Minds & Machines
Towards the digital-industrial company

Carlos Jiménez Härtel
Special Advisor

...with friendly support from
If you went to bed an industrial company, you’re waking up a data & analytics company

Jeff Immelt, former Chairman & CEO (2014)
Investment goods – asset heavy industries

Source: General Electric Inc.
Digitalisation & Software

The Business Case

*productivity improvements & customer outcomes (incl. risk)*

The Challenge(s)

*product vs. service, apps vs. platform, CoreCo vs. NewCo*
Services evolution

Big Iron
- Partners
- Field engineers

'80s
- Advanced repairs
- Part upgrades

'90s
- Risk sharing
- Monitoring & diagnostics

'00s
- Analytics-enabled uptime
- Software-enhanced output/performance
- Remote inspections

Digital Industrial

Technology Application

Customer Outcomes

Source: General Electric Inc.
Digital transformation

The Idea

Industrial productivity

- 4% (1991 - 2010)
- 1% (2011 - 2015)

Meets the Digital Twin

Physics + Analytics

The Principles

- Deliver outcomes
- Consumer ≠ industrial
- Talent follows ideas
- Assets + devices matter

- Build digital content
- Reform IT
- Simplify culture
- Industrials trust each other

Source: General Electric Inc.
Industry 4.0 Opportunity

World Economic Forum & McKinsey & Company: “Industry 4.0 dramatically improves both top & bottom lines” “Early Adopters stand to gain significantly greater benefits”
The building blocks

Advanced data science + Physics-based + Applied engineering

Data
Continuous, accessible

Statistics & Machine learning
Identify trends & anomalies

Physics
Apply asset & domain expertise

Industrial outcomes
One platform for OT & IT teams to collaborate and innovate

Source: General Electric Inc.
### Physics and analytics – a portfolio approach

<table>
<thead>
<tr>
<th>Business Problem</th>
<th>ML Technology</th>
<th>Physics Model</th>
<th>Business Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet Segmentation</td>
<td>Learning from a low number of events Bayesian estimation, similarity search, clustering.</td>
<td>Integration with Lifting Models Spallation, and Metal Fatigue models</td>
<td>Increased uptime, optimize maintenance schedule for aircraft engines</td>
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<tr>
<td>Early Warning</td>
<td>Unsupervised and Supervised Learning of the Asset Operational Model Gaussian Mixture Model, Similarity Based Model</td>
<td>Integration with Performance Model Using Thermal model to produce virtual sensors</td>
<td>Move unplanned downtime to scheduled downtime in Aviation and locomotives</td>
</tr>
<tr>
<td>Performance Optimization</td>
<td>Supervised Learning of Asset performance Neural Network, Active Learning</td>
<td>Systems Performance Models Gate Cycle model of Power Plant, real time control of Power Plant</td>
<td>Reduce fuel consumption while maintaining production MW target</td>
</tr>
<tr>
<td>Services Optimization</td>
<td>Learning from a low number of Shop Events Ridge Regression, Similarity Search</td>
<td>Integration with Selected Domain Knowledge Survival analysis, domain features</td>
<td>Decrease service turnaround time for engines in shop</td>
</tr>
</tbody>
</table>

Source: General Electric Inc.
As the problem becomes more **COMPLEX**, the human ability to deal with it **DECREASES**, and the potential value of software **INCREASES**.
Portfolio solution map

BUSINESS OPTIMIZATION (BO)
- Market Intelligence & Forecasting
- Portfolio Optimization
- Fuel Nominations
- Financial Settlement

OPERATIONS OPTIMIZATION (OO)
- Performance Metrics
- Plant Optimization
- Outage Management
- Fuel Supply Management
- Financial Planning
- Regulatory Compliance

ASSET PERFORMANCE MANAGEMENT (APM)
- Machine & Equipment Health
- Reliability Management
- Maintenance Optimization

Source: General Electric Inc.
Asset Performance Management (APM)

- **Get Connected**
  - Machine & Equipment Health
  - Securely Connect Equipment
  - High Probability of Detection
  - Data-Rich Actionable Insights

- **Get Insights**
  - Reliability Management
  - Confidence Around Best Outcomes
  - Identify Emerging Problems
  - Collaboration

- **Get Optimized**
  - Maintenance Optimization
  - Balance Performance & Reliability
  - Optimize Maintenance
  - Maintenance Strategy

Source: General Electric Inc.
Asset Performance Management

Integrated Data & Insights
- Full Flight Aircraft Data
- Maintenance Data

Predictive Analytics
- Snapshot & Fault Report Data
- Diagnostics
- Predictions
- Monitoring

Actionable & Operational Recommendations
- Recommendations
- Trends
- Root Cause Analysis

**Disparate data** integration, cleansing and validation for asset health monitoring across heterogeneous fleet

**Packaged and customizable** physics, empirical data and machine learning based analytics that enable predictive maintenance

Data driven trend & root cause analysis for **maintenance recommendations**. Case, policy & alert management

Aviation APM provides actionable recommendations for moving from unplanned to planned maintenance

Source: General Electric Inc.
GE’s Brilliant Factory

Enabling the “digital thread”
- Fully-connected
- Automated
- Never surprised
- “Factory that never stops”
Fully Connected, Intelligent, Digital Factory

- Material Allocation to Work Order
- Machine assignment to job
- Analytics on Autoclave temperature profiles
- Tool Maintenance Recommendation
- Auto Inheritance of properties
- Production Work Order projected late
- Material Expiration Warning
- Misplaced Part / Tool
- Quality failure containment

Courtesy Plataine
To create superior value, AI must address the complete workflow: Diagnosis, Prognosis and Treatment.
Additive ... born-digital manufacturing
Enterprise level disruption

**Design**

- **Additive**
  - 1 Digital Twin
  - 6-8 Engineers

- **Conventional**
  - 300 parts
  - 60 Engineers

**Manufacturing**

- 1 Mfg. sources & Inspection Sys.
- 1 data lake...powering PREDIX

**Services**

- 1 Repair Source
- 5 Repair sources
Advanced turboprop engine (ATP)

Combustor test schedule reduced from **12 months** to **6 months**

5% WEIGHT REDUCTION

20% LOWER MISSION FUEL BURN

855 → 12 PARTS
Digital technologies in industry

think productivity and customer outcomes (incl. risk)

all levels matter: product- / operations- / business-optimization

investment lifecycle setting the pace (not Moore’s law)

small changes can mean big wins (it’s not a 10X world)