An Investigation of Options Available to Dürr for its Industry 4.0 Strategy

THE UNIVERSITY OF WARWICK

Presentation for Viva Voce MSc MSEM

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Structure:

Introduction to Dürr

What is Industry 4.0 (Technologies)

Why is it relevant (Market Trends)

What are the options for capitalization

Adopting an Industry 4.0 Strategy

Selecting the right option for Dürr

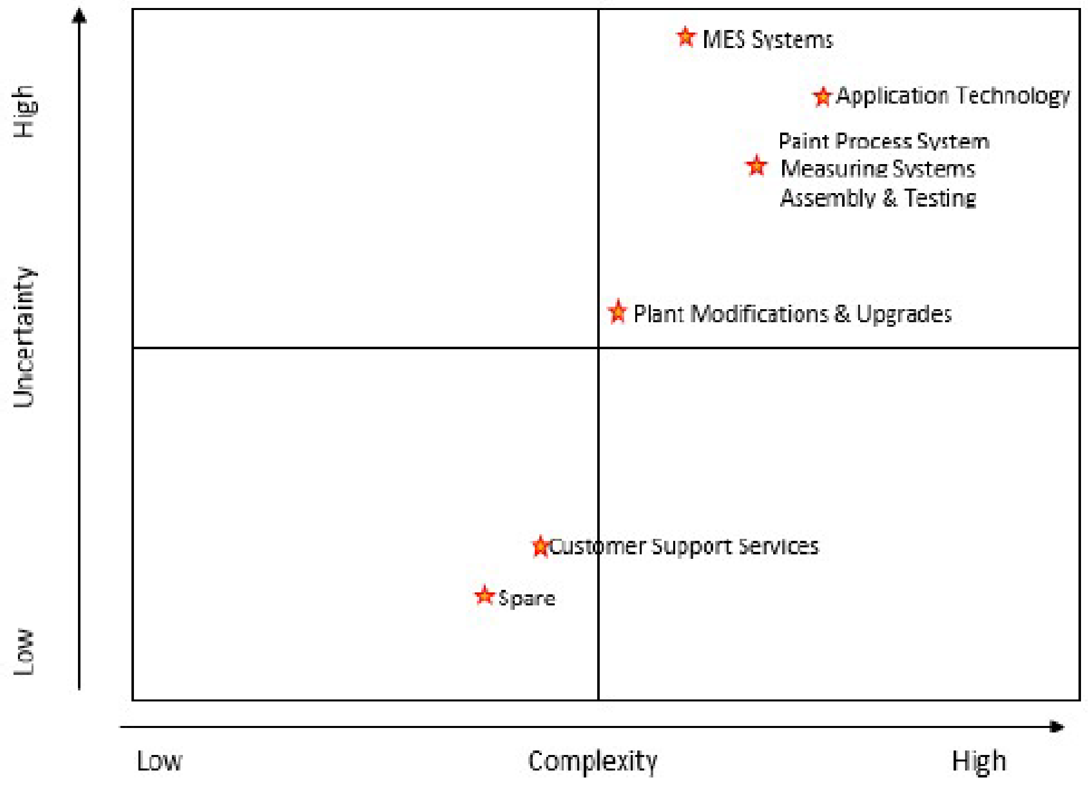
A solution based on the selected option

Requirements to develop other similar solutions

Conclusion/Recommendations

About Dürr

- Product Mix
  - Low Volume / High complexity
  - High Value Product – Puttick Grid
  - Fit for Purpose
- The Market
  - Mid / High Range Automotive
  - manufacturing
- Sources of differentiation
  - Industry Knowledge
  - Efficient Production Systems
  - Focus on R&D
  - Installed base



What is Industry 4.0 (Technologies)

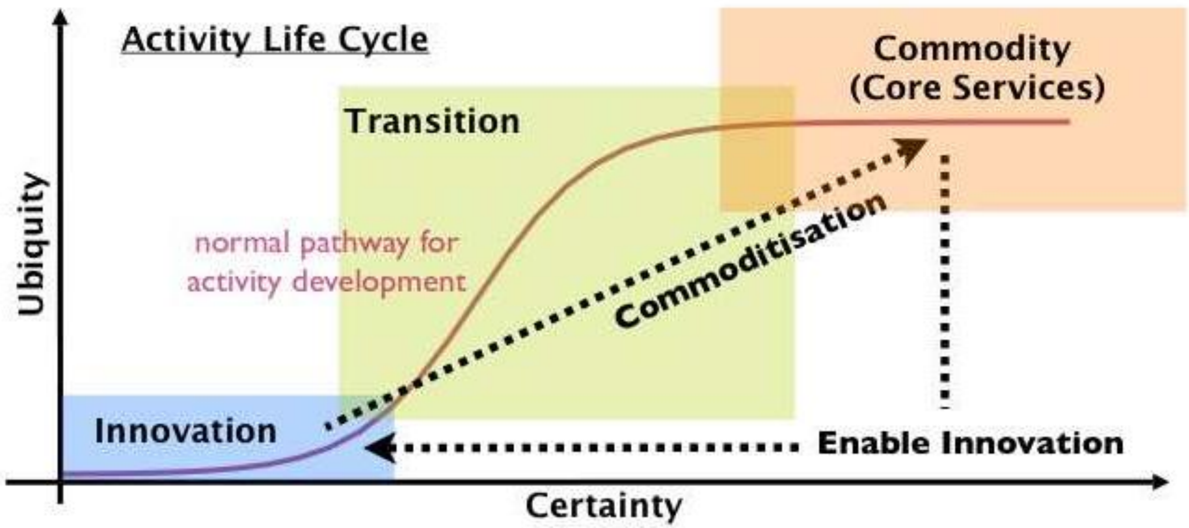
- Cyber Physical Production Systems
  - Smart Assets, high flexibility & integration
- Cloud Computing
  - Data storage & manipulation, Applications (faster development / deployment / volume)
- Data Analytics & Machine Learning
  - Data driven insights, Useful remaining life, Predictive maintenance, System flexibility
- Digital Twins
  - Better performance monitoring, Full life cycle visibility, New business models
- Industrial Internet of Things
  - Ubiquity of connectivity & data, Edge based solutions

Why is it relevant (Market Trends)

- Existing opportunities for cost effective production (Lean, JIT, Out Sourcing) have been exhausted - new methods are now required (Rojko, 2017) .
- Flexible Production Process:
  - Low cost variability – batch size 1 / flexible production processes
  - Supply chain complexity / responsiveness / agility
  - Improved visibility of the material flow & processes
- Shorter Product lifecycles
- Software as a source of differentiation

Market Trend (Commoditization of Technology)

- Commoditization of technology
  - Maturity of production processes
  - Ubiquity of engineering tools & pre-packaged solutions
  - Increased cost pressures due to globalization
- Commoditization Drivers
  - Product Substitutability
  - Emergence of Standard Design
  - Transparency of product features and price
- Signalling commoditization
  - Increasing price sensitivity (increased buyer power)
  - Increasing pricing Competition (reducing margins)
  - Industry consolidation (through M&A)



Source: Rothkopf, M. (2009)

Responses to Commoditization

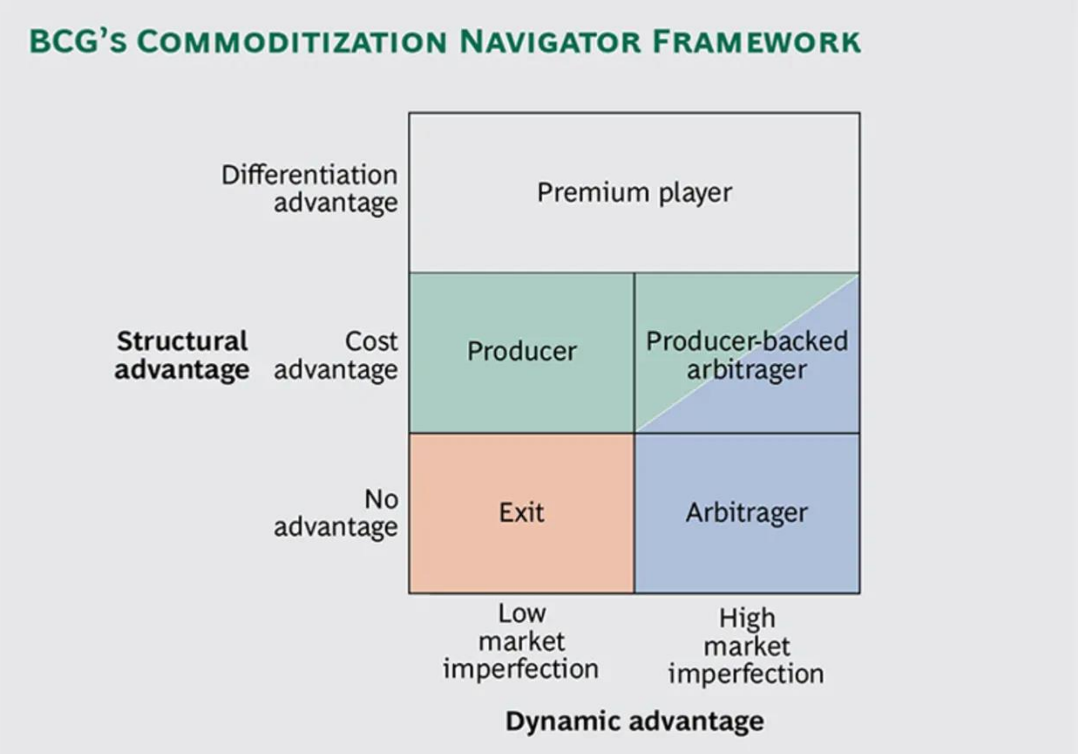
- BCG's Commoditization Navigator Framework:

  Source: (Boudier et al., 2015)

- Framework developed for electronics industry:

  - *Using collaborative innovation for development of breakthrough products*
  - *Developing capabilities for superior product development*
  - *Aligning R&D with business strategy*
  - *Enhancing efficiency of the product lifecycle*
  - *Aligning IT strategy with business needs*

Source: (Olson and Sharma, 2008)



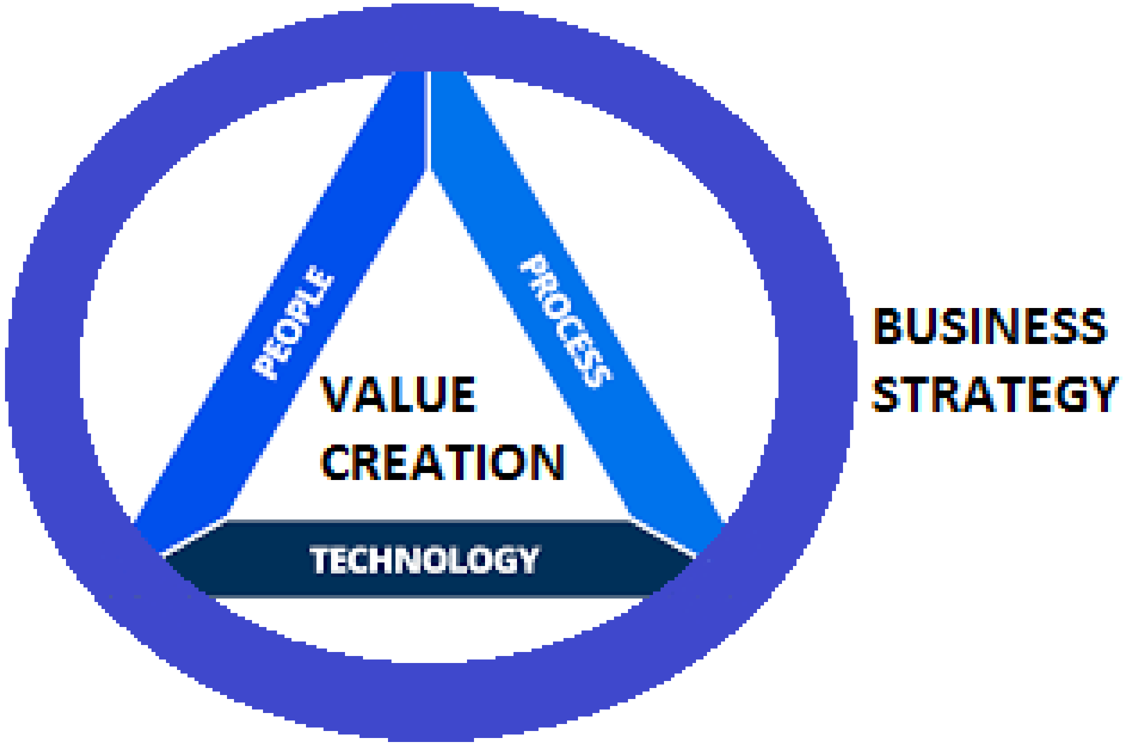
Source: BCG analysis.

Industry 4.0 (Opportunities & Challenges)

- Three main themes (Ehret and Wirtz, 2017):
- Asset Driven Opportunities
    - Smart Assets / Hardware As A Service
    - Software Capabilities / Technology Stack for communications / Operational requirements for services
- Service Driven Opportunities
    - Opportunities targeted at End users / App Market Place / Platform As A Service
    - Fundamental changes in Business Model / Operations / Market
- Innovations to aid manufacturing
    - Increased effectiveness for existing products and solutions / Software As A Service
    - Software Competencies / Additional requirements for solutions
        - Interoperability
        - Scalability
        - Flexibility
        - Data Security
- Alignment with Dürr’s existing business model

Pathways for Adoption

- Strategic Direction / Questions / Implications
- Strategy Alignment Model (Avison *et al.*, 2004)
  - Internal : Skills / Processes / Administration / Information system
  - External : Business Scope (Product – Market fit) / Technology Scope (technology stack)
- Integration – Business Transformation
  - People , Processes & Technology (Leavitt, 1962)
- Value Creation
- Capability Maturity Model (Jaione and Nekane, 2016)
  - Initial: A company specific industry 4.0 vision doesn´t exist
  - Managed: There exist a Roadmap of industry 4.0 strategy
  - Defined: Customer segments, value proposition and key resources defined
  - Transform: Transform the strategy into concrete projects.
  - Detailed BM: Transformation of Business Model



Hypothesis

1. Dürr can use the concepts of industry 4.0 to deliver benefits to the customer by focusing on value creation in manufacturing processes

2. A use case developed with demonstrable benefits for one specific application can be used to distill general principles that can be used for other similar applications

3. The exercise of developing the use case can highlight the capabilities required for further development, generating a pathway for adoption.

Research Methodology (Philosophical Stance)

Beliefs & Assumption		
Ontological (nature of reality or being)	**Epistemological** (what constitutes acceptable knowledge)	**Axiological** (role of values)
1. The measure of success of an organization's strategy is its ability to develop and sustain a competitive advantage. 2. Manufacturers value the ability to manufacture products faster, reliably and cost effectively. 3. A product or service that can deliver capabilities listed above can generate a competitive advantage for the supplier.	1. The available case studies on industry 4.0 technologies are not sufficiently generalizable to be applied to all manufacturers/suppliers. 2. Useful principles can be deduced from studying a single use case, for industry 4.0 technologies, that can be applied to other similar use cases. 3. The principles derived from the above can be reliably translated to a set of requirements in terms of capabilities, processes and technologies.	1. For a product/service to be valuable it must demonstrate an improvement in a measurable metric of performance that is relevant for the customer. 2. The intrinsic value created by a service/product based on industry 4.0 technology should not bound to the subjective values 3. A strategy can be defined in terms of value proposition, required processes, capabilities and resources.

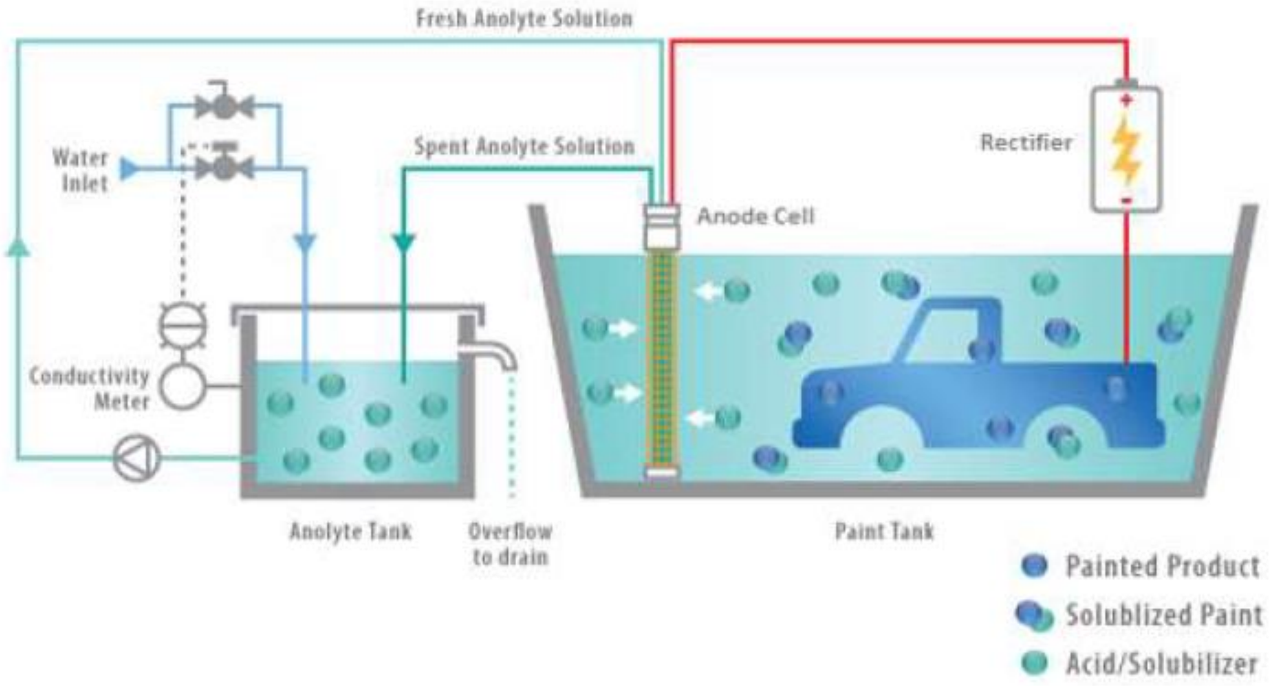
Research Methodology (Philosophical Stance)

Pragmatism			
Ontology (nature of reality or being)	**Epistemology** (what constitutes acceptable knowledge)	**Axiology** (role of values)	**Methods**
Complex, rich, external 'Reality' is the practical consequences of ideas Flux of processes, experiences and practices	Practical meaning of knowledge in specific contexts 'True' theories and knowledge are those that enable successful action Focus on problems, practices and relevance Problem solving and informed future practice as contribution	Value-driven Research. Research initiated and sustained by researcher's doubts and beliefs Researcher reflexive	Following research problem and research question Range of methods: mixed, multiple, qualitative, quantitative, action research Emphasis on practical solutions and outcomes

(Saunders, Thornhill and Philip, 2019)

Research Design (Use Case)

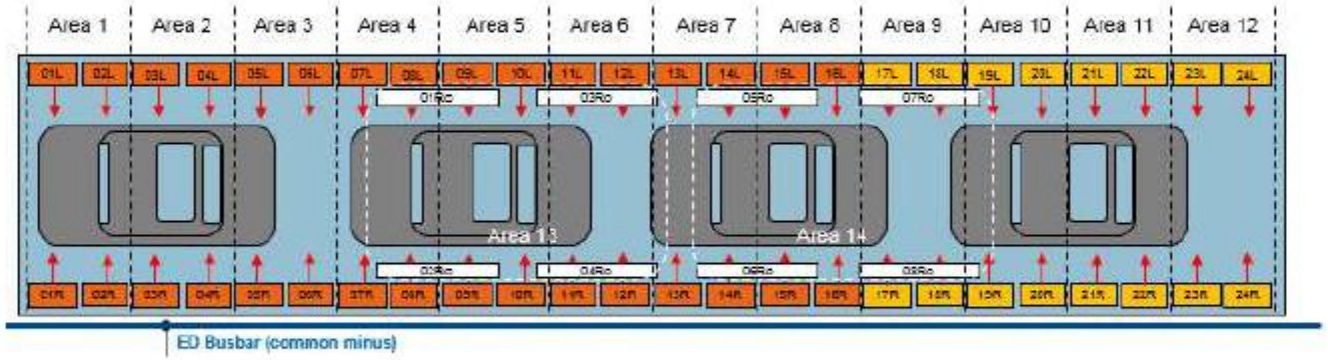
- Selected Application – Electro Coating
  - Core system for Automotive manufacturing process
  - Core product for Durr's PFS division
- Potential Benefits (source of value creation):
  - Reduce cost of production (Energy/Material)
  - Quality (produce better)
  - Availability (produce consistently)
  - Performance (produce faster)
- Proposed Technology:
  - Analytics & Machine Learning

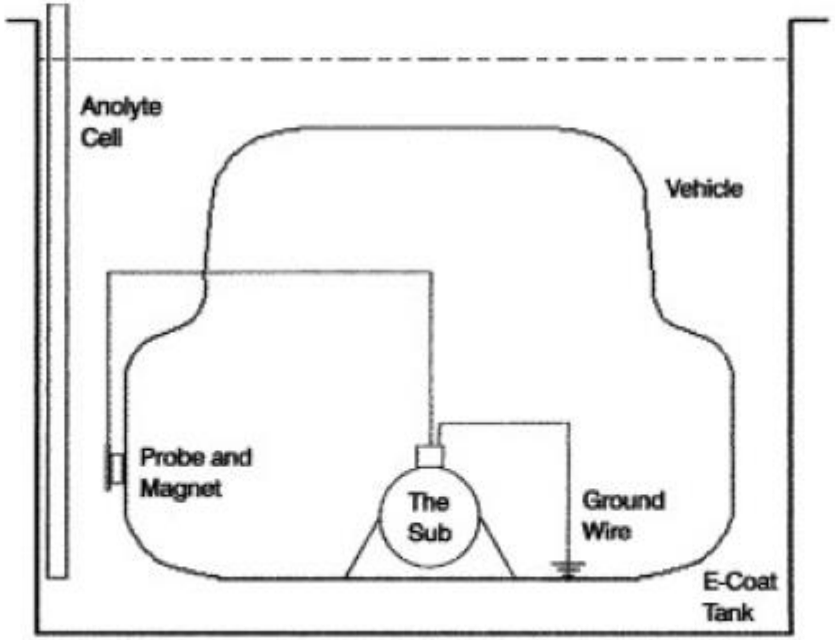


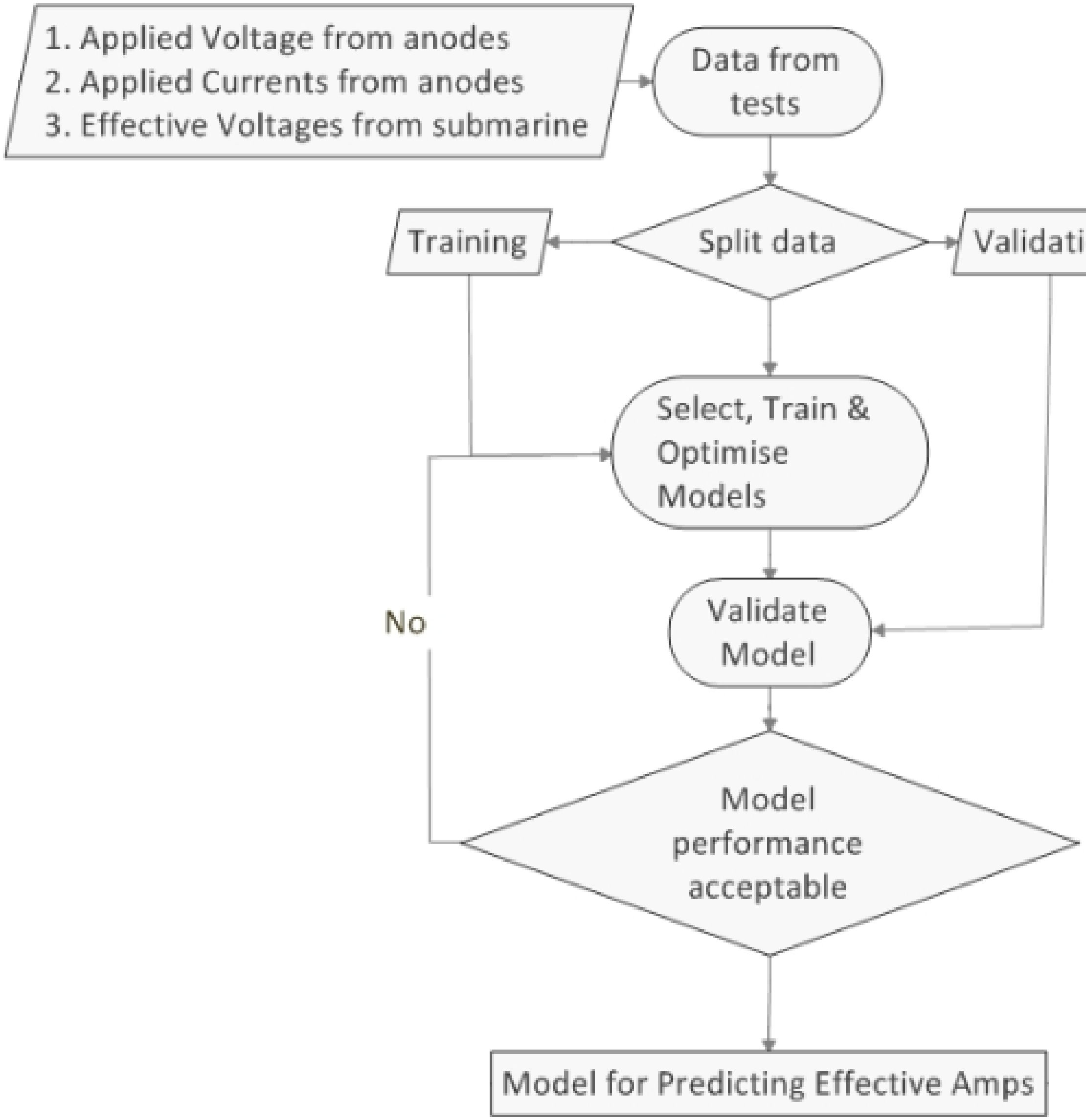
Source: Snyder filtration Systems

Research Design (Data Sources)

- Data Sources:
  - Control System
  - Datalogger
- Control System:
  - 28 Pair of Anodes
  - Applied voltages from 44 IGBTs
  - Applied current from 44 IGBTs
  - Combined into 14 configurable zones (V/I Setpoints)
- Datalogger – Submarine tests:
  - Effective voltages at 5 points on body shell:
    - Roof
    - Front Chassis
    - RH Wing Mount
    - LH Wing Mount
    - Rear Chassis



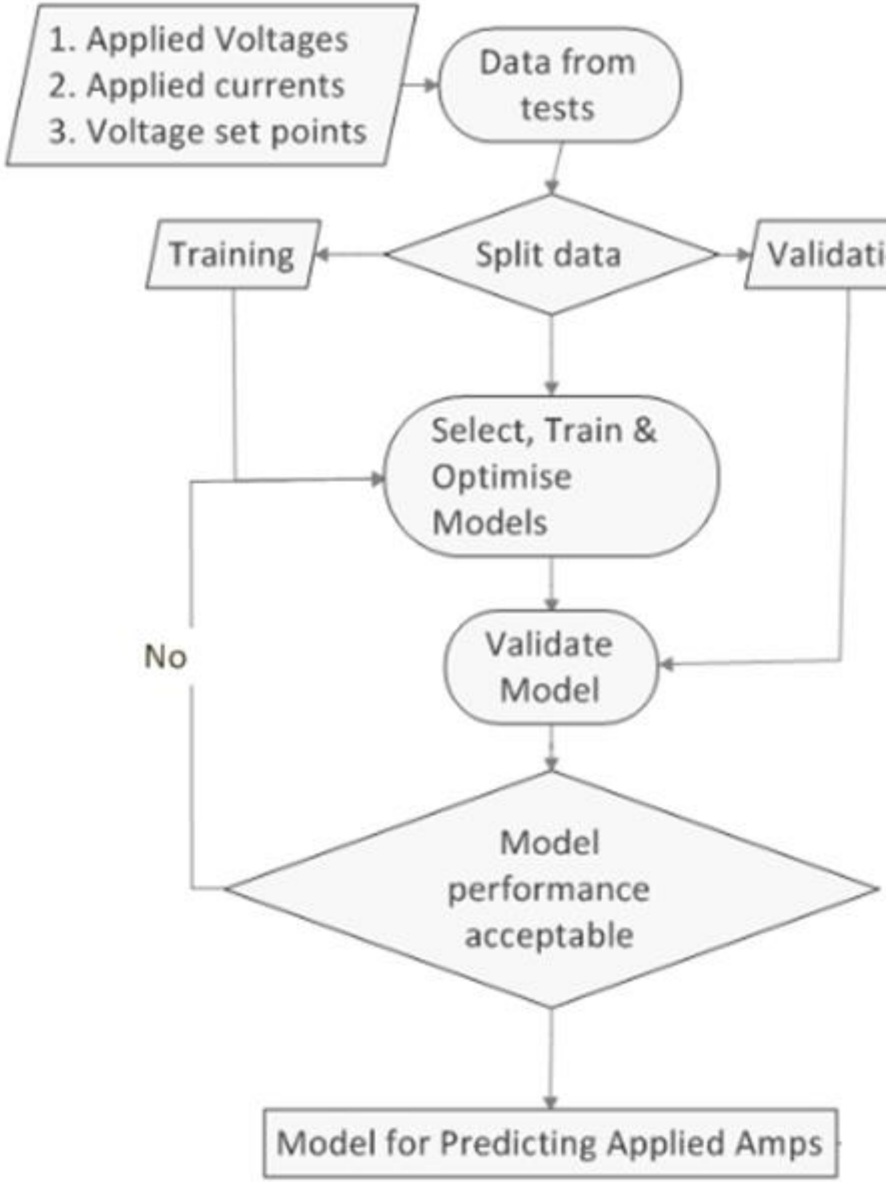




Experiment Design

1. Two submarine tests run data logged

2. Using data from the tests to train and validate a machine learning model to predict effective currents on the body based on the applied voltages.

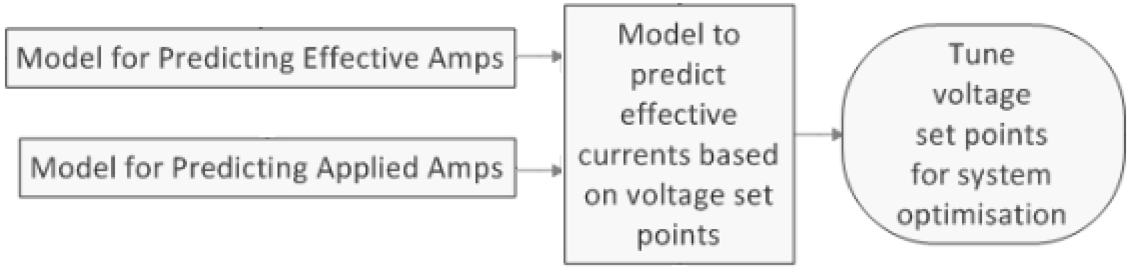


Experiment Design

3. Data from multiple runs for voltage setpoints and applied currents to generate a model for predicting applied currents based on voltage setpoints.

Experiment Design

4. Combining models from 2 & 3 to generate a model for predicting the effective currents on the body based on voltage setpoints to allow process optimization.



Model For Predicting Effective Amps

Purpose: The ability to predict the film build for the car body using the applied voltages and currents

- Factors:
  - Applied voltage
  - State of the anodes
  - Conductivity of the bath
  - Paint adhesion (coulombic yield/throw power)
- Limitations (Assumptions):
  - Anode performance (consistent / represented by data)
  - Bath state (consistent / represented by Data)

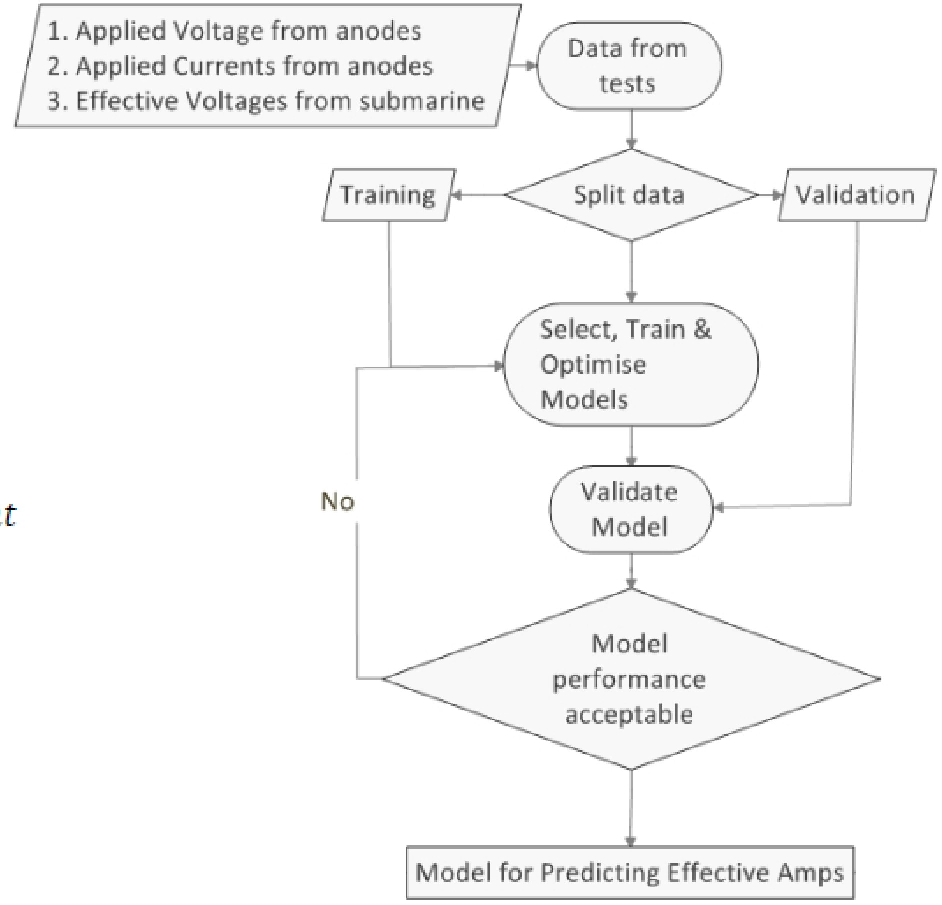
$$FilmThickness = c * Coulombs \qquad c = coulombic\ yield\ for\ the\ paint$$

$$Coulombs(t) = \int_{t=0}^{t} Amps_{tot}(t)dt$$

  - Variation in throw power is negligible on a panel

$$Eff\_Amps_A(t) = Amps_{tot}(t) * Eff\_Volts_A(t)/Eff\_Volts_{tot}(t)$$

  - Bounded system (full body within system at all times)



Model For Predicting Effective Amps

- Model Selection:

Linear Model:

$$y = w_0x_0 + w_1x_1 + b$$

Quadratic Model:

$$y = w_0x_0 + w_1x_0^2 + w_3x_1 + w_4x_1^2 + b$$

Cubic Model:

$$y = w_0x_0 + w_1x_0^2 + w_2x_0^3 + w_4x_1 + w_5x_1^2 + w_6x_1^3 + b$$

$$x_0 = Amps_{total}$$
$$x_1 = Coulombs$$
$$w_x = coeffectient$$
$$b = y\ intercept$$

- Cost Function:

$$\frac{1}{N}\sum_{i=1}^{N}(f_{w,b}(x_0, x_1) - y_i)^2$$

- Model Evaluation:

$$R^2 = \frac{Variance\ explained\ by\ the\ model}{Total\ variance}$$

$$R^2(y, \hat{y}) = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

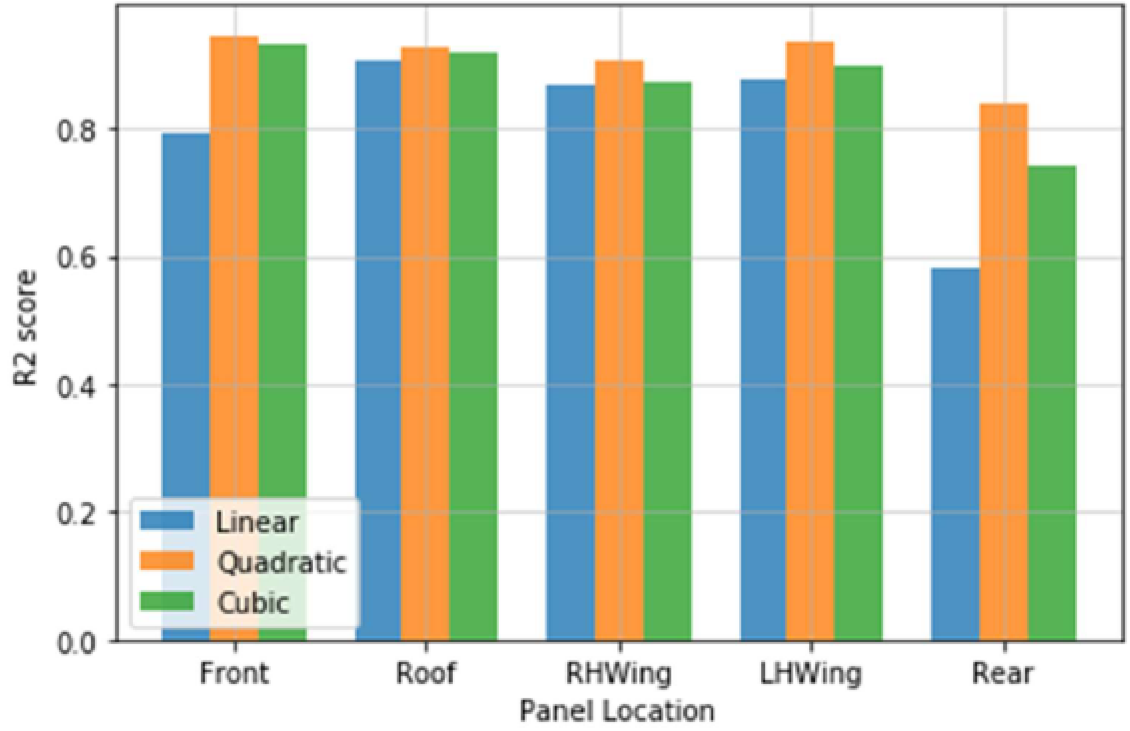
Where:

$\hat{y} = predicted\ value, \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ and $\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 = \sum_{i=1}^{n} \text{error}_i^2$

Model For Predicting Effective Amps

- Quadratic Model Performance on Training Data:

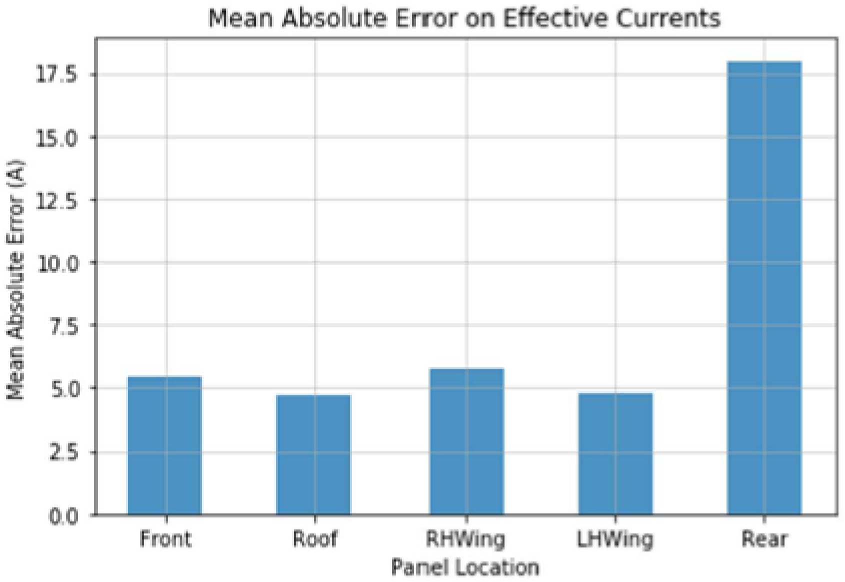
Description	R^2 Score
Front Chassis	0.945
Roof Edge	0.926
RH Wing Mount	0.908
LH Wing Mount	0.936
Rear Chassis	0.840
Average Score	0.946

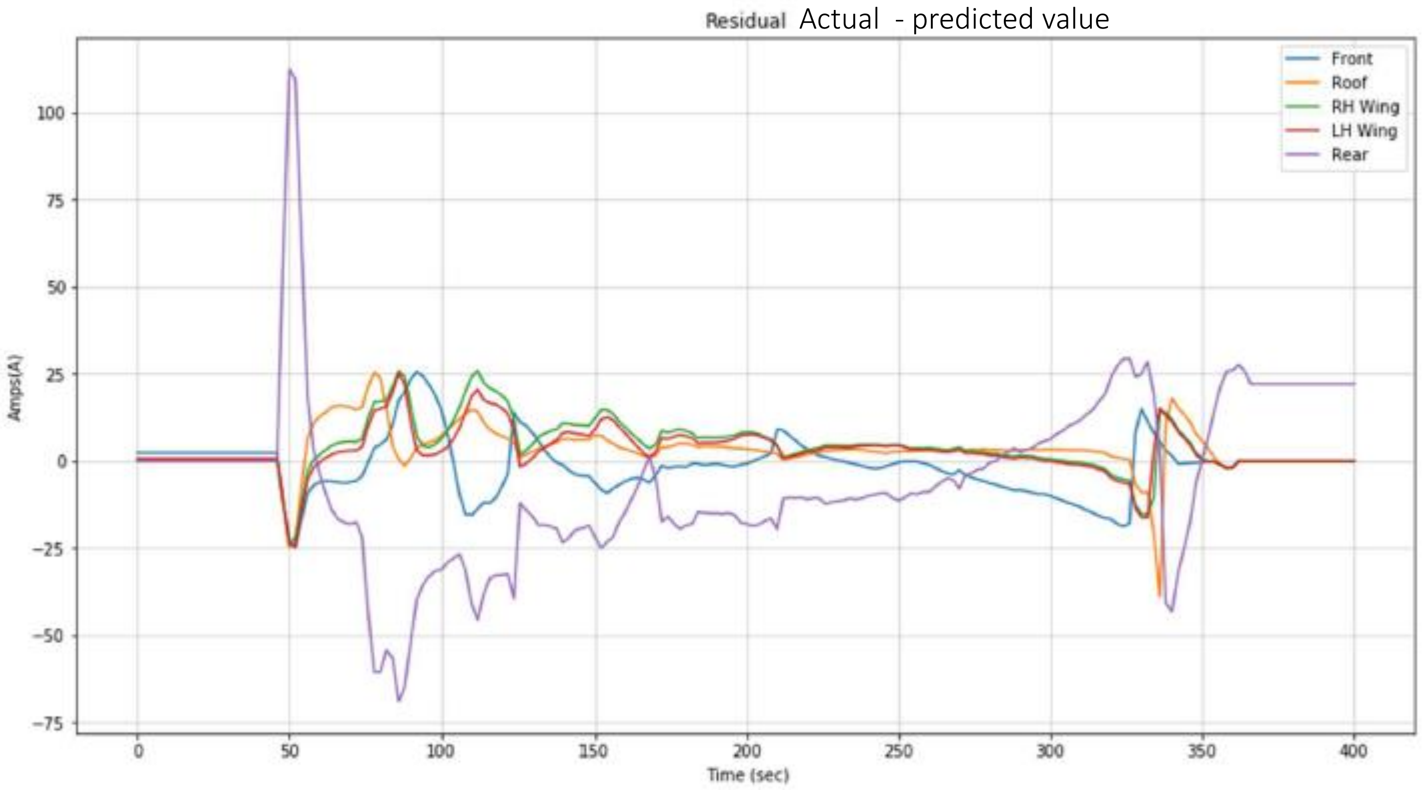


94.6% of the variance in the data is explained by the model

Model For Predicting Effective Amps

- Effective Amps prediction



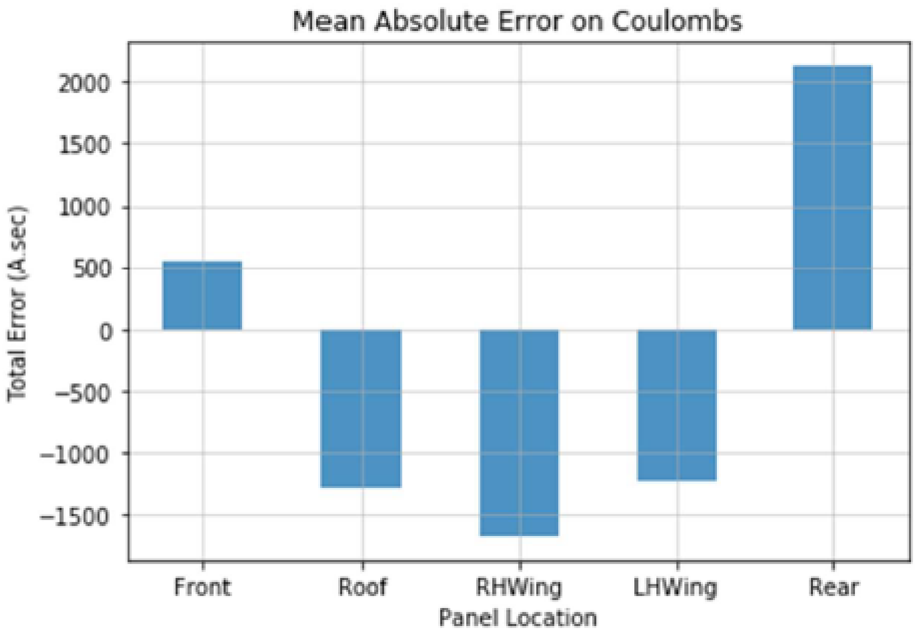


- Higher Error on Rear chassis
  - Body Orientation
  - Location within tank
- Possible Solutions:
  - Parameter for body location / orientation within tank

Model For Predicting Effective Amps

- Film build prediction

Panel	Total Error - Coulombs (Amp.Sec)	Total Error - Film thickness (µm)	Percentage error
Front Chassis	540.5	0.489494	3.4%
Roof Panel	-1276.3	-1.15586	-7.7%
RH Wing Panel	-1675.6	-1.51748	-10.4%
LH Wing Panel	-1233.0	-1.11664	-7.7%
Rear Panel	2127.5	1.92673	8.2%



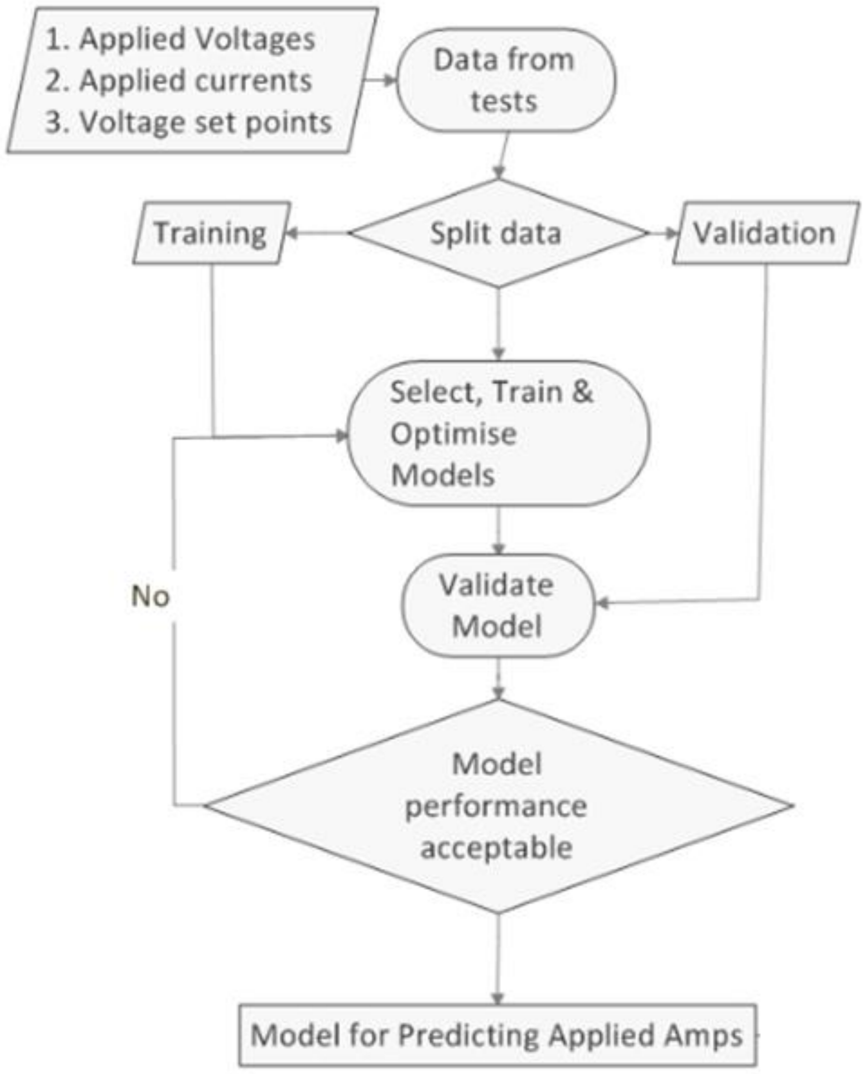
Further improvements:

- larger training dataset
- body location/orientation,
- Age of the anodes
- Bath parameters (temperature, pH etc.)

Model for Predicting Applied Amps

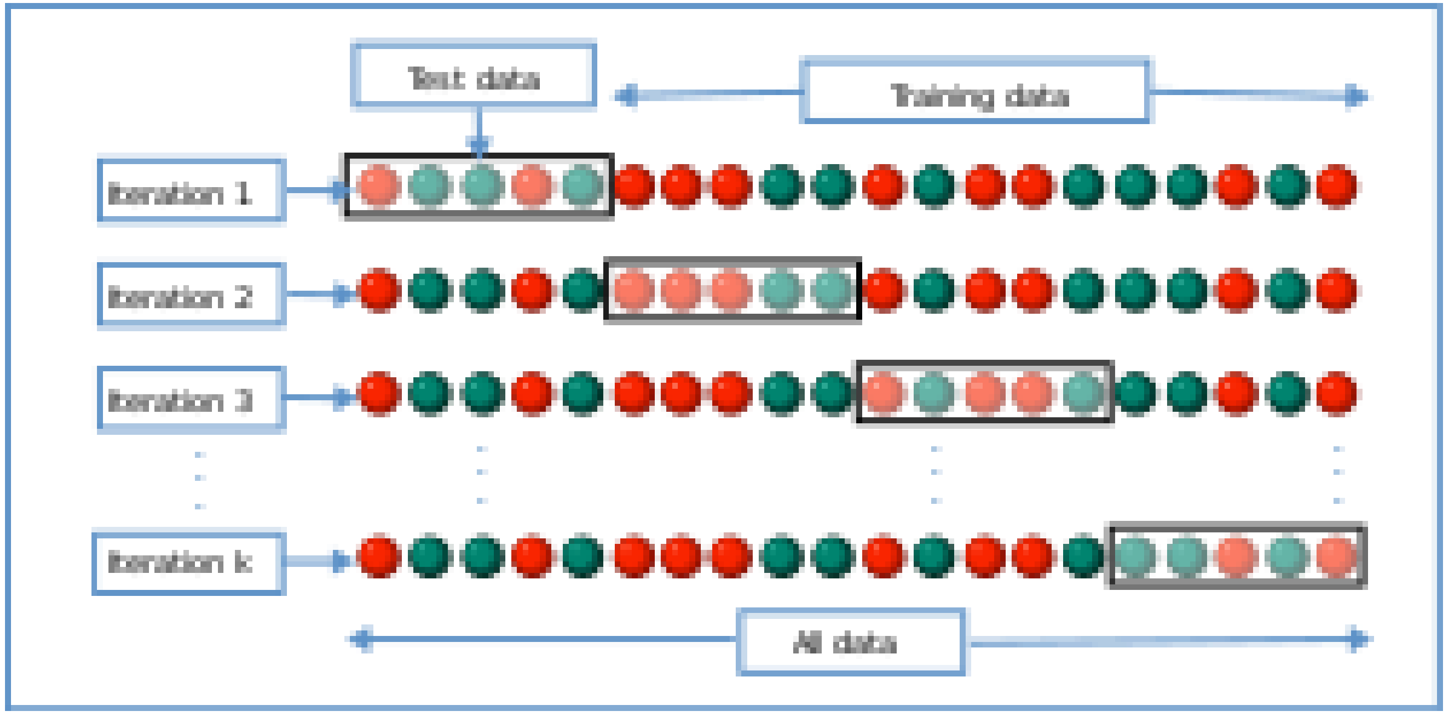
Purpose: The ability to predict applied amps based on setpoints

- Factors effecting applied Amps:
  - Applied voltage
  - State of the anodes
  - Film thickness
  - Conductivity of the bath
- Limitations (Assumptions)
  - IGBT performance (Applied voltage = Setpoint)
  - Anode performance (consistent / represented by data)
  - Bath state (consistent / represented by Data)
  - Current limit – 52A



Model for Predicting Applied Amps

- Models testing with hyper parameter tuning:
  - Linear Model – Unregularized / Ridge Regression
  - Quadratic Model – Unregularized / Ridge Regression
- Regularization / Hyper-parameter tuning:
  - Ridge Regression
  - 5 fold cross validation for hyperparameter tuning
  - Full set cross validation for hyperparameter tuning



- Cost Function:

$$J(w)_{Ridge} = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 + \propto \sum_{j=1}^{m} w_j^2$$

Here: $L2: \propto \sum_{j=1}^{m} w_j^2$

Model for Predicting Applied Amps

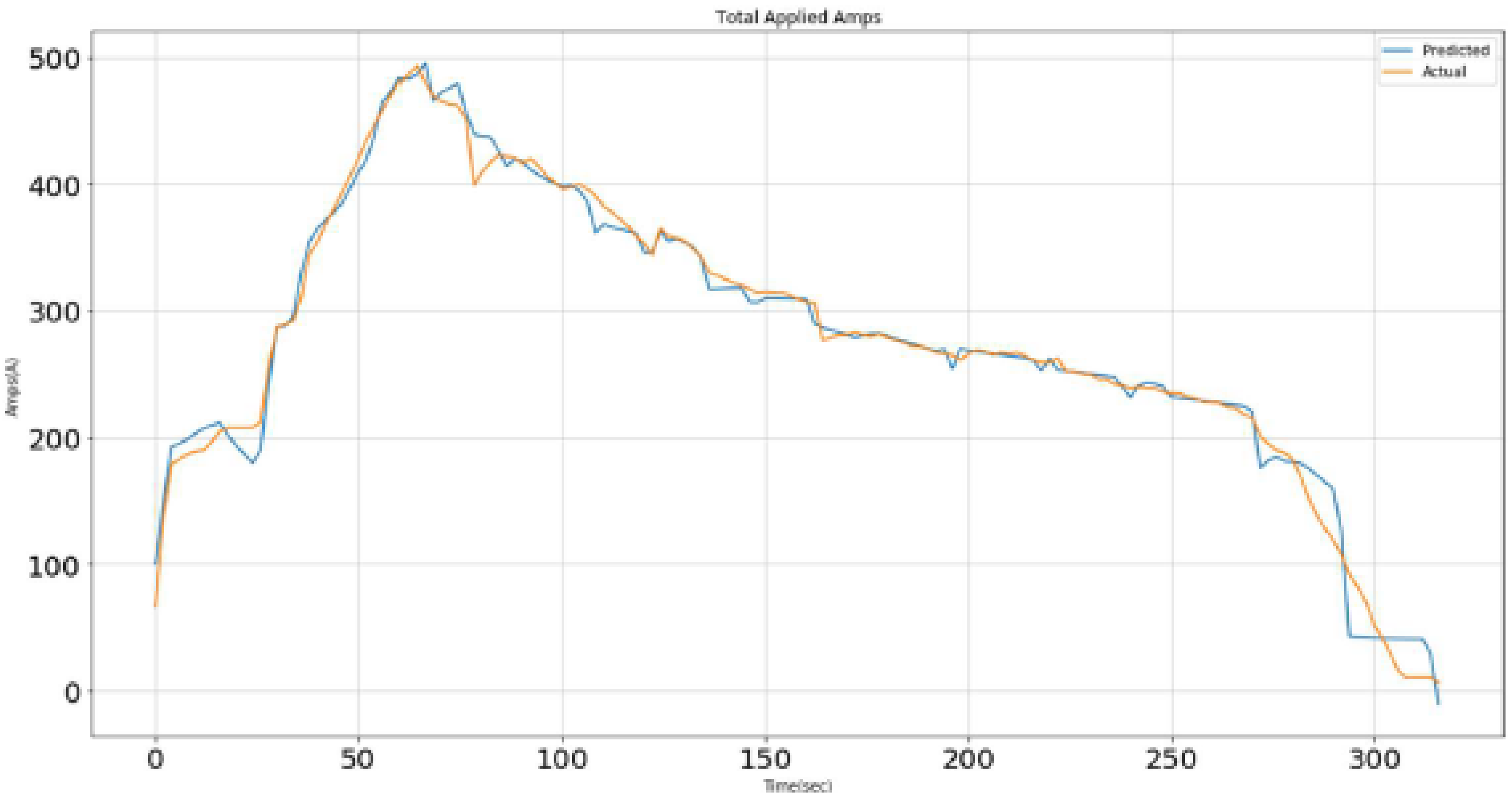
- Performance Metric (MAE):
  - Differences in training & Validation dataset size
- Model Evaluation:

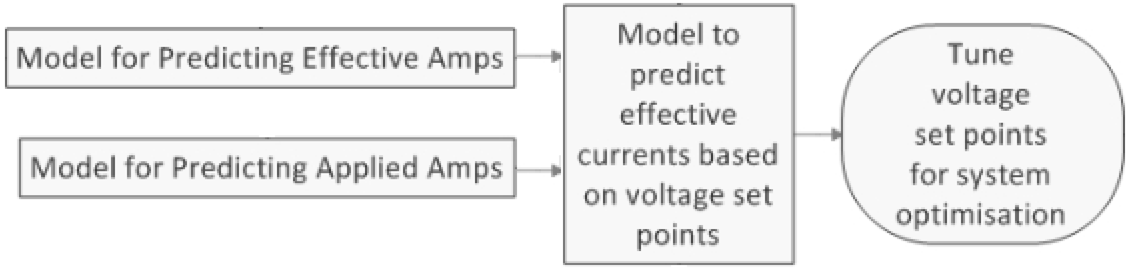
Model	MAE
Linear Regression model (unregularized)	23.52
Linear Ridge Regression model with 5-fold cross validation	69.42
Linear Ridge Regression model with “full set” cross validation	31.8
Quadratic regression model (unregularized)	7016.37
Quadratic Ridge Regression model with 5-fold cross validation	10.52
Quadratic Ridge Regression model with “full set” cross validation	8.80

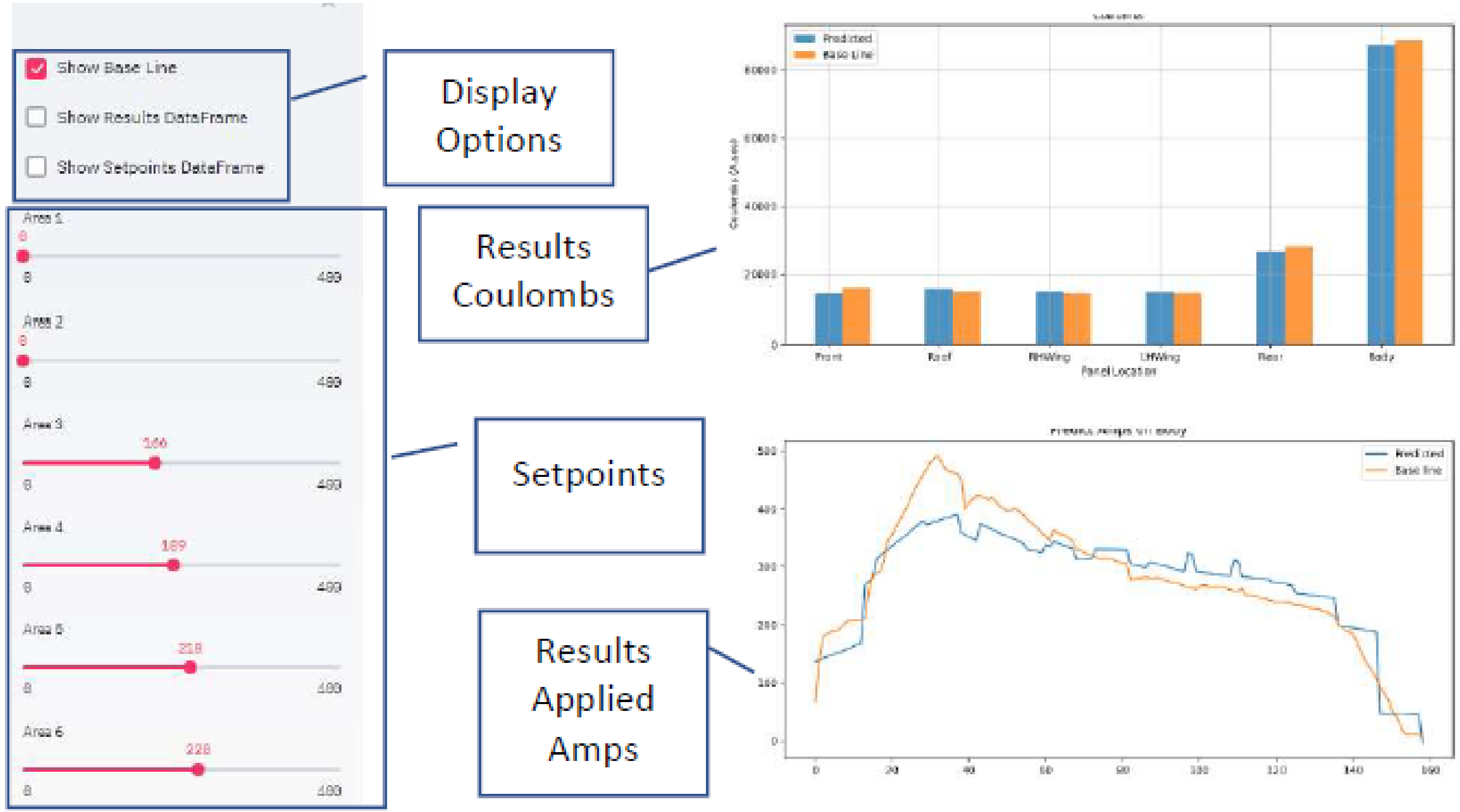
For the training data: Quadratic ridge regression model, with the hyper parameter tuned using full set validation, predicts the applied amps against the voltage setpoints with a mean error of +/- 8.80 A

Model for Predicting Applied Amps

- Model Validation
- Average MAE for voltages applied by 44 IGBTs: 0.709
- Model is likely overfitted
- **Further Improvements:**
  - Additional training datasets
  - More validation tests
  - Data without current limit
  - Bath parameters
  - Body location with tank





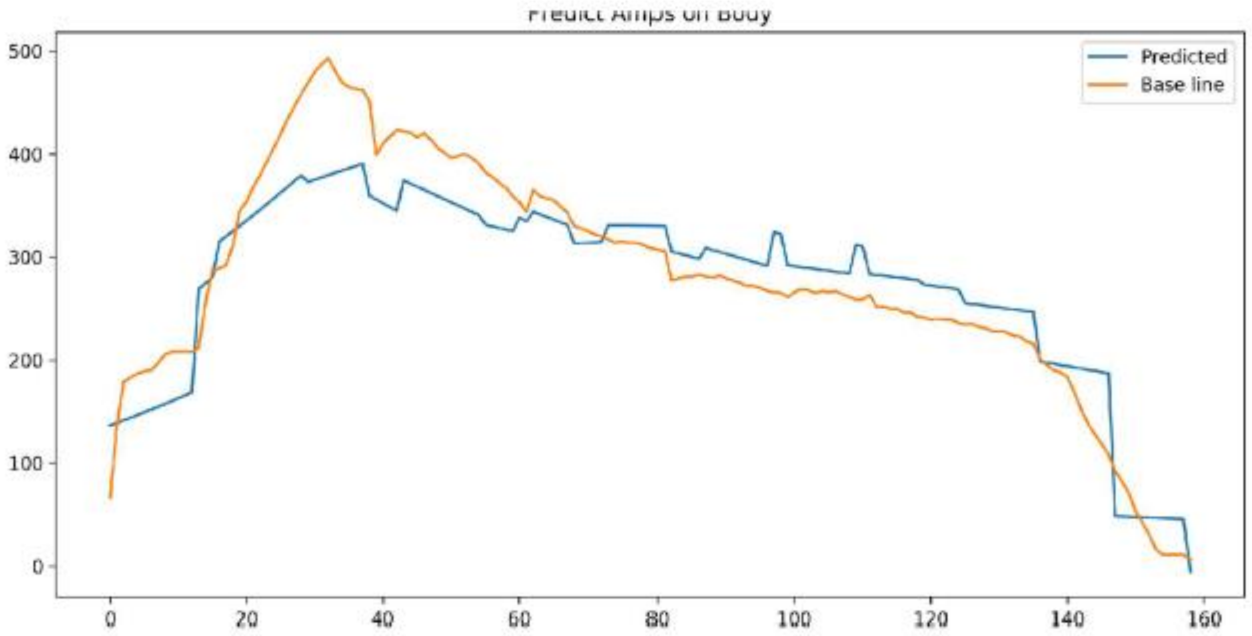


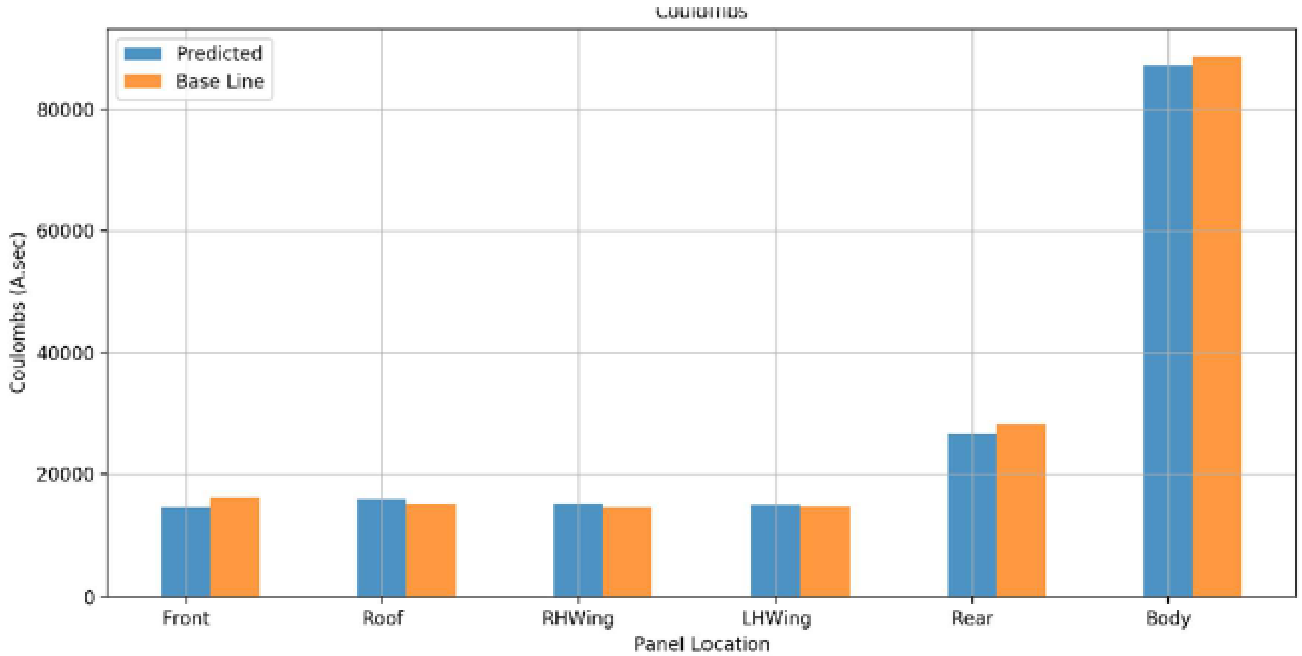
Combining the Models

Aim:

Ability to simulate the film build quality using different setpoints

1. Applied Voltages from Setpoints
2. Effective Amps from Applied voltages





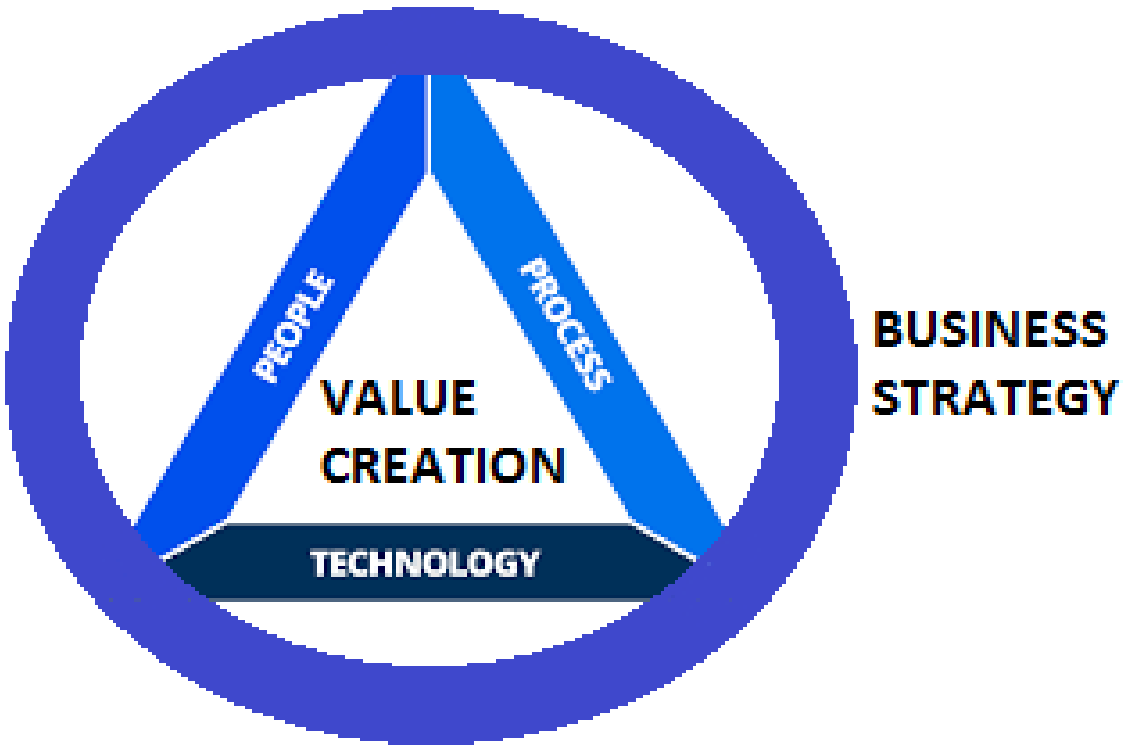
Results

1. Better Quality Monitoring at reduced cost

2. Improved film build – through system optimization

Implementing the strategy

- People:
    - Competencies:
        - Software
        - Data Analytics (Data collection / optimization)
- Process:
    - Opportunities for value creation
    - Data collection
    - System development / deployment / optimization
    - Services
- Technology:
    - Data collection (technology stack)
    - Solution development (design paradigm)
    - Deployment challenges (impact on production critical systems)
- Need for organic growth - Leveraging the existing industry knowledge with new competencies



Recommendations

1. Leverage industry knowledge to identify new solutions using ML/Analytics – multi-disciplinary teams.
2. Leverage market position - Co-creation with customers of new and efficient manufacturing processes.
3. Carryout market research to gauge the efficacy and perceived value for the potential solutions.
4. Develop new competencies related to data science, analytics and machine learning
5. Establish processes and methods for gathering and analysing data from Dürr’s installed base.
6. Develop and validate machine learning based solutions on real world production data in a controlled environment.
7. Identify technologies and opportunities to deploy the new solutions alongside production critical equipment.
8. Execute small scalable pilot (bolt-on) projects to establish deliverable benefits.
9. Develop a technology roadmap in line with the organization’s strategy for industry 4.0 and its current self-assessment against the capability maturity model.
10. Investigate opportunities for value creation for the customer using other industry 4.0 technologies such as remote monitoring and cloud computing

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