What Machine Learning can do for you using FactoryTalk® InnovationSuite

Rockwell Automation

Agenda

1 Introduction

2 Adoption Strategy

3 Data Science Process

4 ML on FactoryTalk® InnovationSuite

5 ML Reference Architectures

6 Data Pipelines / Big Data Pipelines

7 Data Scientist / Citizen Data Scientist Experiences

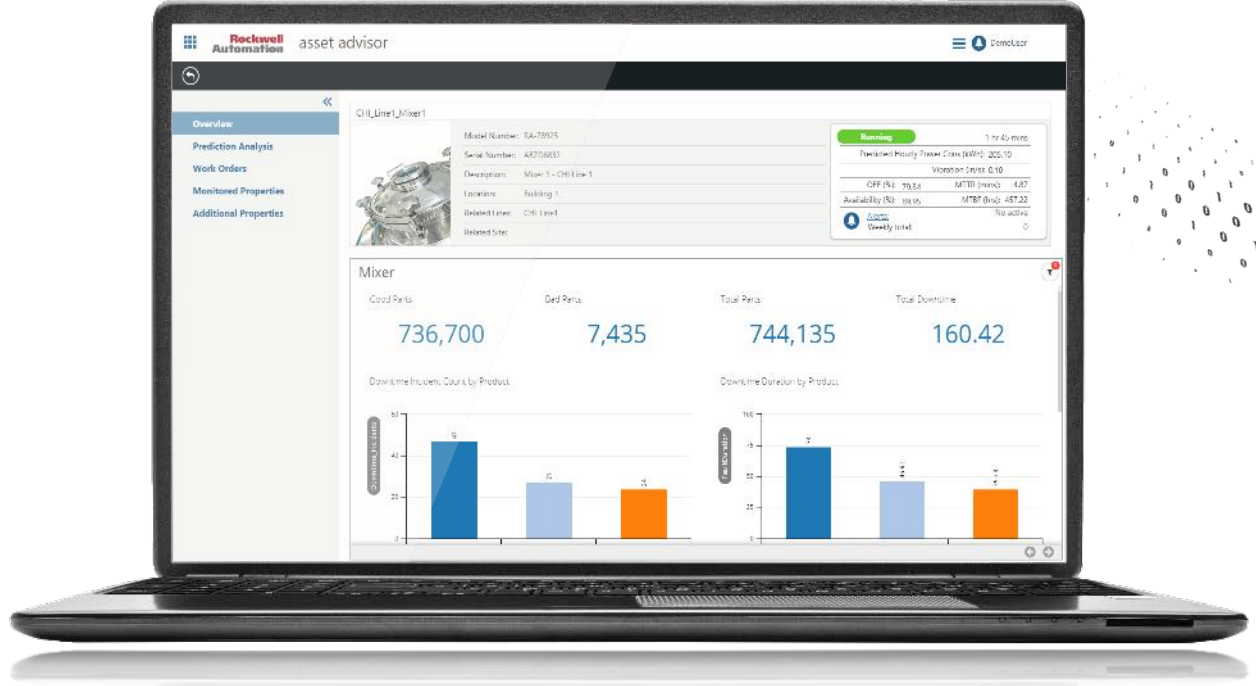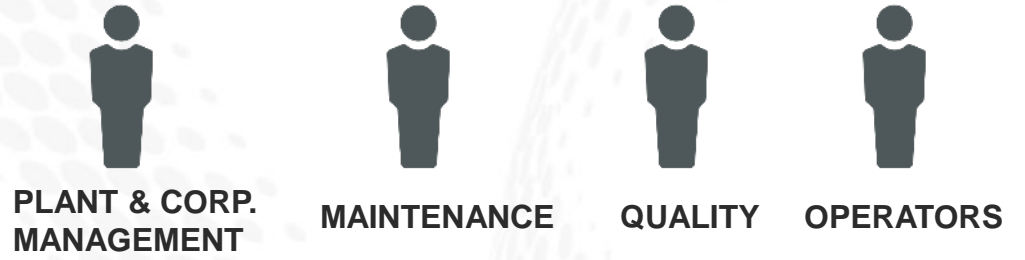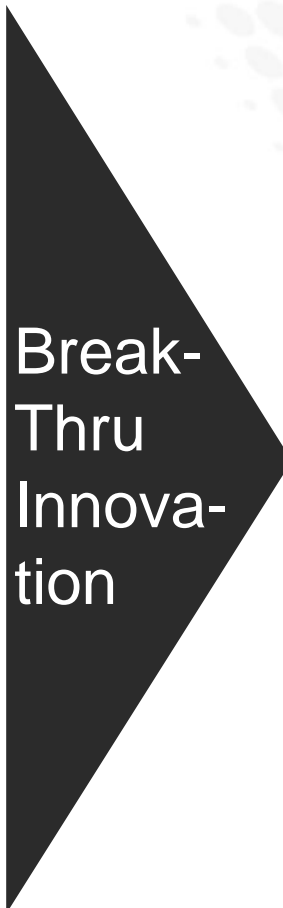**8** Citizen Data Scientist Demo

ML on the **FT** InnovationSuite
powered by **PTC**
Introduction

Manufacturing is going digital

Current

Industrial Innovation Platform

ISA-95

L4/ L5	Business Systems (ERP, SCM, PLM) Governance & planning
L3	Production Execution (MES / MOM)
L2	Process Monitoring (HMI-SCADA)
L1	Process Sensing, Manipulating (PLC)

LOGISTICS   SUPPLIERS   ENVIRONMENTAL   IOT GATEWAY

Innovation Platform

Engage

Orchestrate

Synthesize

Contextualize

Source

Break-Thru Innova-tion

PLANT & CORP. MANAGEMENT   MAINTENANCE   QUALITY   OPERATORS

- **Connected**
- **Real-time / Streaming Data**
- **Role-based**
- **Predictive / Prescriptive**
- **Mobile & augmented**
- *Wrap and extend Innovation*

Rockwell Automation

InnovationSuite
powered by **PTC**

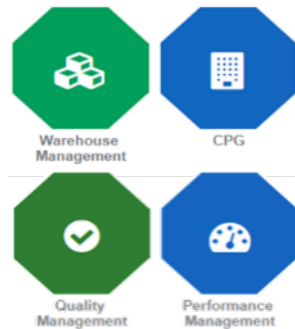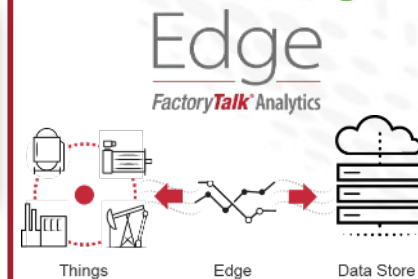| IOT	AR	Fit for Purpose	Data Analytics	Edge Compute	ML and AI
Market-leading industrial innovation platform to drive digital transformation for increased operational performance and agility across all factories	Industry-Leading augmented reality development tools to improve workforce efficiency and training	A set of tools built on top of our FactoryTalk® ProductionCentre® MES Platform that target specific needs of Manufacturing Operations: Performance, Quality, Production & Warehouse	Data Visualization / Data Discovery tool. Self-service Analytics with Insightful Storyboards that may be saved, shared and viewed on any form factor or device	Streaming / Machine Data from your PLCs / Controllers, low latency, with the capability to store and forward data. Enables closed loop feedback applications and provides advanced analytics in the "hardware stack". **Operationalizes ML and AI at the Edge.**	**Solve Engineering Challenges through Machine Learning and AI. Scalable from on-prem to the cloud – Connects to Data Lakes / Big Data, Structured / Unstructured Data, and Streaming / Machine Data.**

thingworx®

vuforia™

Warehouse Management · CPG · Quality Management · Performance Management

DataView
FactoryTalk® Analytics

Edge
FactoryTalk® Analytics

Things · Edge · Data Store

DataFlowML
FactoryTalk® Analytics
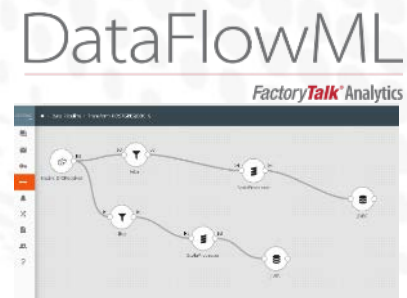
CLOUD | HYBRID | ON-PREM

ML on the FT InnovationSuite powered by PTC Adoption Strategy

ML on the InnovationSuite powered by PTC

ML Adoption Strategy

Product Path

FactoryTalk®

InnovationSuite powered by PTC

Step 1 – Digitization

FactoryTalk® Historian SE   *FactoryTalk® ProductionCentre*

- Historical Data
- Time Range Aligning Between Machine Tags

- Product, Batch, etc.
- Contextualize Your Data

Step 2 – Visualization / Streaming

DataView
FactoryTalk® Analytics

- Visualizing Data
- Feature Selection

Edge
FactoryTalk® Analytics

- Streaming Data
- Writeback to the Controller

ThingWorx

- ThingWorx Mashup
- ThingModel

Step 3 – Machine Learning

DataFlowML
FactoryTalk® Analytics

- Data Acquisition
- Exploratory Data Analysis
- Feature Selection
- Data Wrangling
- ML

Edge*
FactoryTalk® Analytics

- Streaming Data
- Writeback to the Controller

ThingWorx Analytics

- ML

Interactive ML Studio

- ML

If a Customer already has a component (e.g. MES or Historian), then those components can be used instead for that aspect of their Connected Enterprise Journey.

Discussions about Machine Learning can occur during the Connected Enterprise Journey... Digitization and Visualization / Streaming are precursor steps to Machine Learning

* Edge can also assist with Data Pre-processing @ the Edge

ML on the **FT** InnovationSuite *powered by PTC*

ML Adoption Strategy Steps

FactoryTalk®

Digitization
- FactoryTalk® Historian SE or equivalent Historian
- FactoryTalk® Production Centre or equivalent MES

ML Starts with Data!

FT InnovationSuite *powered by PTC*

Visualization and Streaming
- DataView
- Edge
- ThingWorx {ThingWorx Mashups, ThingModel}

Understand your Data!

ML – Part A
- DataFlowML
- Edge (if not already Purchased)
- ThingWorx Analytics / Interactive ML Studio

Get ML-Ready!

ML – Part B
- Define Business Problem
- Map to ML Problem
- …
- Model…
- …
- Operationalize…

Dive In! Predict and Prescribe!

… More on ML – Part B Next…

ML on the **FT** InnovationSuite powered by **PTC**
Data Science Process

Data Science Process

Overview

| Define Business Problem | → | Map to Machine Learning (ML) Problem(s) | → | Exploratory Data Analysis | → | Data Preparation / Data Wrangling | → | ML Model Building (Train / Test) | → | ML Model Evaluation | → | Operationalize |

80% of work

20% of work

100% of value

Rockwell Automation
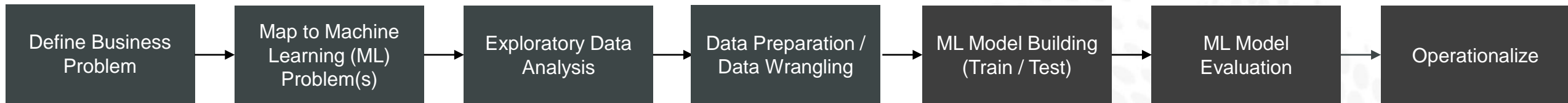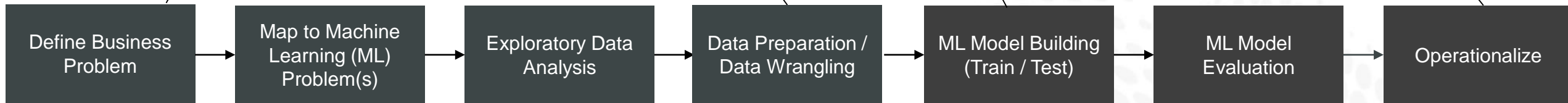
Data Science Process

Detail

- Clearly defined Business Problem
- Set Success Criteria
- Define clear Data Science Objectives
- Determine ROI
- Determine Budget
- Determine Executive Sponsorship

- Understand data points and constraints
- Formulate Data Science Strategy
- Perform required Data Transformations / Data Wrangling / Data Preprocessing

- Experiment with multiple ML Models
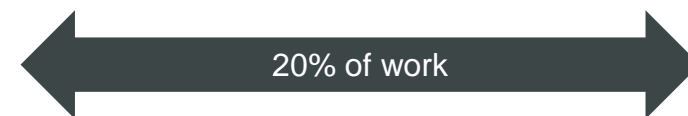- Tune Hyperparameters

- Operationalize your ML Model against Streaming Data from the PLC / Controller
- Data Transformations / Data Wrangling / Data Preprocessing need to be applied
- **Maximum value realized**

| Define Business Problem | Map to Machine Learning (ML) Problem(s) | Exploratory Data Analysis | Data Preparation / Data Wrangling | ML Model Building (Train / Test) | ML Model Evaluation | Operationalize |

- Break Business Problems into Data Science (DS) Problems
- Identify Machine Learning (ML) Problems

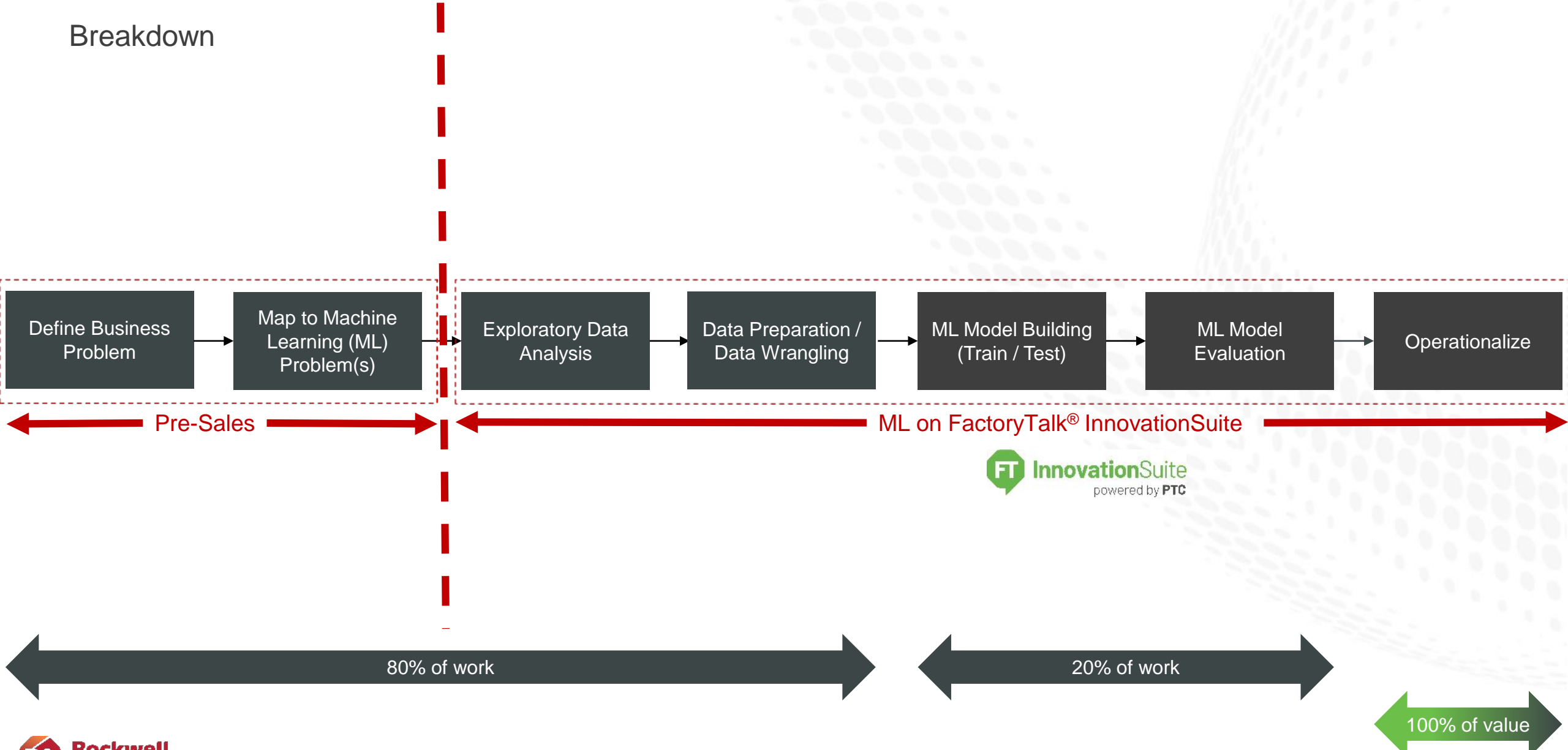- Perform Statistical Analysis / Data Science Analysis
- Discover and handle Outliers/Errors
- Shortlist Machine Learning (ML) Modeling Techniques

- Choose the Optimal Model

80% of work → 20% of work → 100% of value

Data Science Process

Breakdown

| Define Business Problem | Map to Machine Learning (ML) Problem(s) | Exploratory Data Analysis | Data Preparation / Data Wrangling | ML Model Building (Train / Test) | ML Model Evaluation | Operationalize |

← Pre-Sales →   ← ML on FactoryTalk® InnovationSuite →

FT InnovationSuite powered by **PTC**

← 80% of work →   ← 20% of work →

100% of value

Data Science Process

Options

Option 1 – Use FactoryTalk® InnovationSuite for ALL your ML Needs

Define Business Problem	Map to Machine Learning (ML) Problem(s)	Exploratory Data Analysis	Data Preparation / Data Wrangling	ML Model Building (Train / Test)	ML Model Evaluation	Operationalize

Pre-Sales

ML on InnovationSuite powered by PTC

Option 2 – Use "BYODST" for Some of the Steps Prior to Operationalize

Then Use InnovationSuite powered by PTC to Operationalize

80% of work

20% of work

100% of value

Rockwell Automation

Data Science Process

Products & People

Data Scientist /
Citizen Data Scientist

DataView

ThingWorx
- Mashup,
- ThingModel

ThingWorx Analytics
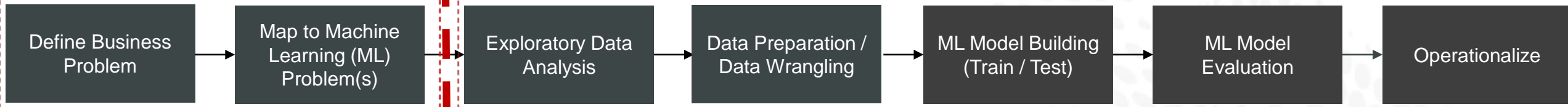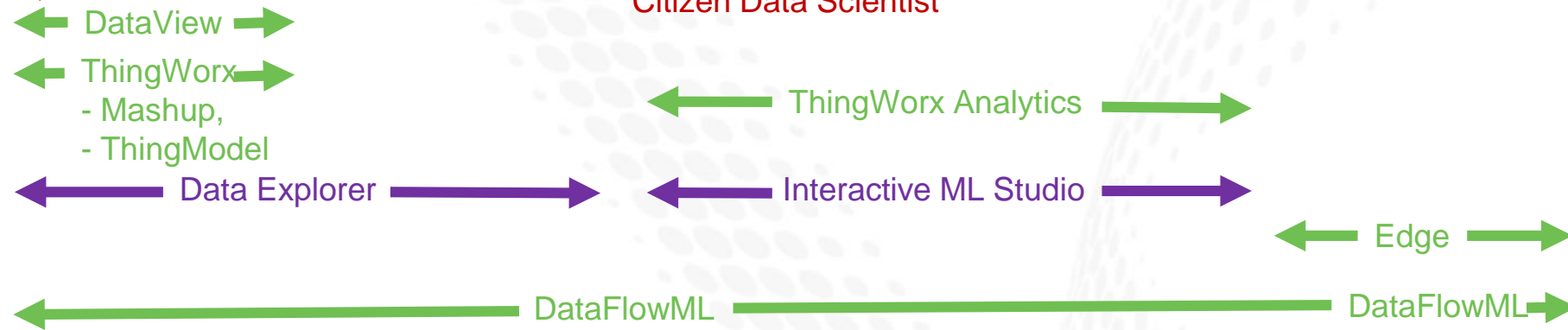
Key People
- Executive Sponsorship
- Account Management / Sales
- Data Scientist
  - {RA, Customer}
- Domain Expert / Engineers
  - {RA, Customer}

Data Explorer

Interactive ML Studio

Edge

DataFlowML

DataFlowML

Define Business Problem	Map to Machine Learning (ML) Problem(s)	Exploratory Data Analysis	Data Preparation / Data Wrangling	ML Model Building (Train / Test)	ML Model Evaluation	Operationalize

Pre-Sales

ML on FactoryTalk® InnovationSuite

FT InnovationSuite
powered by PTC

"BYODST"
Multiple Options
Available

"BYODST"
Multiple Options
Available

Edge

Operationalizing Considerations
- Prediction Pipeline
  - Prediction Itself
- Retraining Pipeline

DataFlowML
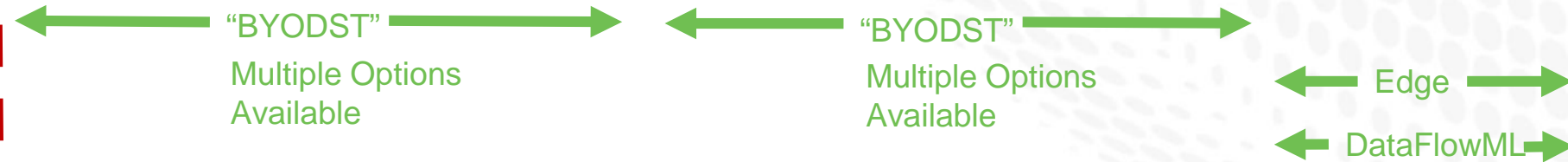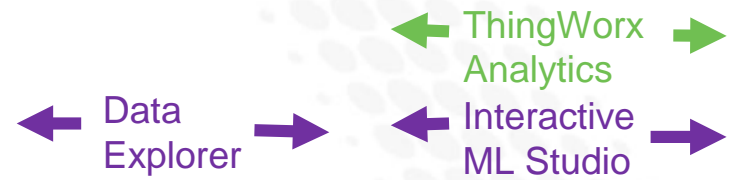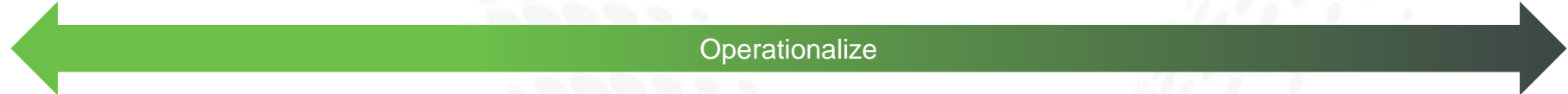
40% of work

10% of work

50% of work

100% of value

Rockwell Automation

Data Science Process

Critical Success Points

80% of work

20% of work

100% of value
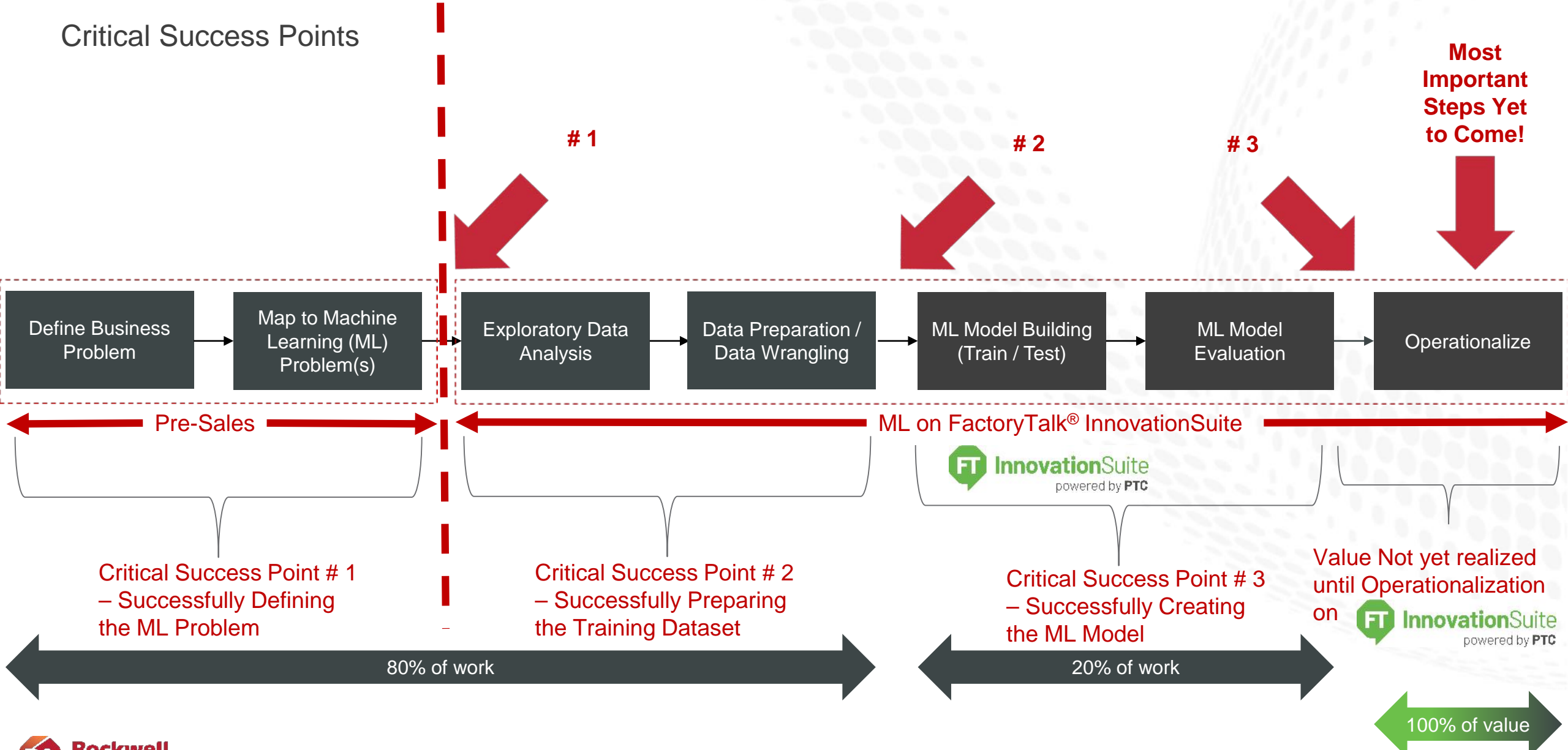
Data Science Process

Operationalize Step

Prediction Pipeline

Operationalize →

ThingWorx Analytics ← →

Data Explorer ← → Interactive ML Studio ← →

InnovationSuite powered by PTC

can assist with these operationalization considerations

DataFlowML / Edge ← →

Got a Prediction … Then What?
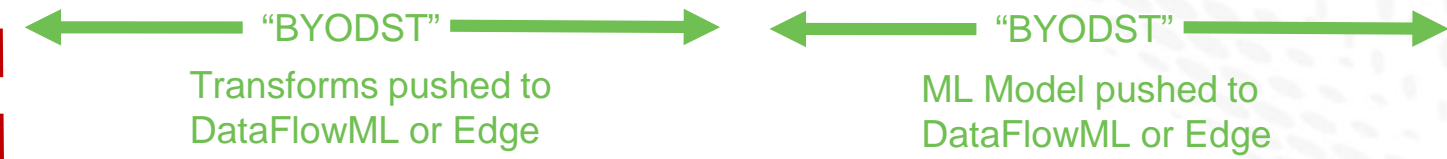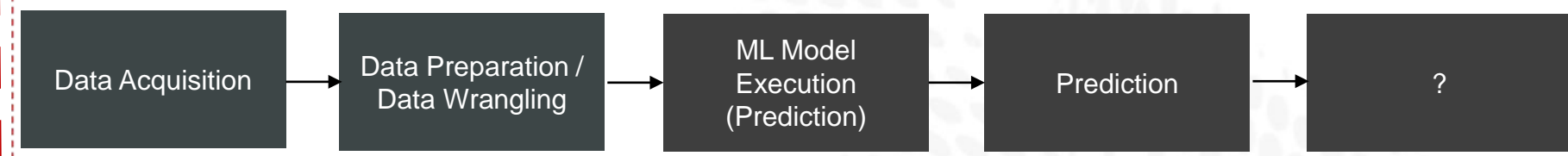
Data Acquisition	→	Data Preparation / Data Wrangling	→	ML Model Execution (Prediction)	→	Prediction	→	?

InnovationSuite powered by PTC

can assist with Training your ML Model and the Entirety of the Data Science Process

ML on FactoryTalk® InnovationSuite ← → **InnovationSuite** powered by PTC

"BYODST" ← →   "BYODST" ← →

Transforms pushed to DataFlowML or Edge

ML Model pushed to DataFlowML or Edge

InnovationSuite powered by PTC **can operationalize ML Models created with "BYODST"**

Question
- What does your "BYODST" do?

50% of work →

100% of value ←

Rockwell Automation

Data Science Process

Operationalize

Prediction Pipeline

- Prediction

FT InnovationSuite powered by **PTC**

can assist with these operationalization considerations

FT InnovationSuite powered by **PTC**

can assist with Training your ML Model and the Entirety of the Data Science Process

Operationalize - Prediction

Visualization {Streaming Predictions}

Real-time Predictive Analytics Driving Human Decision Making

Saving Predictions {Data Lake, SQL Data Store}

DataView
Vuforia
ThingWorx
- Mashup,
- ThingModel

Edge
DataFlowML

Prediction

Edge
DataFlowML

WriteBack to Controller {CIP, FTLD, OPC-UA*}

Decision Making Done For You Prescriptively By ML and AI

Sending to Another Process {MQTT, Message Queue, IoT Hub}

Edge
DataFlowML

Edge
DataFlowML

Question
- What does your "BYODST" do?

ML on **FT InnovationSuite** powered by **PTC**
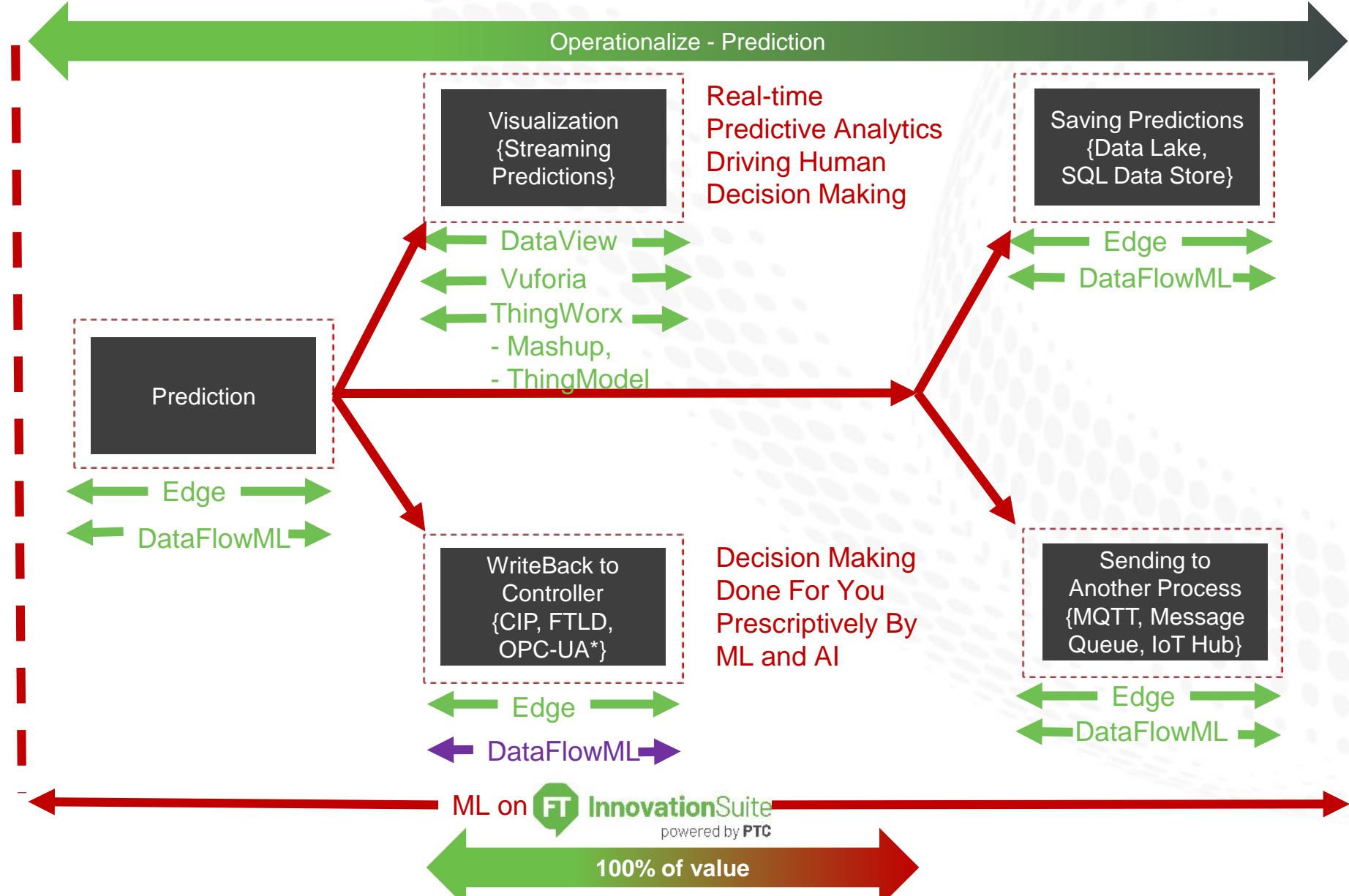
100% of value

Rockwell Automation

* OPC-UA

Data Science Process

Operationalize

Retraining Pipeline

FT InnovationSuite powered by **PTC**

can assist with these operationalization considerations

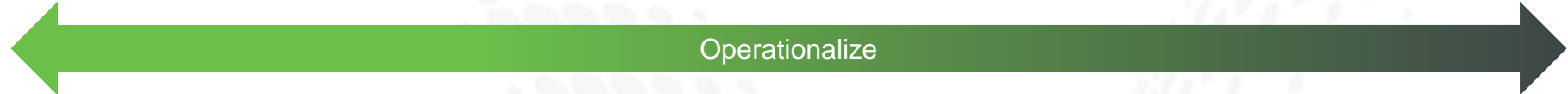Operationalize

Manual Retraining   Auto Retraining   Online Learning

FT InnovationSuite powered by **PTC**
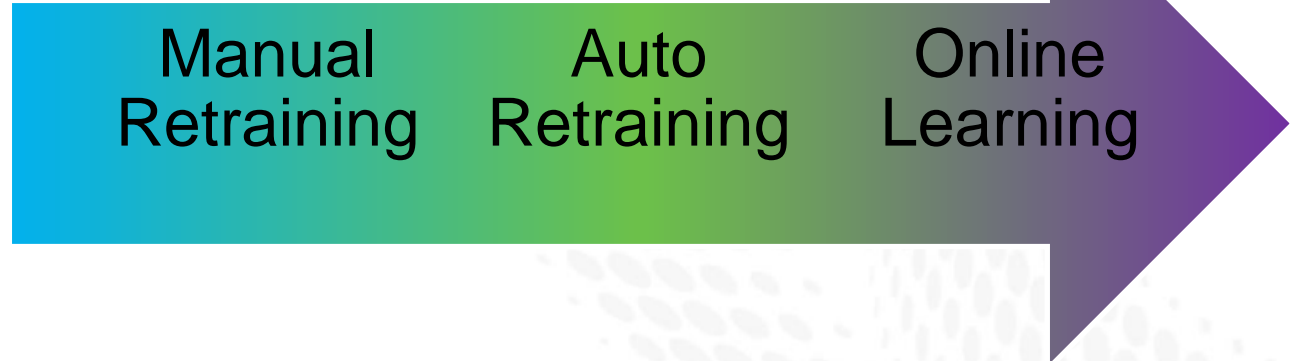
can assist with Training your ML Model and the Entirety of the Data Science Process

ML on **FT InnovationSuite** powered by **PTC**

Legacy Approach

Available **FT InnovationSuite** powered by **PTC**

Roadmap **FT InnovationSuite** powered by **PTC**

Manual…

Automating…

Teaching AI to "Think like a Human" & "Learn like a Human"

Question
- What does your "BYODST" do?

ML on the **InnovationSuite** powered by **PTC**

Then… and Now…

ML on the ![FT InnovationSuite powered by PTC]

Then… Fall 2018

That was Then…

Data Scientist / Machine Learning (ML) Options on FT Innovation Suite (Fall 2018)

Data Acquisition	Message Queues	SQL DBs	FLTD / CIP (Edge, DataFlowML)
Data Wrangling		DataFlowML Drag and Drop Blocks	
ML – Training (DataFlowML)	TWA		
ML– Scoring / Prediction (DataFlowML)	TWA	PMML	
ML – Scoring / Prediction (Edge)		Python	
ML – "BYODST" / ML Model	PMML (DataFlowML)		

Fall 2018

ML on the FT InnovationSuite powered by PTC

Now… Summer, 2019

This is Now…

FT InnovationSuite powered by **PTC**

is rapidly expanding its capabilities, features, and interoperability related to Data Science, Machine Learning, and AI

Data Scientist / Machine Learning (ML) Options on FT Innovation Suite

Data Acquisition	Message Queues	MQTT / IoT	Azure IoTHub / AWS IoT	DataLake / HDFS	SQL DBs	FLTD / CIP / OPC-UA	EDWs / Redshift

Data Wrangling	DataFlow ML GUI / Livy	Spark SQL	Python / R	Jupyter NB (Python, Scala, PySpark, R, Julia)	Data Explorer	Scala / Java	C/C++ / C#.Net

ML – Training (DataFlowML)	ThingWorx Analytics	Spark ML	Python / R	Jupyter NB (Python, Scala, PySpark, R, Julia)	Interactive ML Studio	Scala / Java	C/C++ / C#.Net

ML – Scoring / Prediction (DataFlowML)	ThingWorx Analytics	Spark ML	Python / R	Jupyter NB (Python, Scala, PySpark, R, Julia)	H20 / PMML	Interactive ML Studio	Scala / Java	C/C++ / C#.Net

ML – Scoring / Prediction (Edge)	ThingWorx Analytics	Python	Javascript	H20 / PMML	Interactive ML Studio	Java	C/C++ / C#.Net

ML – "BYODST" / ML Model	Spark ML	Python / R	Javascript (Edge)	H20 / PMML	Scala / Java	C/C++ / C#.Net

ML on the **FT** InnovationSuite
powered by **PTC**

ML Reference Architecture

ML on the ⬡ FT InnovationSuite *powered by PTC*

Reference Architecture

Model Training Process

⬡ FT InnovationSuite *powered by PTC*

simplifies and streamlines the process for
- **Data Acquisition,**
- **Data Wrangling,**
- **Model Training**

… allowing multiple options for each

Historical Data Source

Primary Sources
- Historian
- MES
- Custom SQL DB
- EDWs
- Redshift
- DataLake
- HDFS

Data Acquisition / Big Data Pipeline / Retraining

DataFlowML — *FactoryTalk Analytics*

Data Wrangling

DataFlowML — *FactoryTalk Analytics*

DataFlowML GUI / Livy	Python	Java
	R	C/C++
Jupyter NB (Python, Scala, PySpark, R, Julia)	Spark SQL	C#.Net
	Scala	Others

Model Training

DataFlowML — *FactoryTalk Analytics*

ThingWorx Analytics	Jupyter NB (Python, Scala, PySpark, R, Julia)
Python	
R	Interactive ML Studio
Spark ML	C/C++
Scala	C#.Net
Java	Others

FT Innovation Suite's Model Training Process leverages DataFlowML as an integral part

Rockwell Automation

ML on the InnovationSuite powered by PTC

Reference Architecture - Model Execution Process - ML NOT @ the Edge
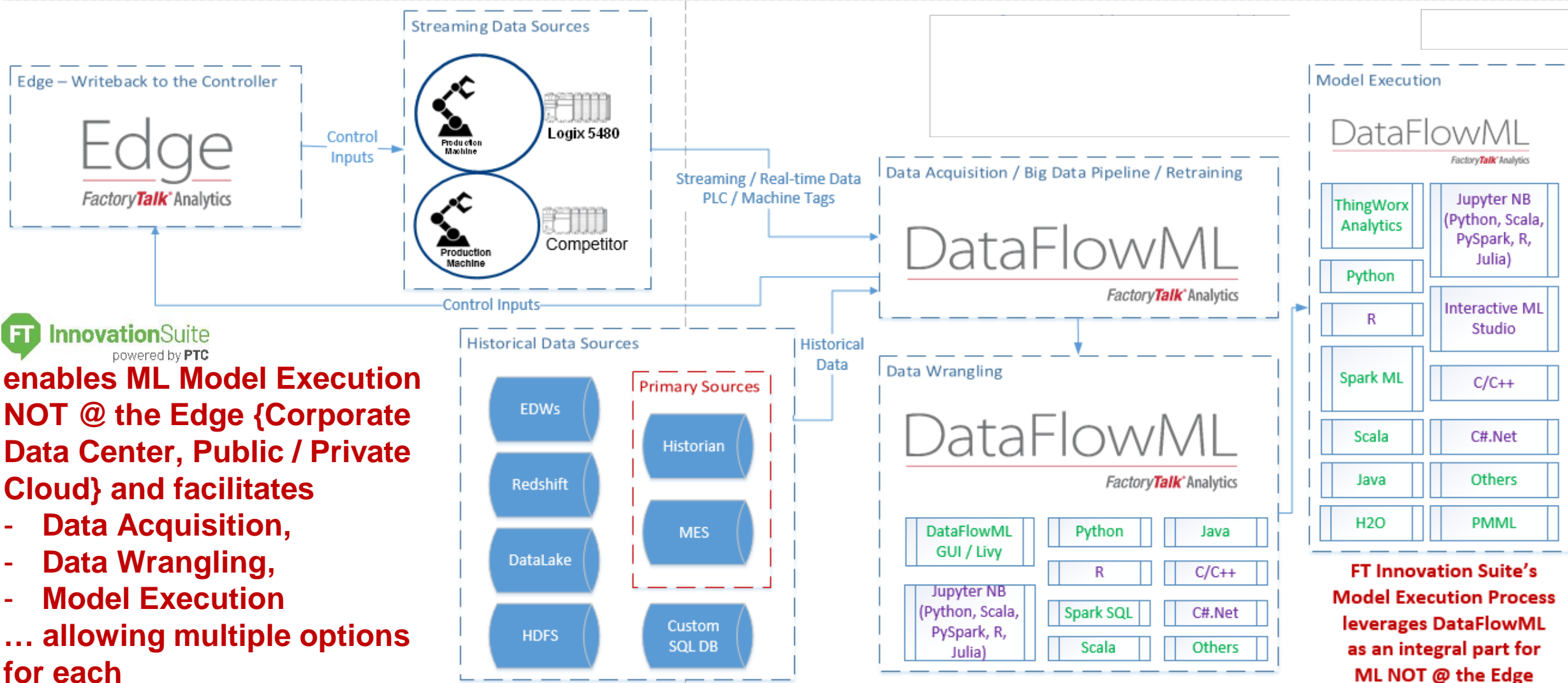
FT InnovationSuite powered by PTC **enables ML Model Execution NOT @ the Edge {Corporate Data Center, Public / Private Cloud} and facilitates**
- **Data Acquisition,**
- **Data Wrangling,**
- **Model Execution**

… allowing multiple options for each

ML on the ![InnovationSuite powered by PTC]

Reference Architecture - Model Execution Process - ML @ the Edge
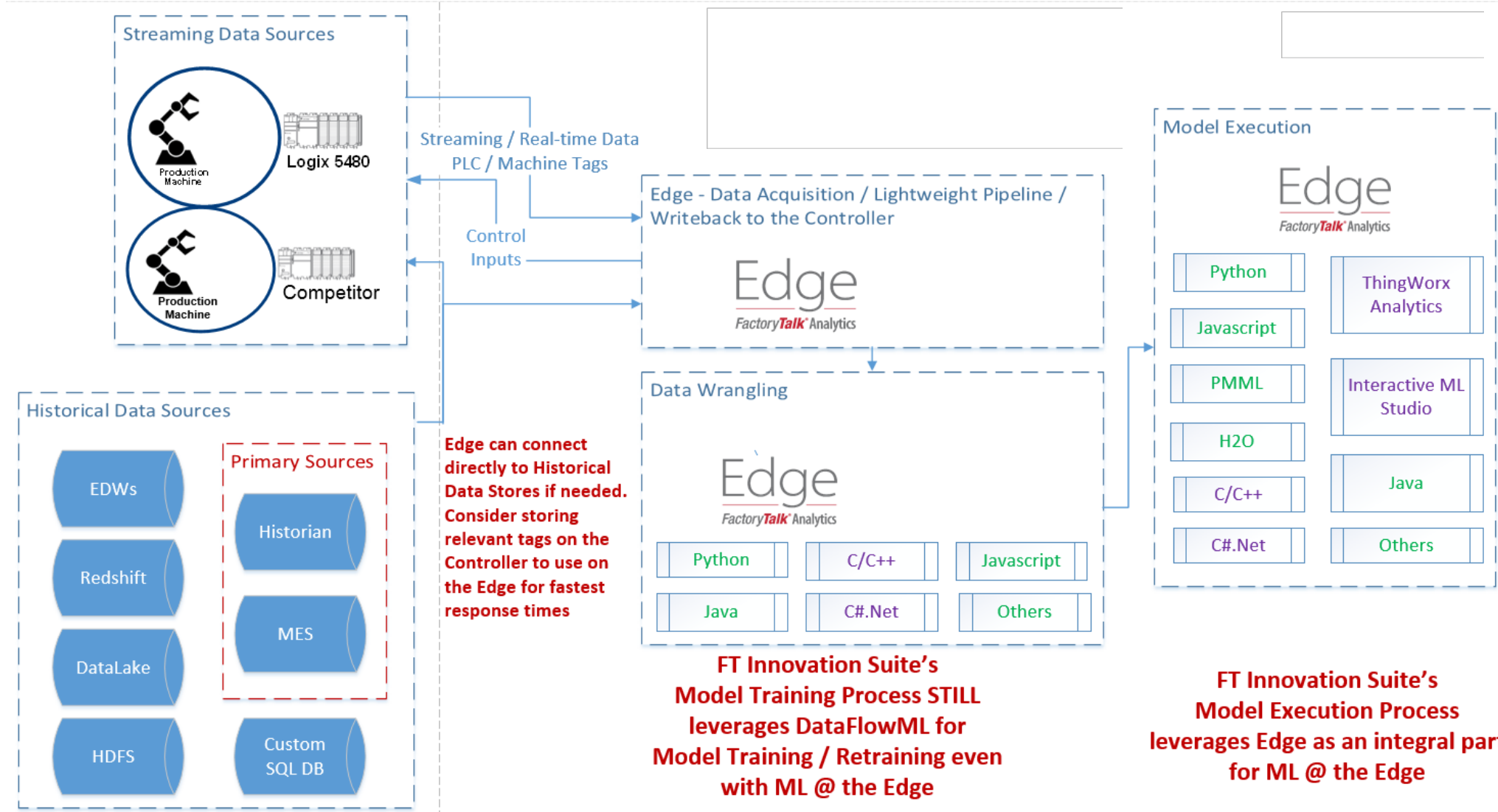

![InnovationSuite powered by PTC]

enables ML Model Execution @ the Edge and facilitates
- **Data Acquisition,**
- **Data Wrangling,**
- **Model Execution**

… allowing multiple options for each

Streaming Data Sources
- Production Machine — Logix 5480
- Production Machine — Competitor

Streaming / Real-time Data PLC / Machine Tags

Control Inputs

Edge - Data Acquisition / Lightweight Pipeline / Writeback to the Controller

Edge — FactoryTalk Analytics

Historical Data Sources
- EDWs
- Redshift
- DataLake
- HDFS

Primary Sources
- Historian
- MES
- Custom SQL DB

Edge can connect directly to Historical Data Stores if needed. Consider storing relevant tags on the Controller to use on the Edge for fastest response times

Data Wrangling

Edge — FactoryTalk Analytics

| Python | C/C++ | Javascript |
| Java | C#.Net | Others |

FT Innovation Suite's Model Training Process STILL leverages DataFlowML for Model Training / Retraining even with ML @ the Edge

Model Execution

Edge — FactoryTalk Analytics

Python	ThingWorx Analytics
Javascript	Interactive ML Studio
PMML	
H2O	Java
C/C++	
C#.Net	Others

FT Innovation Suite's Model Execution Process leverages Edge as an integral part for ML @ the Edge

![Rockwell Automation]

ML on the FT InnovationSuite powered by PTC

Data Pipelines

Data Pipelines

Legacy ML Approach

Queries

```
Select
M1. a AS Temp1
M1. b AS Press1
,M1. AS Temp1
,M2.d AS Press2
,M3.e AS Temp3
,M3.f AS Press3
FROM
M1
INNER JOIN
M2
ON
M2.time BETWEEN
M1.time + 1s and
M1.time -1s
INNER JOIN
M3
ON
M3.time BETWEEN
M2.time + 1s and
M2.time – 1s
```

Code

```
# -- Comment
Print(Temp1)

# Adjust input by 5%
Temp1 = Temp1 * 1.05

# -- Comment
Print(Temp1)
```

Various Tools

Prediction
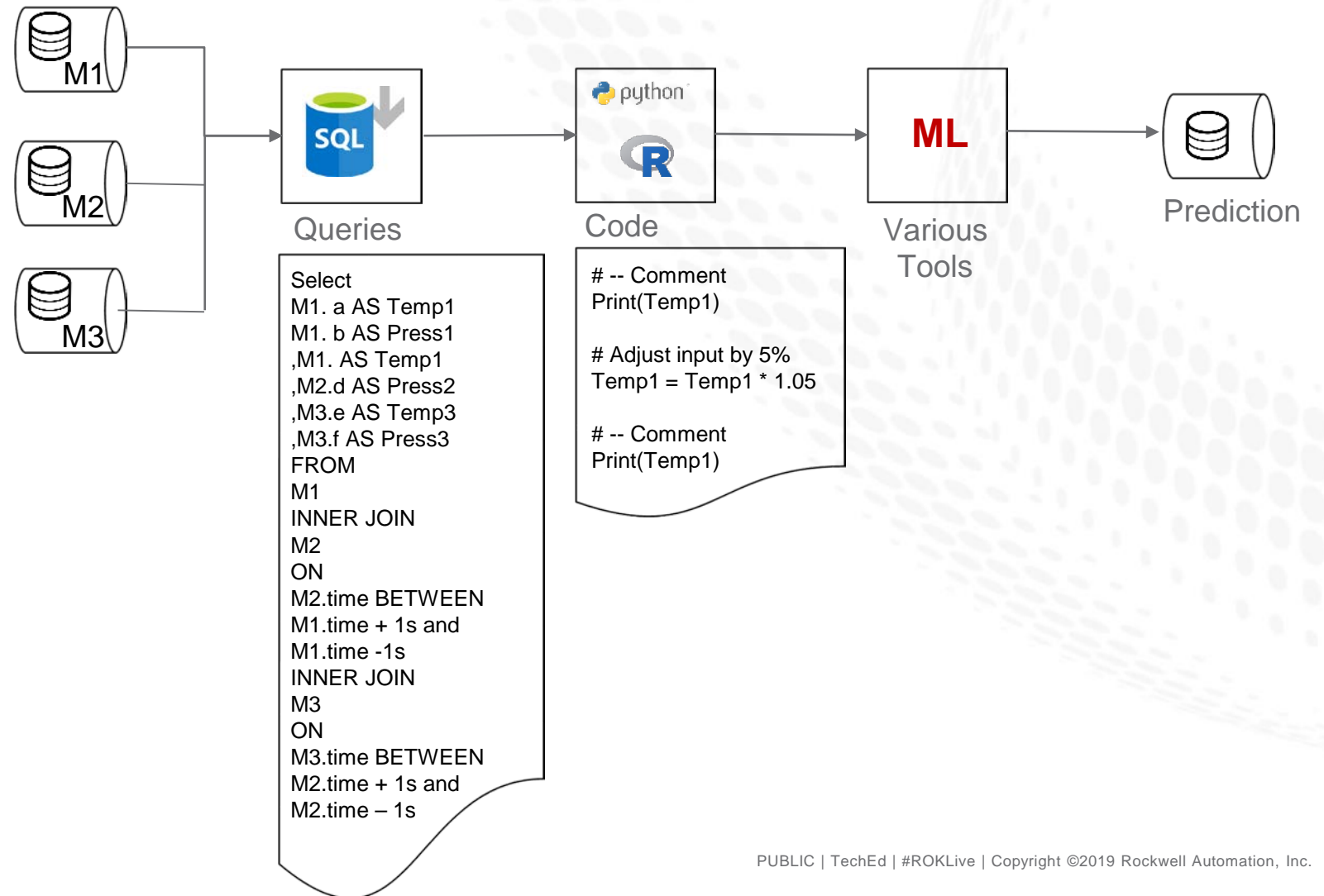
Data Pipelines

Legacy ML Approach

Manual Steps

can eliminate these Manual Steps and streamline your Data Pipeline and your Data Science Process!

Lots of CSVs!

Lots of Imports / Exports!

M1

M2

M3

Queries

```
Select
M1. a AS Temp1
M1. b AS Press1
,M1. AS Temp1
,M2.d AS Press2
,M3.e AS Temp3
,M3.f AS Press3
FROM
M1
INNER JOIN
M2
ON
M2.time BETWEEN
M1.time + 1s and
M1.time -1s
INNER JOIN
M3
ON
M3.time BETWEEN
M2.time + 1s and
M2.time – 1s
```

Code

```
# -- Comment
Print(Temp1)

# Adjust input by 5%
Temp1 = Temp1 * 1.05

# -- Comment
Print(Temp1)
```

ML

Various Tools

Prediction

Difficulty Time-Aligning Time Series Data

Rockwell Automation

Big Data Pipelines

ML on **FT** InnovationSuite
powered by **PTC**

Queries

```
Select
M1. a AS Temp1
M1. b AS Press1
,M1. AS Temp1
,M2.d AS Press2
,M3.e AS Temp3
,M3.f AS Press3
FROM
M1
INNER JOIN
M2
ON
M2.time = M1.time
INNER JOIN
M3
ON
M3.time = M2.time
```

Code

```
# -- Comment
Print(Temp1)

# Adjust input by 5%
Temp1 = Temp1 * 1.05

# -- Comment
Print(Temp1)
```

ML

Various
Tools

Prediction

Big Data Pipelines

ML on **FT** InnovationSuite
powered by PTC

Streamlined Approach!

No CSVs!
Inline Data!

M1

M2

M3

APACHE
Spark
SQL ●

Queries

```
Select
M1. a AS Temp1
M1. b AS Press1
,M1. AS Temp1
,M2.d AS Press2
,M3.e AS Temp3
,M3.f AS Press3
FROM
M1
INNER JOIN
M2
ON
M2.time = M1.time
INNER JOIN
M3
ON
M3.time = M2.time
```

jupyter ●
python ●
R ●

Code

```
# -- Comment
Print(Temp1)

# Adjust input by 5%
Temp1 = Temp1 * 1.05

# -- Comment
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```

ML

Various
Tools

Prediction
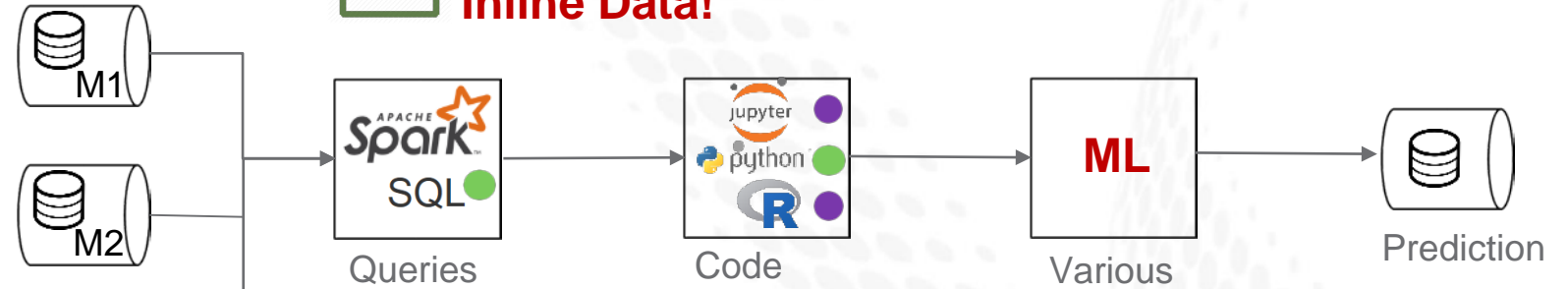
Accounts
for Time
Aligning
of Data

Rockwell
Automation
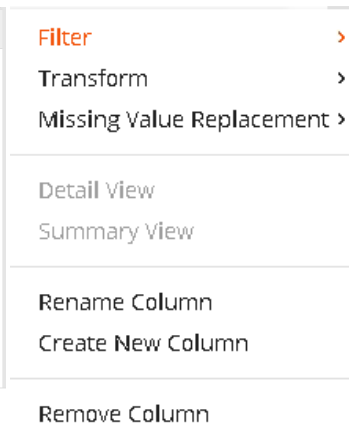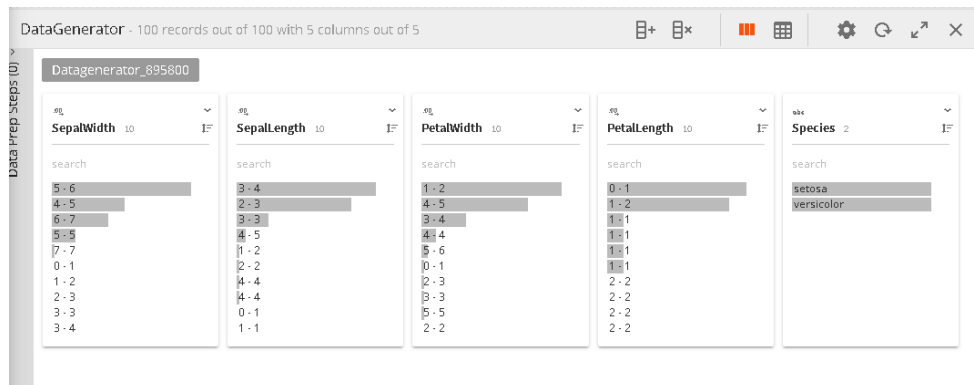
ML on the FT InnovationSuite powered by PTC

Data Scientist / Citizen Data Scientist Experiences

Citizen Data Scientist Experience

ML on **FT** InnovationSuite
powered by PTC

FT InnovationSuite powered by PTC **simplifies the Data Science Process … making harnessing the Power of Spark and the Scalability of Big Data as simple to leverage as "Point and Click" in Excel**

GUI Based
Data Wrangling

DataFlowML
GUI / Livy

GUI Based
Model Execution

ThingWorx
Analytics

Data
Wrangling

Machine
Learning

Data   Data Preparation   Model Execution   Prediction

Data Scientist Experience

Available ▌Roocmap

ML on **FT** InnovationSuite powered by PTC

Custom Code Data Wrangling

SQL Based Data Wrangling

Spark SQL

GUI Based Data Wrangling

DataFlowML GUI / Livy

Data Explorer

Jupyter*	Java
Python	Scala
R	C/C++/C#.Net

GUI Based Model Execution

ThingWorx Analytics

Interactive ML Studio

Custom Code Model Execution

Jupyter*	Java
Python	Scala
R	C/C++/C#.Net

M1
M2
M3

Data

Data Wrangling

Machine Learning

Model Execution

Prediction

```
Select
M1. a AS Temp1
M1. b AS Press1
,M1. AS Temp1
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,M3.f AS Press3
FROM
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M2.time = M1.time
INNER JOIN
M3
ON
M3.time = M2.time
```

Data Preparation

Filter
Transform
Missing Value Replacement

Detail View
Summary View

Rename Column
Create New Column

Remove Column

See Visual on Previous Slide for Enlarged Image

```
# -- Comment
Print(Temp1)

# Adjust input by 5%
Temp1 = Temp1 * 1.05

# -- Comment
Print(Temp1)
```

* Jupyter
- Python,
- R
- PySpark
- Scala,
- Julia

"BYODST" Model Execution

Jupyter*	Scala	PMML
Python	Java	SparkML
R	C/C++/C#.Net	H2O

Interoperability with your Data Science Tools!

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