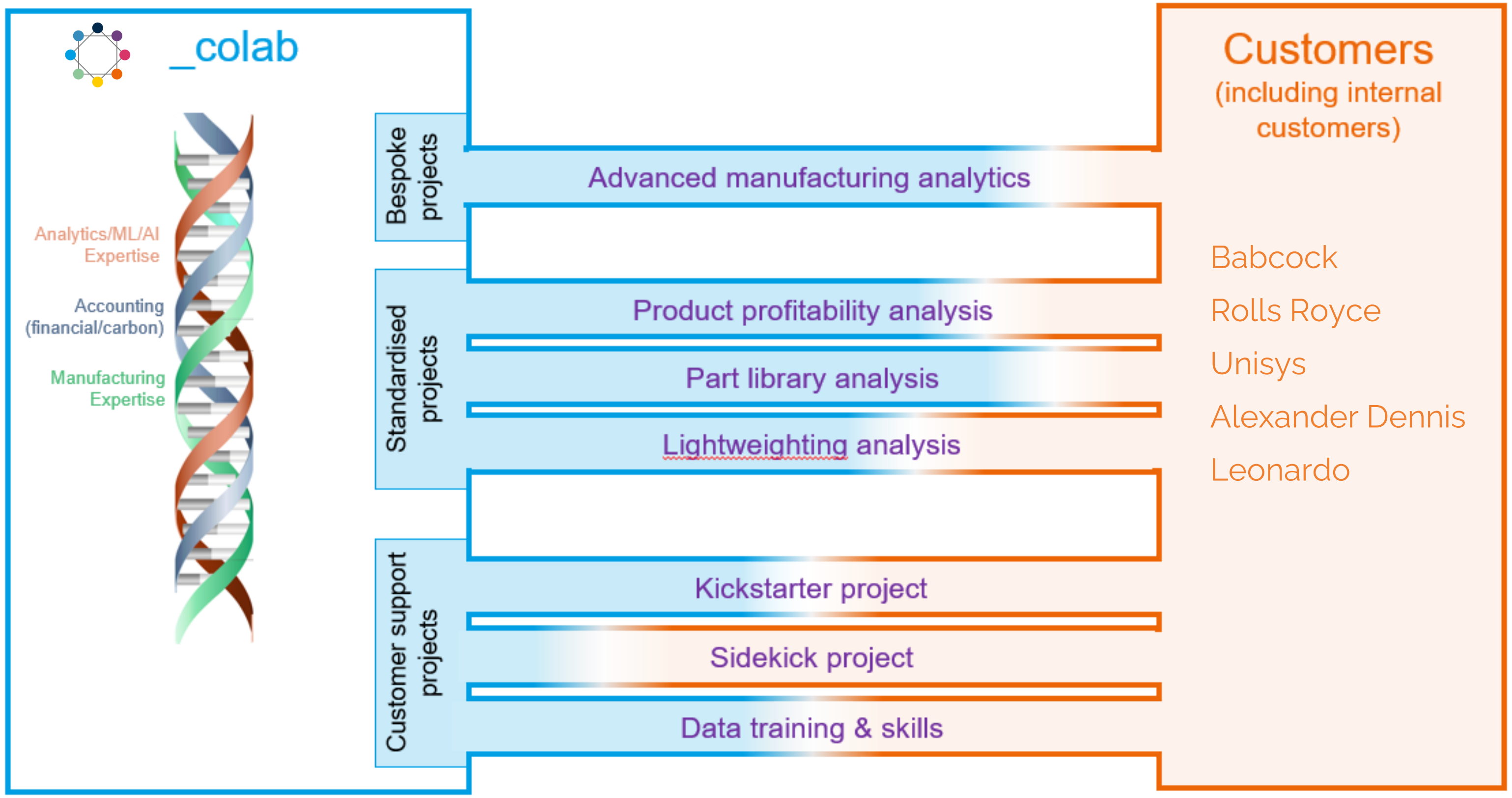
python git jupyter Go OpenCV NVIDIA CUDA ANACONDA SQLite TensorFlow ubuntu unity kubernetes

DDM@NMIS: DDM _colab



DDM@NMIS: Data Science Infrastructure

Deep Learning Cluster

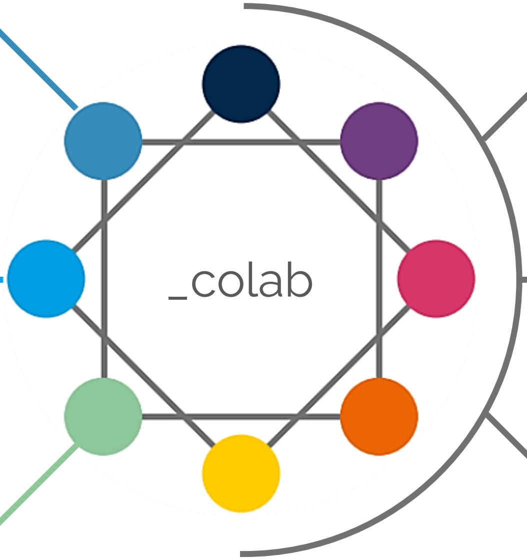
+120GB combined GPU and high-end CPU's
Run.ai AI scheduler functional
On premise k8s cluster

IBM Power 9 ML/AI

Accelerated labelling of images/video
Standard model library and can import others
Counterpart installation at AMRC

Standalone Linux servers

Various GPU/CPU/storage nodes for projects
Can be used for IP sensitive work and external _colab
Edge devices for data engineering/low-latency analytics



Edinburgh International Data Facility

Alan Turing Institute

HVMC Data Groups

Scotland's AI Strategy

NMIS Partner tech providers (Run.ai, AWS and GCP)

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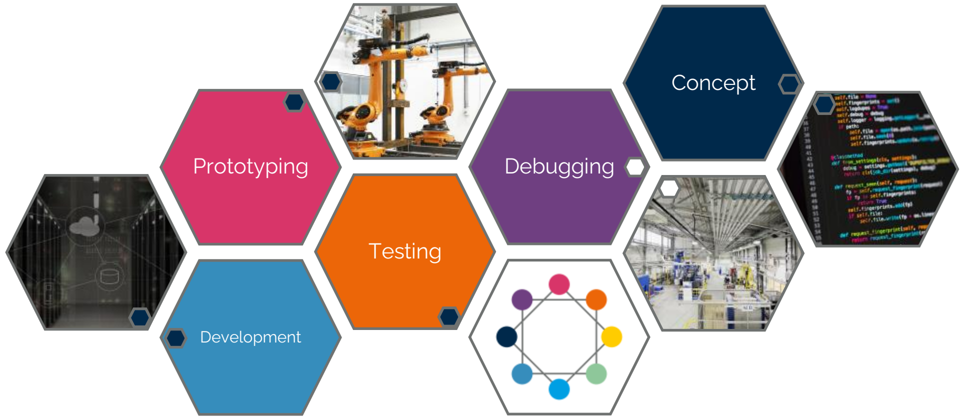
DDM@NMIS: Software Engineering

Ability to develop high-quality production-ready code – tested, documented, reusable.

Adopt design and operating principles as found in software development environments:

- Coding standards and common programming languages/frameworks (Python, Torch, etc)
- Dev Op tools and frameworks
- Version control
- Continuous Integration and Deployment
- Agile software development
- **Licensable IP**



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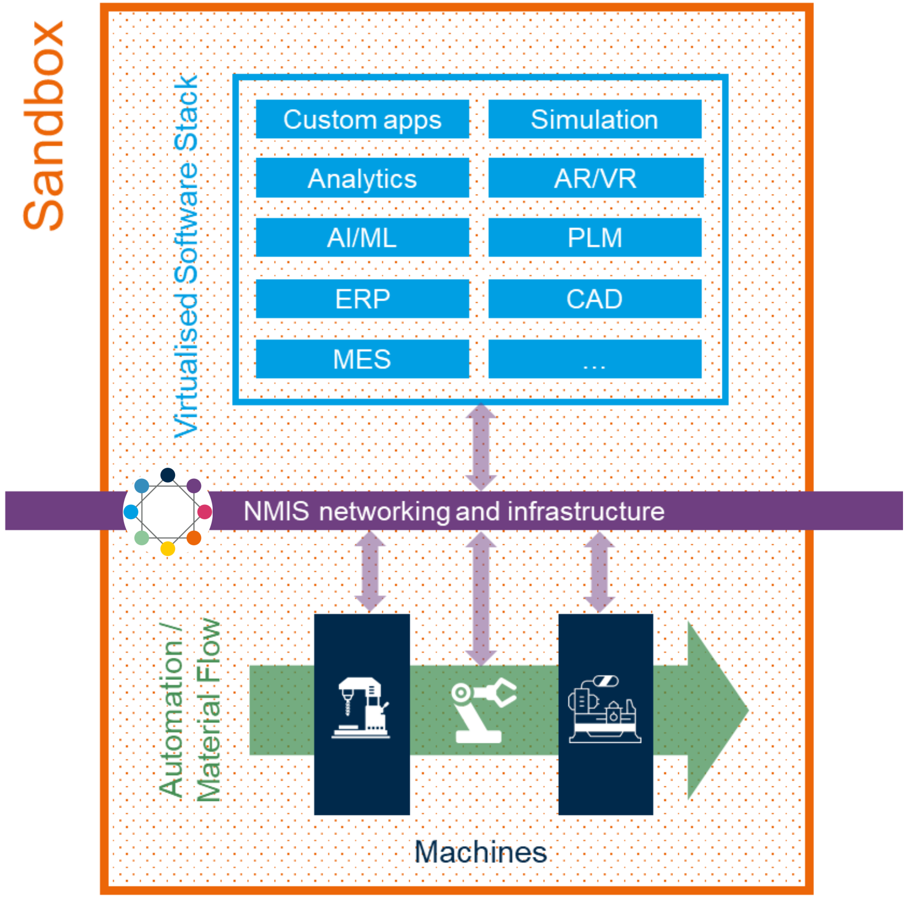
DDM@NMIS: Manufacturing Sandboxes

- The sandbox is a working facsimile of a manufacturing system - securely replicating the appropriate parts of a customer's equipment, software and data stacks.
- Allows new technologies, physical and digital, to be safely developed and/or deployed.
- Can be a clone of customer's own system or be a representative system for a typical client group.
- Allows customer, machine tool company, software partners and NMIS to work together.
- NMIS can host multiple sandboxes simultaneously.



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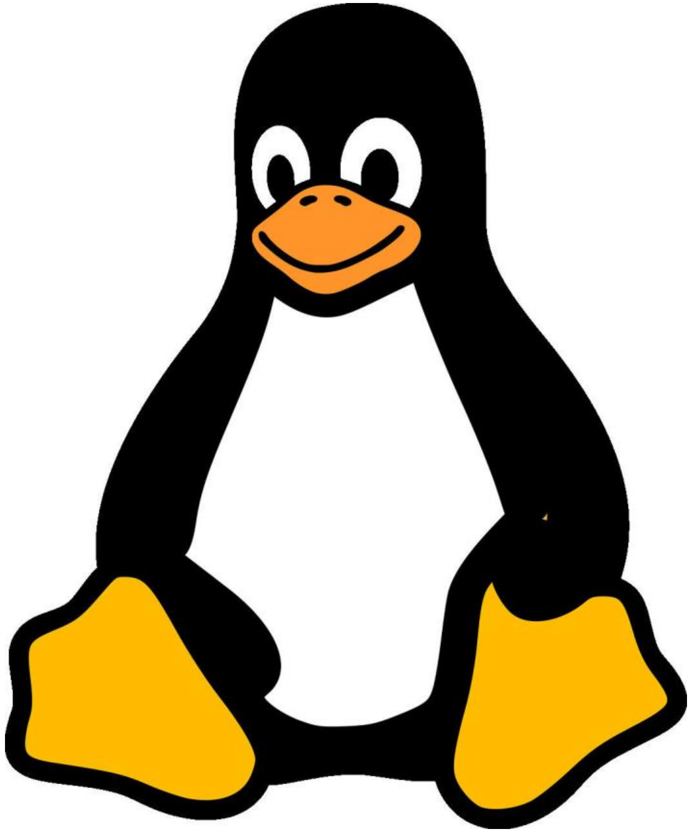
DDM@NMIS: FOSS

Free & Open Source Software (FOSS)

- Engineers use data analytics frameworks all the time
- Proprietary (i.e. paid) frameworks dominate for many reasons
- Open-source frameworks can have advantages for data science
- Many 'proprietary' systems are built entirely on open-source frameworks but hidden behind



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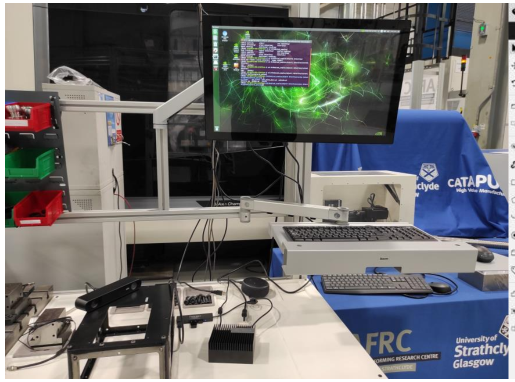
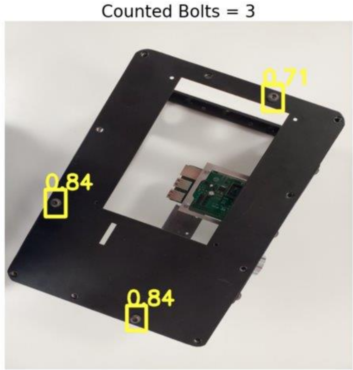
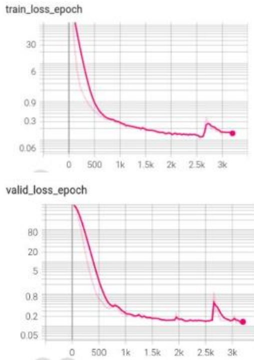
Case Study: Augmented Manual Assembly

- Outline - Innovate UK project with industrial partner with DDM tasked to provide data science support
- Objective – develop technologies to assist manual assembly of low-volume, high mix defence components
- Outcome - created a computer vision system to validate the correct assembly of a component in real time using recurrent convolutional neural networks







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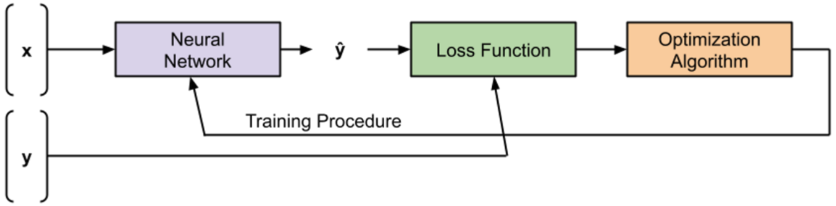
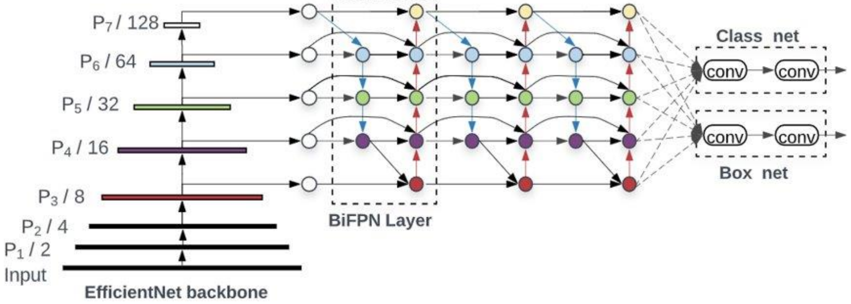
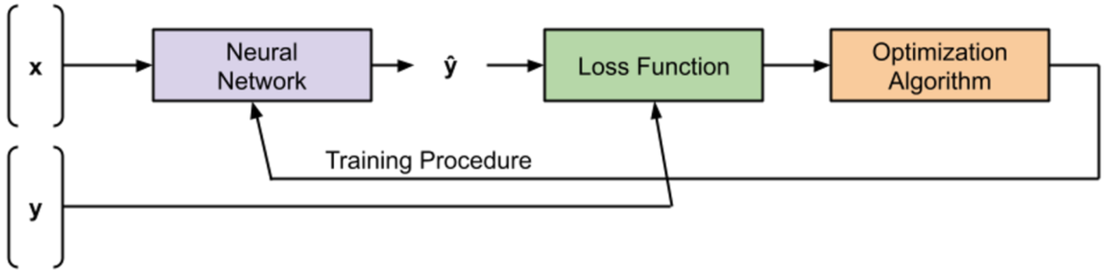




Case Study: Model Outline

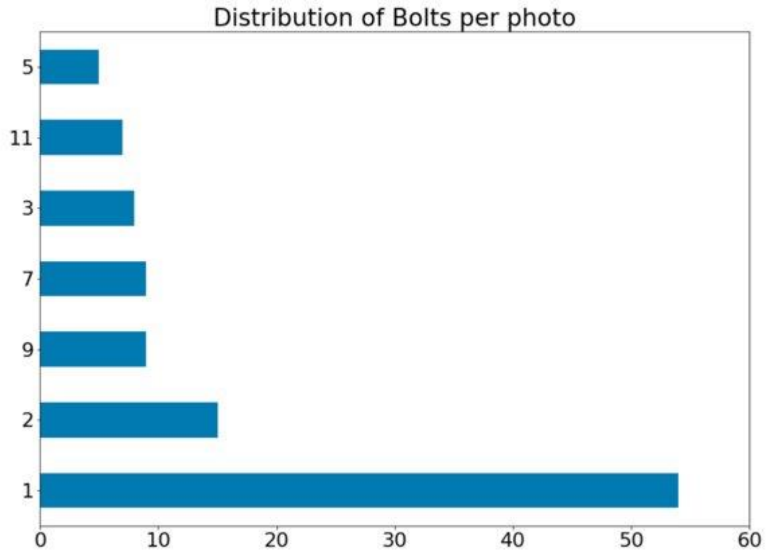


- X = images
- Y = labels (bolt, background) + bounding boxes (coordinates of the boxes imposed on the images)
- labels -- classification problem
- Bounding boxes -- regression problem

Case Study: Data Collection

- Images captured using depth camera (ZED) powered by edge device (Jetson Nano)
- Images labelled using CVAT (https://github.com/openvinotoolkit/cvat)

Case Study: Data Train/Valid/Test



- 60% ‘train’ for training model
- 20% ‘valid’ for checking model according to validation loss
- 20% ‘test’ for testing on data completely unseen by model developed during train/valid stages
- Datasets were stratified to ensure model was not affected by more numerous single bolt image instances

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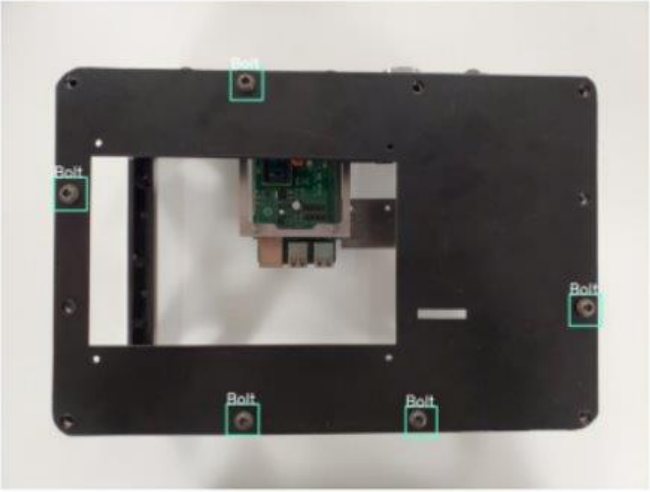
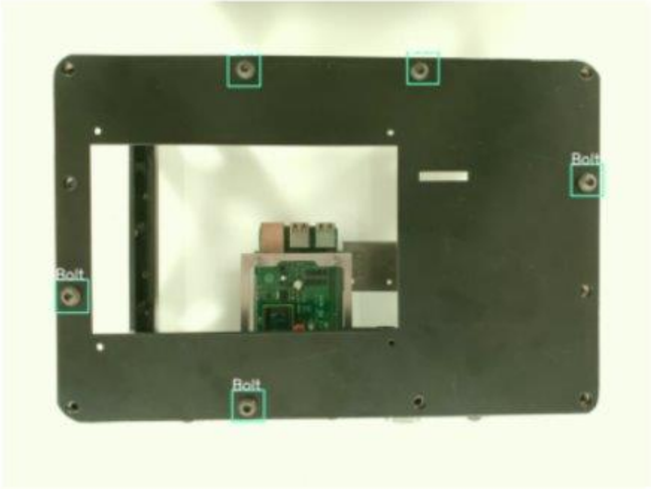
Case Study: Dataset Augmentations

Original Sample



Augmented Sample



- Technique to improve the models ability to generalize and reduce chance of over fitting
- Can be used (in some cases) to increase dataset if sparsity is an issue

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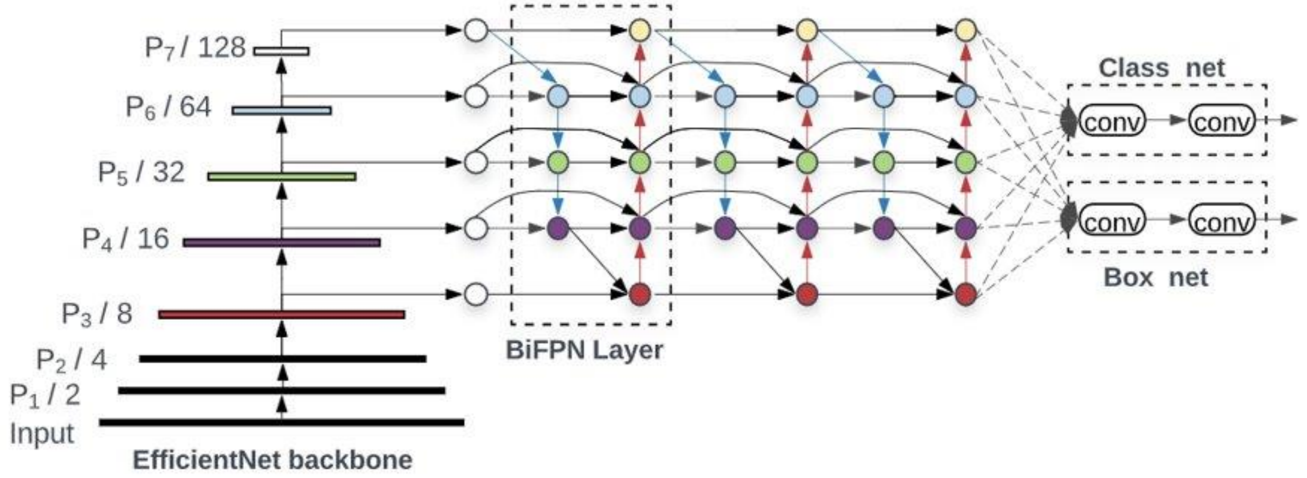
Case Study: SOTA Model -- EfficientDet



- State-of-the-art (SOTA) model used was EfficientDet (https://github.com/xuannianz/EfficientDet)
- Model is over-powered for application – but good to gain understanding as the intention is to apply to more complex tasks

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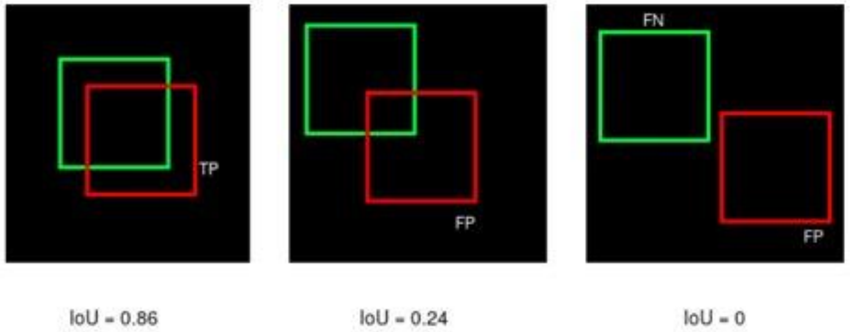
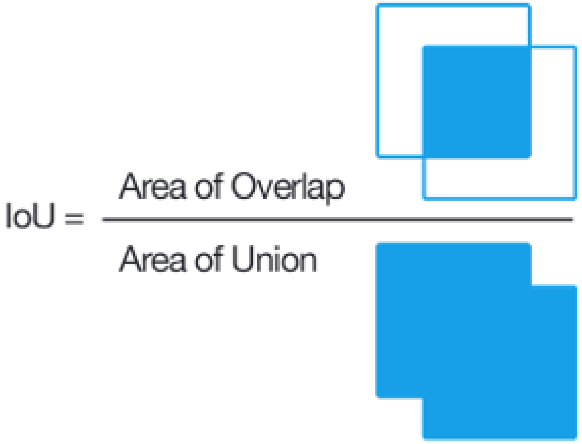
Case Study: Metrics





- Average Precision (AP) and mean Average Precision (mAP) are the most popular metrics used to evaluate object detection models (https://towardsdatascience.com/on-object-detection-metrics-with-worked-example-216f173ed31e)
- Validation Set Average Precision (AP) = 0.766
- Test Set Average Precision (AP) = 0.720
- The reason for the relatively large error was due to target of matching bounding boxes – bolt detection had F1 score of 0.98

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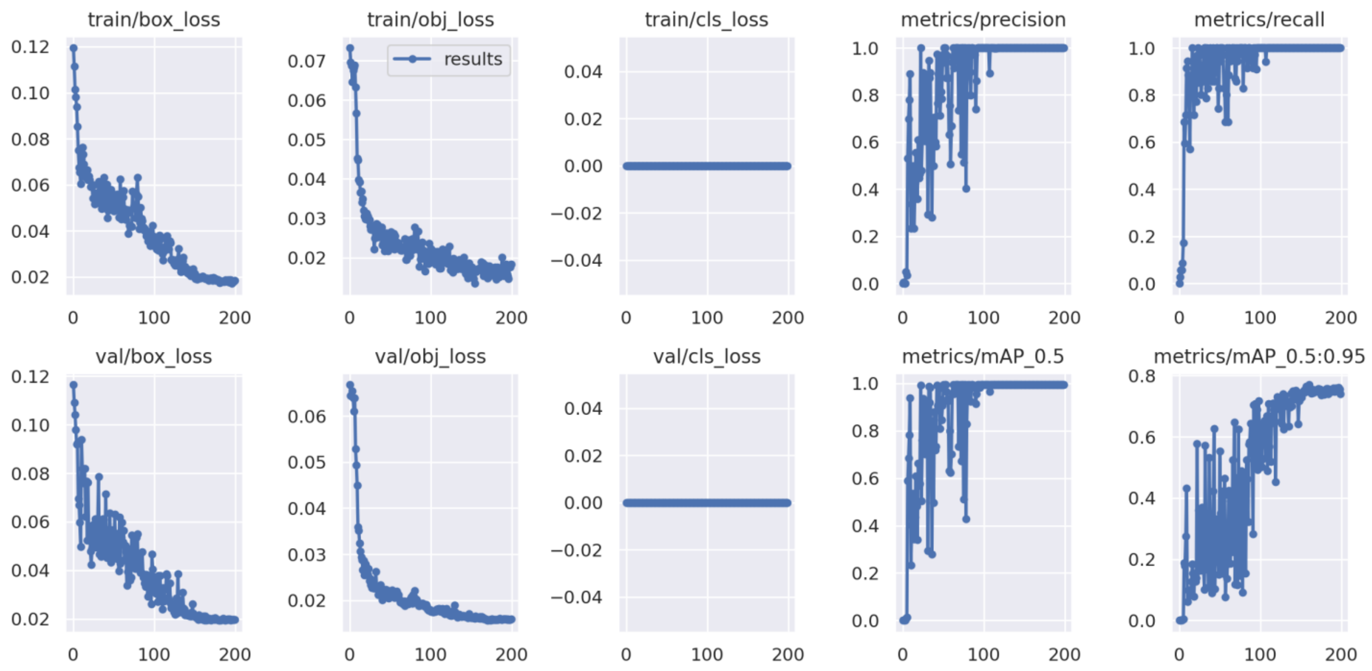
Case Study: Model Training



- 200 epochs,
- learning rate of 0.01
- SGD optimizer
- Images resized to 1024x1024
- The model that provides the lowest validation loss is kept at the end of the training

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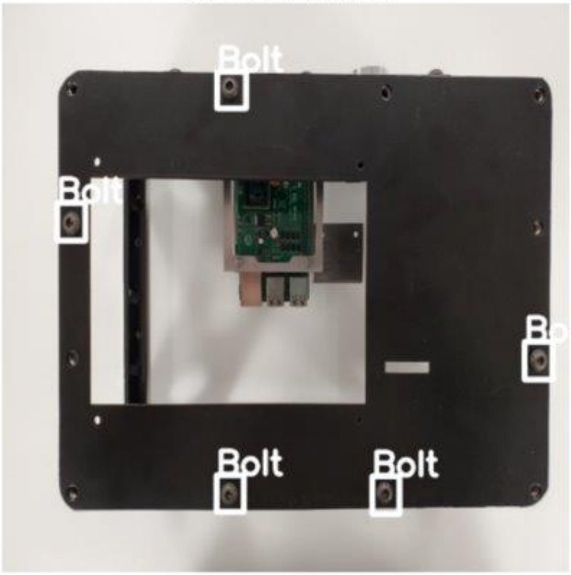
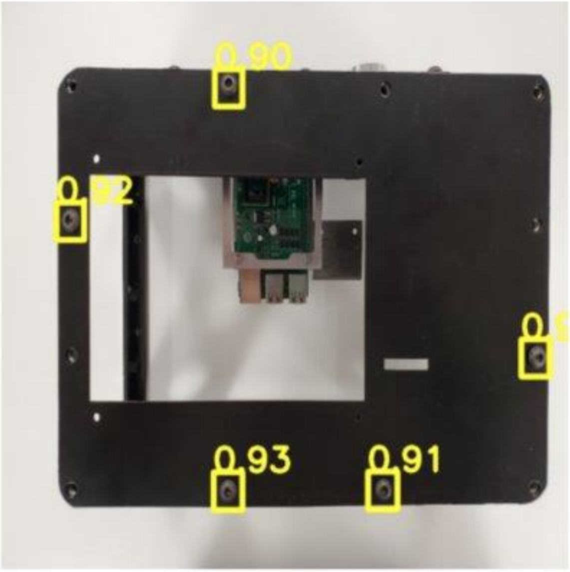
Case Study: Inferencing on Test Data

Ground Truth



Prediction: Counted Bolts = 5



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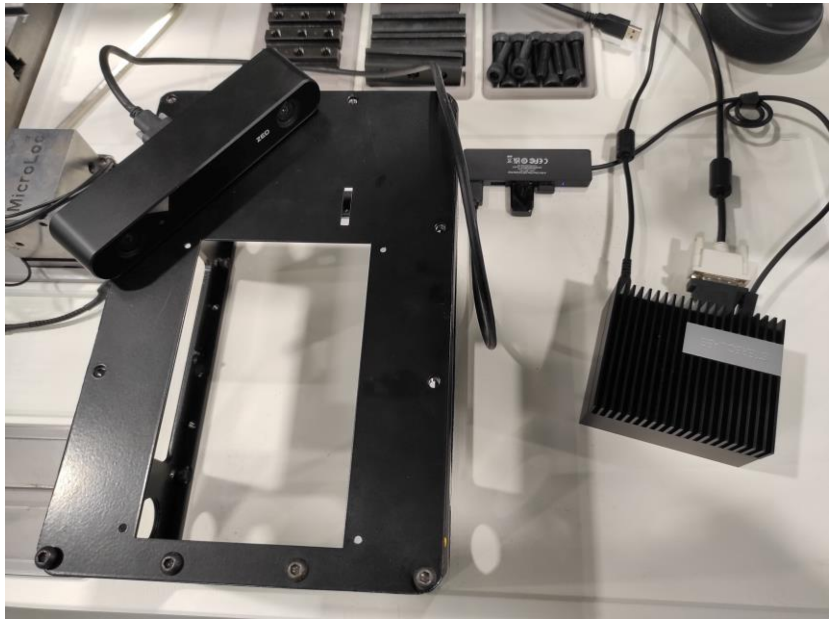
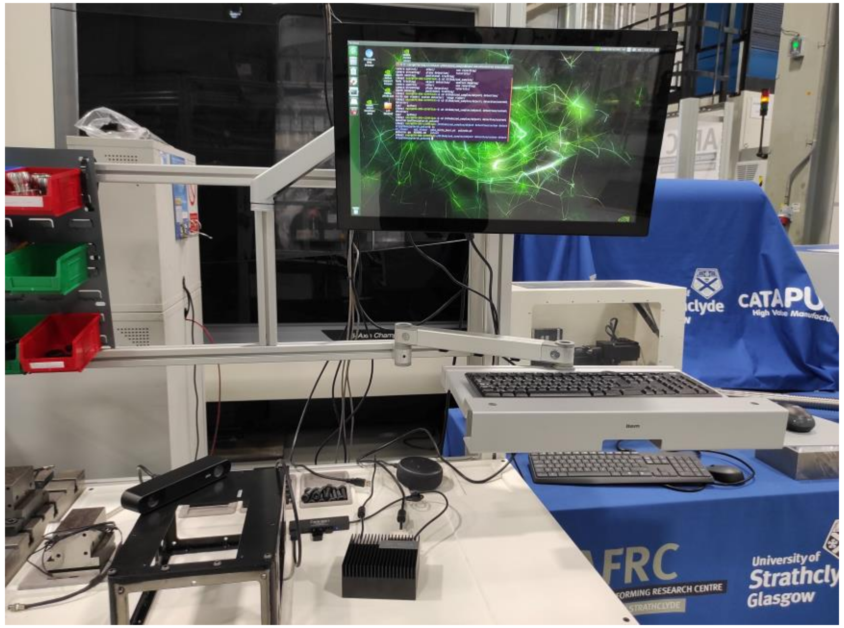
Case Study: Implementation into Production





- ZED camera provides live video feed that can reach 100 FPS and
- Edge AI Gateway is a compact gateway powered by NVIDIA Jetson that allow model deployment
- Edge AI Gateway device works as an Ubuntu machine

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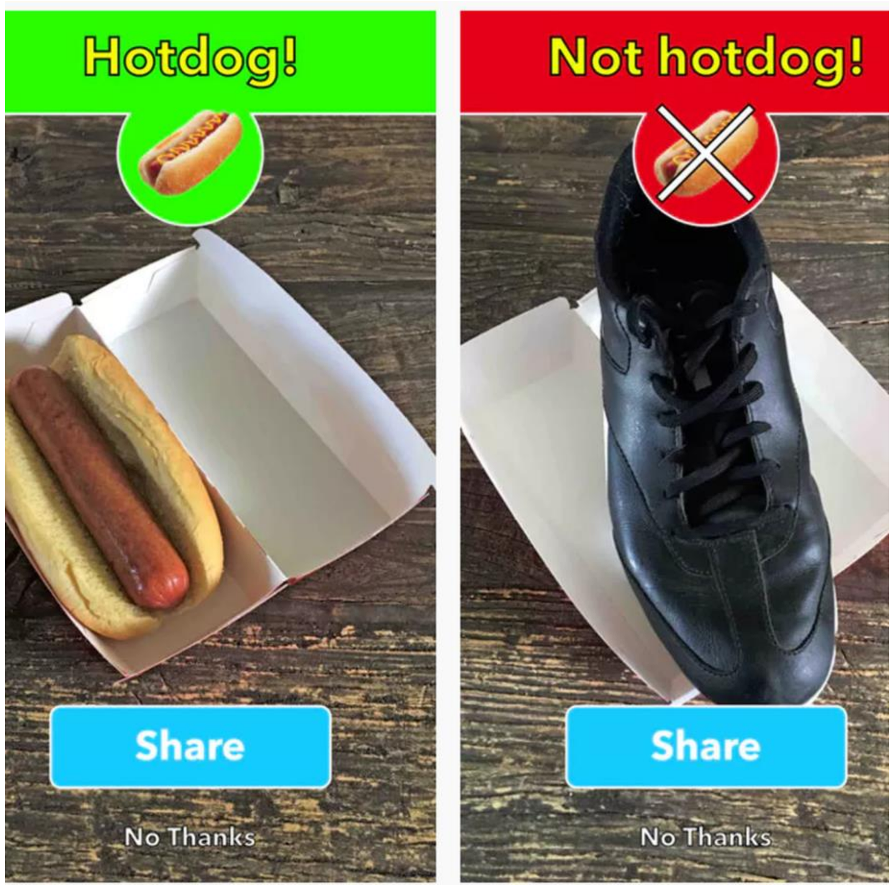
Case Study: Potential Issues

- Mix of regression (identifying coordinates of bounding box) and classification for purely binary problem – easy to identify objects with bounding boxes but this can introduce errors
- Model is trained for one PCB assembly – changes to design may cause model to be invalid without re-training
- Artifacts not fully tested (hand in frames, extraneous objects -- typical production system issues)
- Can tell if bolt is in place, but not screwed in



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