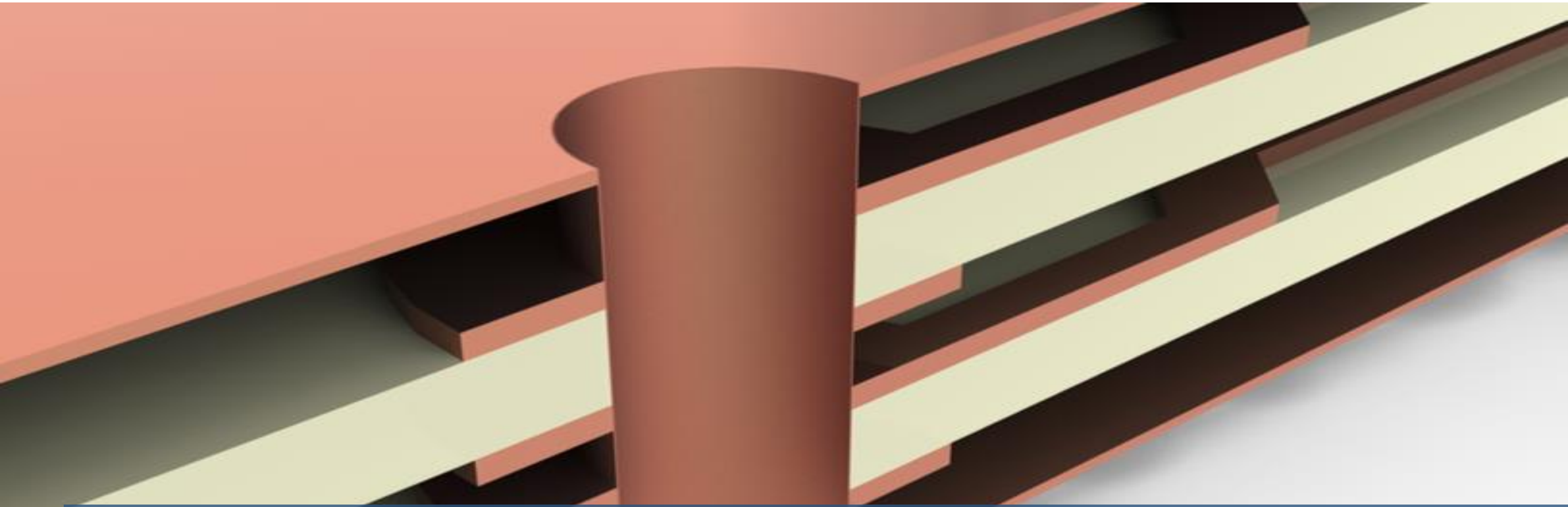
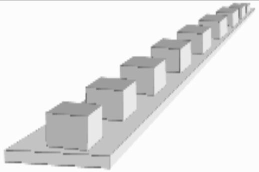
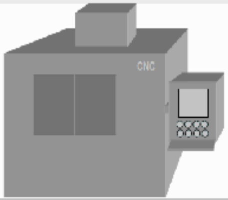
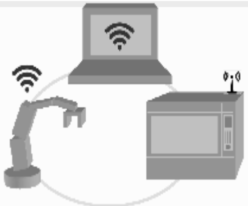


Andrew Kelley | CTO at XACTPCB Ltd

The Problem of Registration Control within the PCB “Smart Factory”

Over a period of 250 years…
There have been four industrial revolutions

	First Industrial Revolution	Factories and Mechanisation
	Second Industrial Revolution	Mass Production and Electricity
	Third Industrial Revolution	Computer Control and Automation
	Fourth Industrial Revolution	IoT Autonomous Intelligent Systems

Industry 4.0 – The concept is a paradigm shift leaving many managers wondering where to start

Organisation
- New level of organisation and control
- Full digitisation of operations

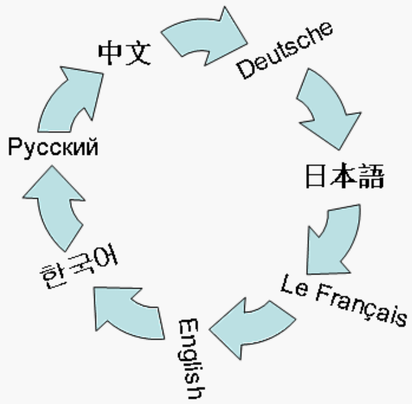
Integration
- Vertical from shop floor to senior management
- Horizontal linking suppliers and customers

Communication
- Infrastructure required for open wireless network
- Reliability and stability for critical communications

Security
- Open network introduces risk
- Need to protect industrial know how held in data

People
- Lack of adequate skills
- Threat of redundancy

Industry 4.0 is a very ambitious and aspirational objective, but the steps to achieve this are not clear



- Many machines already communicate data but in their own proprietary “language”
- Communication between software and machines from different vendors is difficult

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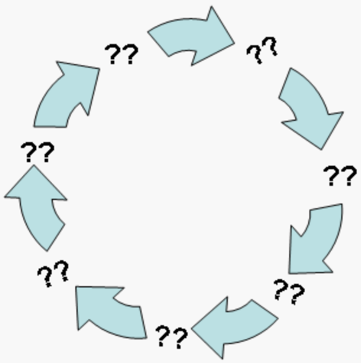
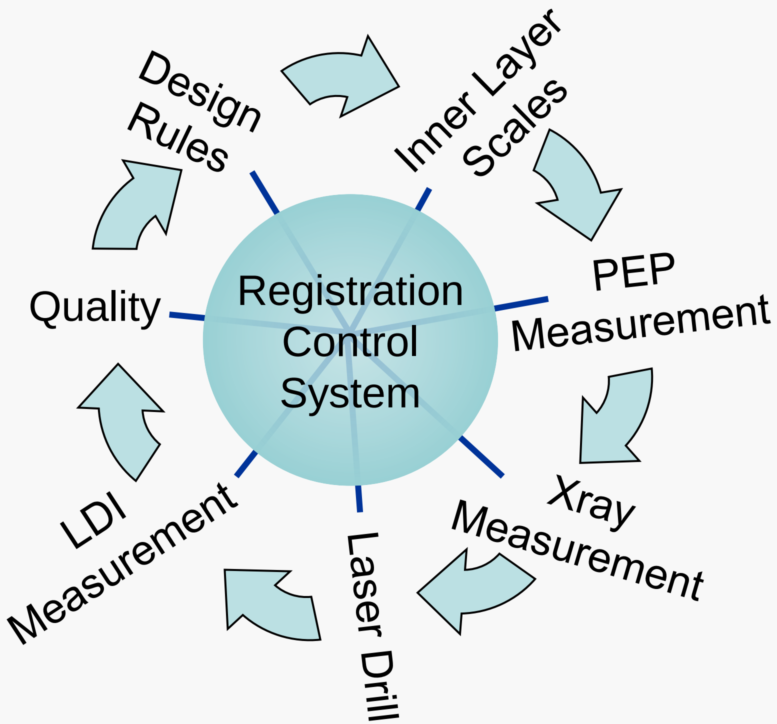
- Industry 4.0 pushes for all machines to use a standardised communication
- Standardisation will require significant upgrades or replacement of equipment
- Who creates the standard?
- When will the standard be available?



Smart Factory enables existing equipment and infrastructures to be adapted to the challenge of smart manufacturing

Smart Factory

- Allows use of existing equipment
- Application focused data control and communication systems
- Step by step implementation
- Strengthens existing infrastructure
- Does not require a new factory
- Is achievable in the short term



Smart Factory – A first step to introduce intelligence into the PCB manufacturing process

Strategy

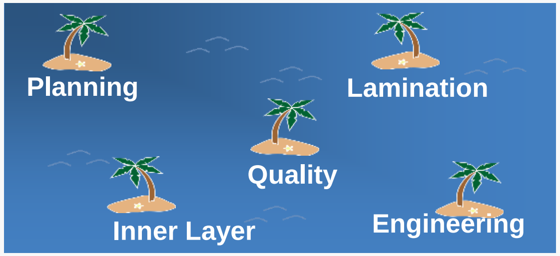
- Innovation-driven development
- Apply smart technologies
- Strengthen foundations
- Upgrade from quantity to quality

Practical

Unlike Industry 4.0, focus is not on the most advanced technology but on the practical implementation of existing leading technologies

The PCB fabricators have a number of problems to overcome to achieve the benefits of Smart Factory

Islands of Information



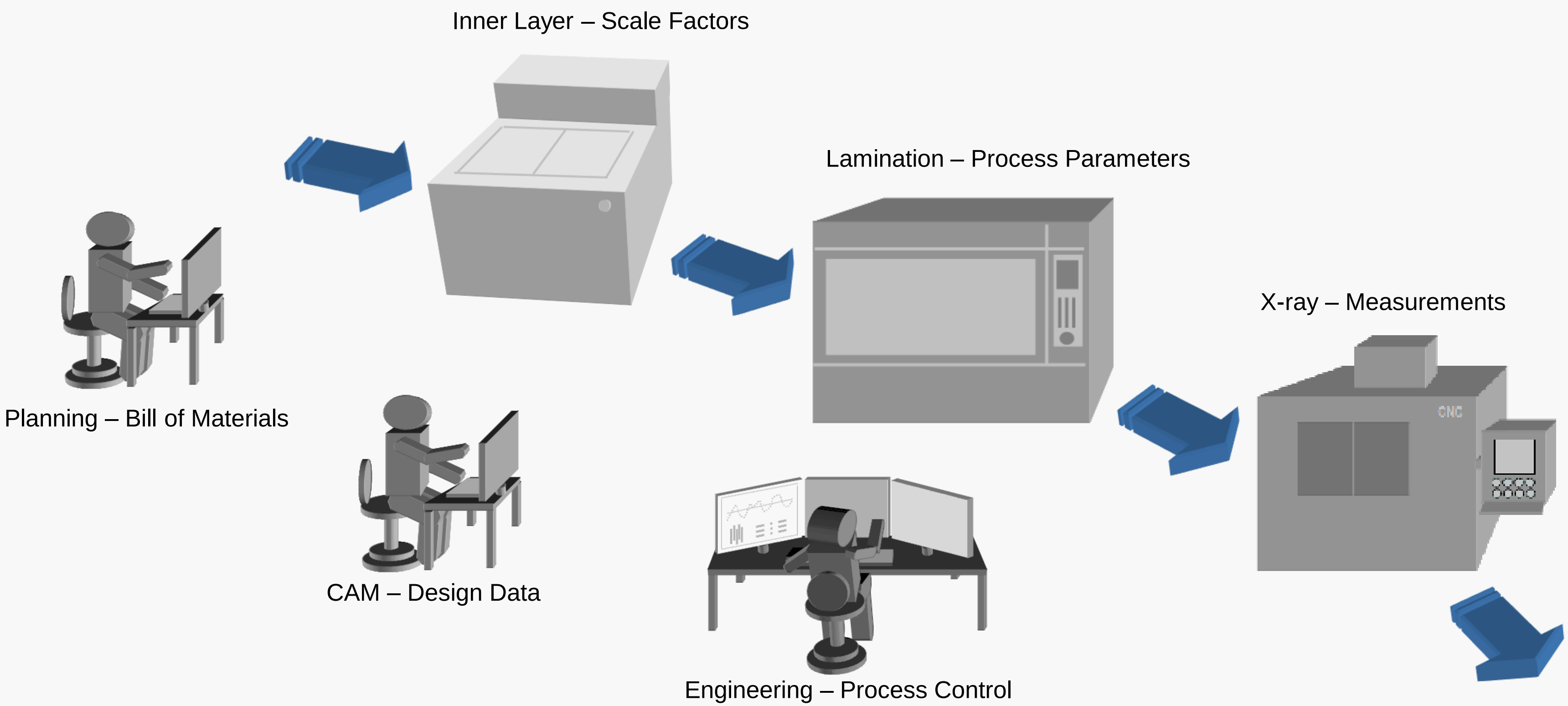
- Fragmented view
- Duplicated data
- Local variants of “same” data
- Difficult to get timely accurate information
- Data usage driven by reports not manufacturing

Resistance to Change

- Poor communication between different organisation locations
- Departmental “experts”
- Just enough technology
- Under utilised technology

Too many times people think they are too busy to look at ways to improve what they are doing

Looking at typical factors used to control inner layer registration we can see some of these islands of data



The problem of registration control becomes a need to develop raw data into an intelligent manufacturing solution

Typical Registration Control

- Pilot batches
- Cross Section Analysis
- Scale Factor Look-up Tables
- Xray Drill Optimisers
- Coordinate Measurement Machines

This creates lots of disconnected data with limited understanding or analysis

The goal of manufacturing intelligence is to capture, collate, integrate and understand process data

Integrated Manufacturing Systems

Get the right data

In real time

In the right context

And act as quickly as possible

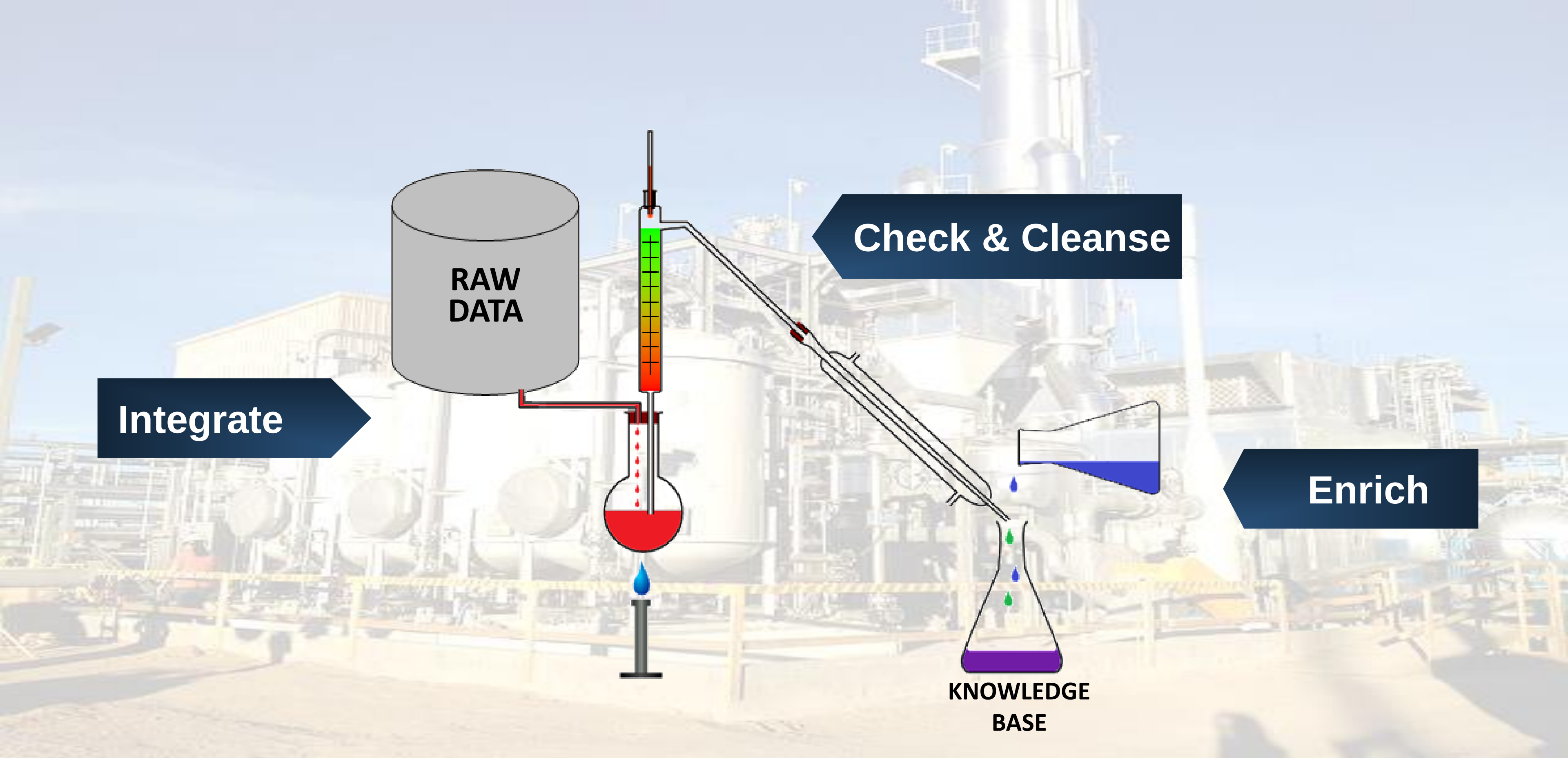
The goal of manufacturing intelligence is to capture, collate, integrate and understand process data

Integrated Manufacturing Systems

Provide a bridge between people generating data

and those using it

There are key data refinement steps that must be taken to ensure the value of data can be realised



Connect those islands of data to the Smart Factory with hardware and software infrastructure to remove inefficiency

Integrate

Machine Networking

- Data captured during production must be accessible from remote systems via factory networks.
- Network may be wired or wireless, but MUST be robust and reliable.
- Systems reliant on data transfer can not afford loss of communication.

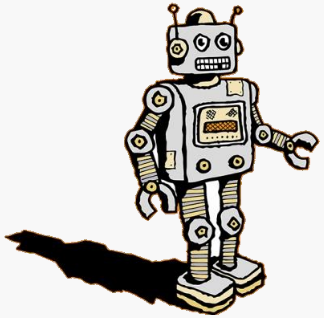
Automated Data Capture

- Monitoring systems gather data as it is created – either pulled from remote system, or pushed to remote system.
- Manual data transfer is no longer an option.

Automation of data capture will not improve manufacturing intelligence if the data is not correct

"The first rule of any technology used in business is that automation applied to an efficient operation will magnify the efficiency.

The second is that automation applied to an inefficient operation will magnify the inefficiency."



Bill Gates – Cofounder Microsoft

Create a solid framework for data quality and integrity to remove risks around existing operational processes

Check & Cleanse

Data Quality

- People quickly lose trust in the information if inconsistent or inaccurate
- Value of data is lost if you don't have data quality in manufacturing.

Data Integrity

- Companies will resort to old ways and knowledge if data is not integrated in a reliable way.
- A lot of data is pushed into projects and reports without being evaluated for correctness.

Robust process controls are vital from the start to ensure data quality instead of correcting after mistakes

Control The Measurement Process!!

• Measurement machines must be maintained and calibrated to prevent noise or shift within the data captured.

• Control the environment around the machines – changes in temperature and humidity will be reflected in the data.

• Monitor changes in data quality with daily checks using known standards.

• Use statistical control to determine when maintenance or calibration is required – don’t wait for the schedule.

Measurement Systems Analysis will determine accuracy and precision of the measurement process

MSA verifies differences in data are due to actual differences in the product being measured and not due to variation in measurement methods.

Are all operators equal?

It is critical the machine is set-up consistently for each batch, no matter who is performing the setup.

Perform Gauge R&R to check repeatability and reproducibility.

Random noise should be filtered but out of tolerance products may still provide valuable data

Filtering of spurious measurements can not be done in isolation

- Consider each individual measurement relative to other measurements on the same layer.
- Consider measurements for each layer relative to the other layers in the same panel.
- Consider measurements for each layer relative to the same layer in other panels.

When compared to previous lots, it will also be possible to determine if the material movement for the lot is unusual.

Only those who understand the data can truly add value

Leading measurement capable machines can apply a tolerance to the measurement data to make a simple GO-NO GO decision

However, out of context that decision may be incorrect…

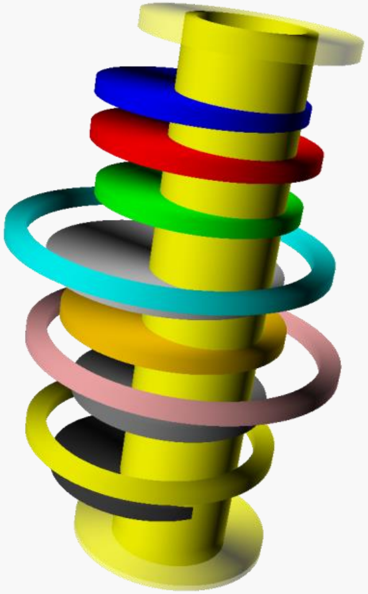
Measurements for an intermediate stage of a sequentially laminated product are unlikely to be nominal dimensions due to additional material movement during subsequent processing.

Without knowing the measured product is not at final lamination, analysis of measured positions would imply the product is out of specification.

In the PCB factory there is a lot of design and manufacturing data in multiple places and formats

Enrich

By combining data from multiple sources it is possible to derive additional information which will aid in our understanding of the process.



Combining measurement data with design information such as annular ring and drill to copper we can decide if a product meets requirements or if process parameters need to be changed to improve yield/reliability.

Integrating relevant data from multiple sources builds our understanding of the processes and materials

Combining measurement data from multiple sources (e.g. Exposure, PEP, X-ray Drill) we can determine material movement through each processing stage.

Combining inner layer scale factors with measured scale errors we can determine the total material movement for each core in the construction and compensate for it.

Comparing total material movement for materials across multiple batches of the same product, we can identify unexpected behaviour caused by a process or material change.

Supplementing data with engineering expertise converts data into a dynamic knowledge base

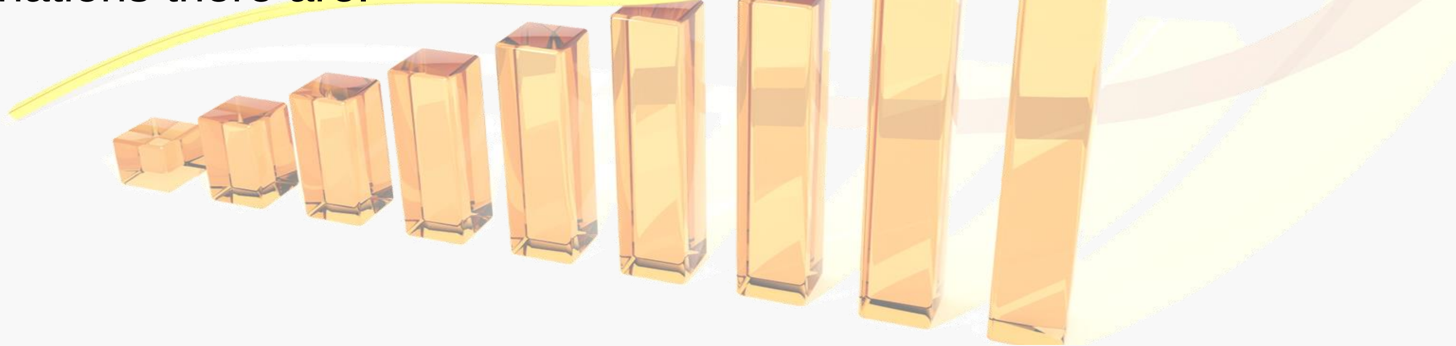
If we can answer **WHY** unexpected behaviour occurred, then we can truly enrich the data.

The volume of data generated requires automated systems to be smart and flexible

The manufacturing industry is changing to a higher product mix and lower volumes.

Product lifecycles are shorter and require new products to be launched every few months rather than every few years.

Consider the number of variables that are now involved and how many potential combinations there are.

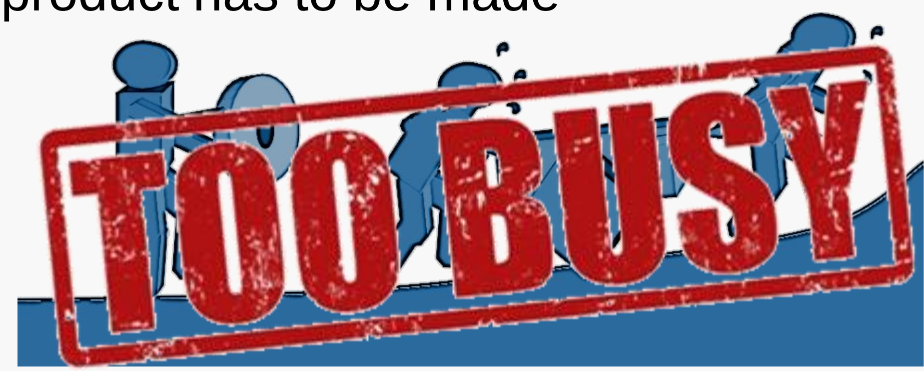


For inner layer measurements at the x-ray optimiser, machine capacity is often a restriction preventing useful data capture

Measuring a single set of targets allows product to be optimised ready for the drill process without any real understanding of the inner layer registration.

In high volume manufacture with lot sizes >100 panels, the increased cycle time for measuring all layers significantly reduces the capacity of the process.

Failing to control registration so that product has to be made again reduces capacity as well!



It is not feasible to acquire the amount of data required to always know which inner layer scale factors to use

For a single lamination 8 layer product – how many different material/process combinations could be involved?

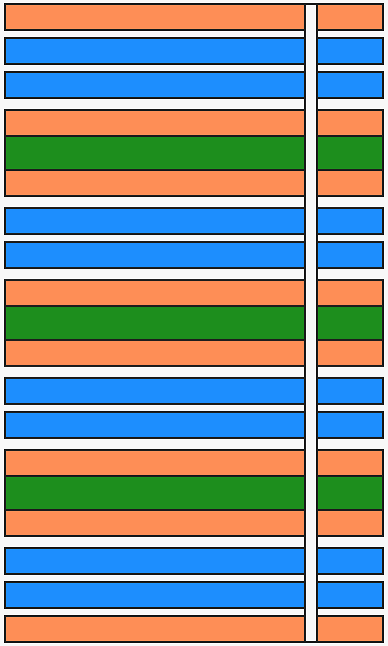
Considering a simple material list and assuming a balanced build:

- 5 core resin systems
- 10 core thicknesses per resin system
- 2 constructions per core thickness

$$5 \times (10 \times 2)^2 = 2{,}000$$

- 5 prepreg resin systems
- 4 glass cloths per resin system
- 2 resin contents per glass cloth

$$5 \times (4 \times 2)^4 = 20{,}480$$



There are more than **40 million** potential combinations without considering the options of copper thickness, copper pattern or process routes.

Increasing technical capability will have a significant effect upon the number of potential material and process combinations

Typical Technical Roadmaps…

Increased number of layers

+

Increased number of laminations

+

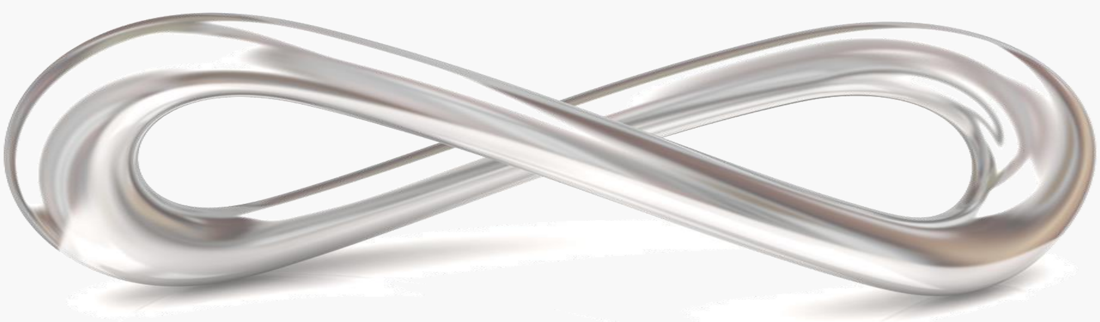
Increased number of materials

=

More possible combinations

+

Less or no knowledge of how they behave



It is clear that historical data alone will never be able to provide all the answers required

When there is no data available – people turn to the “experts”.

An expert will make an informed guess based on past experience.

Human experts do not work 24 hours / 7 days a week and may even leave taking their knowledge with them.

Multiple experts may have different opinions – how do you decide?

In an effort to improve, computerised experts have been developed – from simple spreadsheets to more complex rules based systems.

Dynamic decision making requires expert systems to be replaced by self-learning systems

An expert system uses a complex set of rules to make decisions.

The rules are fixed and do not change without manual intervention.

Given the number of possible design permutations, it is not possible to have a rule for every situation.

Smart Factories require their own intelligence…

Artificial Intelligence (A.I.)

How do we put the Intelligence into the Smart Factory?

The term “Artificial Intelligence” was coined in the 1950’s though the concept of developing human-like intelligence within computers has been around since the first electronic computers.

In 1950, Alan Turing famously asked the question “Can machines think?” and raised the possibility that a computerised system might learn from experience much like we do as children.

Progress in this field is now rapidly moving forwards in the field of manufacturing due to 3 primary factors:

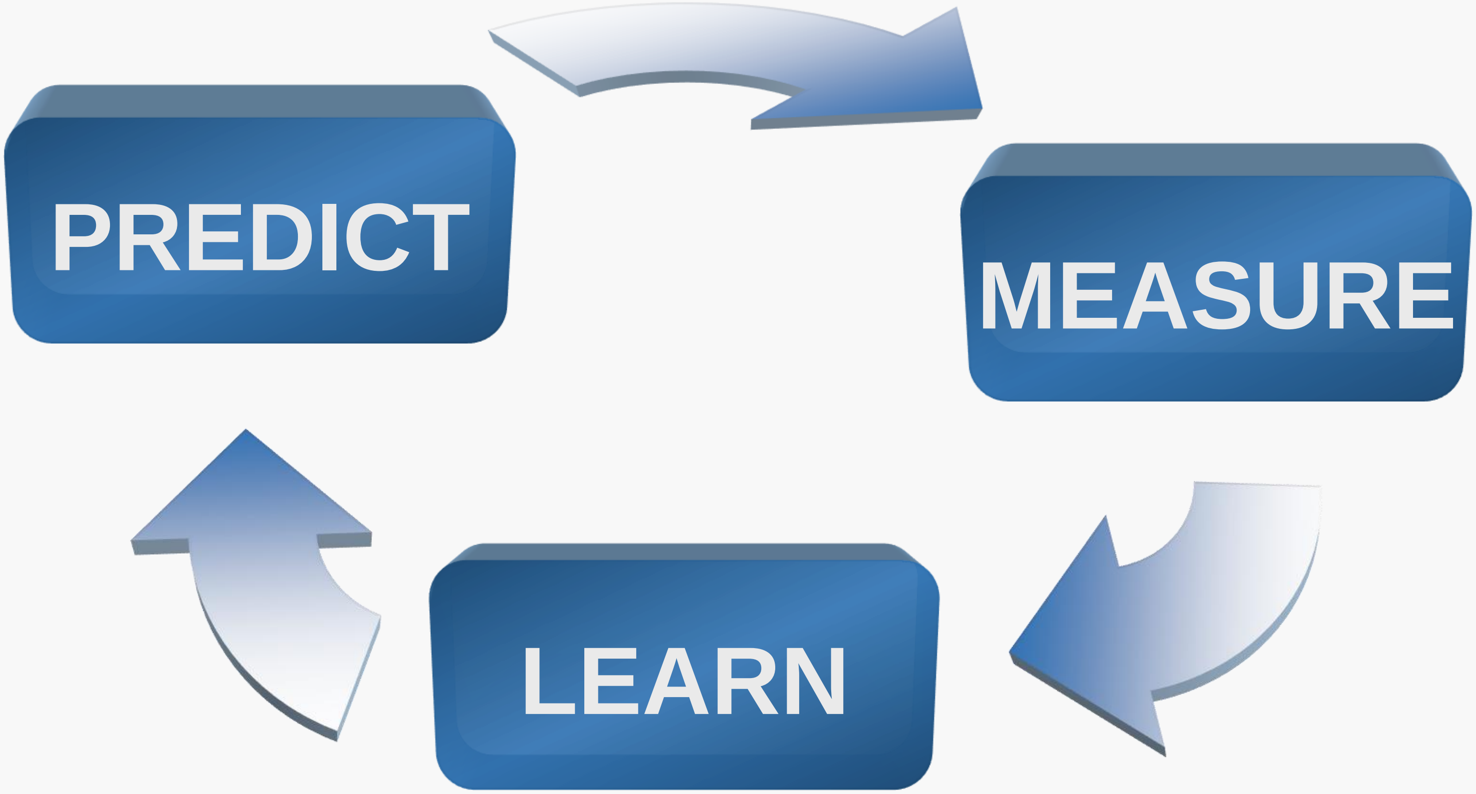
- Availability of data
- Improved machine learning and algorithms
- More powerful computers

Machine learning can be used where it is not feasible or difficult to write down explicit rules to solve a problem

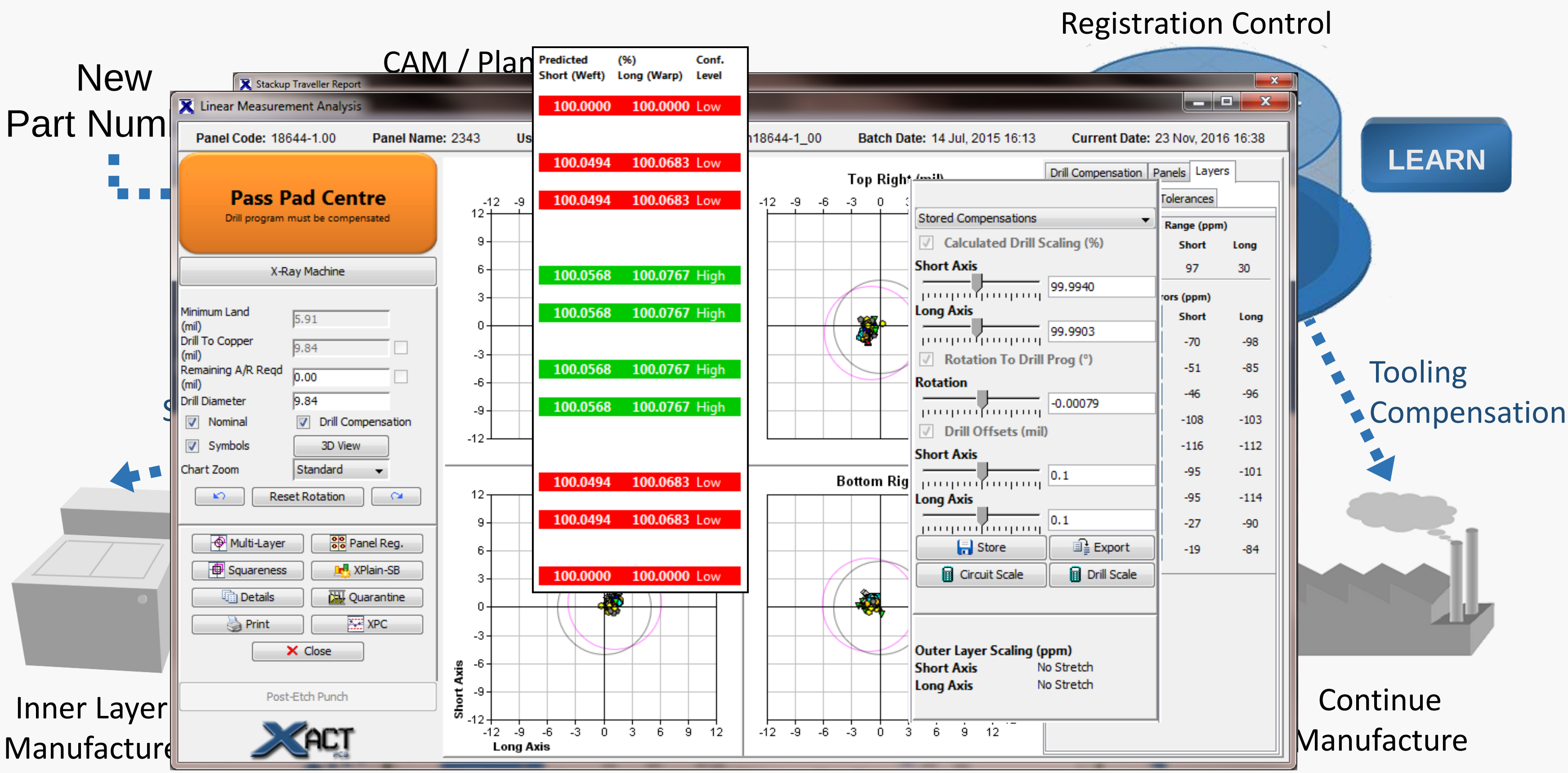
Machine learning is a statistical process that uses accumulated data and uses this to derive an algorithm or procedure that explains the data and can be used to predict future data.

A model with millions of parameters will have an **astronomical number of possible outcomes** and therefore to be successful machine learning must find a simplified set of parameters that can achieve the greatest accuracy and repeatability with a feasible level of computational effort.

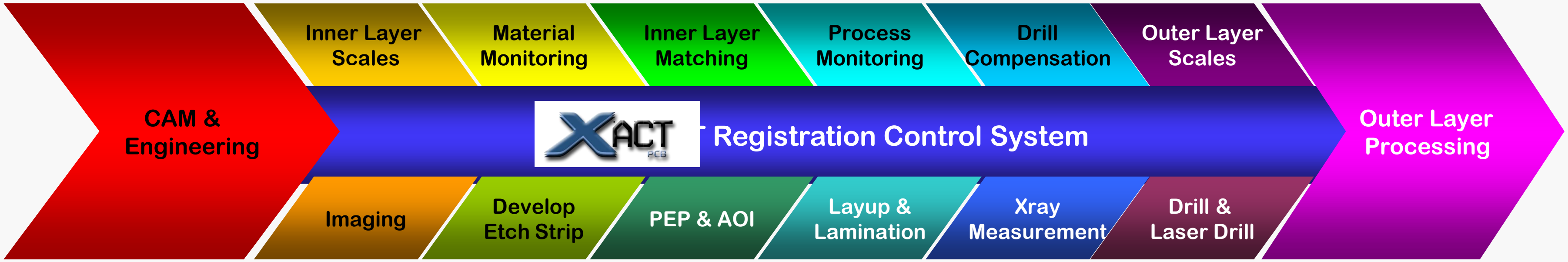
Effective machine learning follows a simple cycle of events



In registration control we see how these steps are applied to the manufacturing process



A registration control system provides a platform for exchange of data allowing a wide range of processes to seamlessly interact



- Step by step implementation establishes proof of concept and demonstrates return on investment.
- A common registration control “backbone” allows a wide range of vendors to be a part of a platform that they don’t need to develop.

The Smart Factory develops by integrating all functions from enterprise to shop floor to enable truly automated value chains

Take the first step