

# MATLAB EXPO 2021

**MathWorks助力轨道交通企业的数字化转型**  
**Accelerate the pace of digital transformation in Rail**

宋胜凯 / Shengkai Song



# 轨道交通行业动态及挑战

Trends and key business challenges



## 中共中央关于制定国民经济和社会发展第十四个五年规划和二〇三五年远景目标的建议

提升产业链供应链现代化水平：实施产业基础再造工程

发展战略性新兴产业：推动互联网、大数据、人工智能等同各产业深度融合

统筹推进基础设施建设：加快建设交通强国

加快数字化发展：推进数字产业化和产业数字化

[http://www.china-railway.com.cn/xwzx/ywsl/202011/t20201104\\_110189.html](http://www.china-railway.com.cn/xwzx/ywsl/202011/t20201104_110189.html)

### 专栏 6 中国的高速铁路

中国构建了完备的高速铁路技术体系,总体技术水平迈入世界先进行列,部分领域达到世界领先水平。截至 2019 年底,全国高铁运营里程超过 3.5 万公里,占全球高铁运营里程的三分之二以上,初步实现了相邻大中城市间 1 小时至 4 小时交通圈、城市群内半小时至 2 小时工作生活圈。以“八纵八横”高速铁路为主通道,建成了北京到天津、上海到南京、北京到上海、北京到广州、哈尔滨到大连等一批设计时速 350 公里、具有世界先进水平的高速铁路,累计安全运行里程超过 75 亿公里。2019 年动车组发送旅客 23.6 亿人次,中国高铁不仅代表了“中国速度”,更续写了经济高质量发展的新篇章,为经济社会发展注入了磅礴活力,铺平了人民的幸福路。

《中国交通的可持续发展》白皮书

## 中国国家铁路集团：

“紧密对接国家重大战略，持续优化高铁网、普速铁路网、城际铁路网规划布局，切实发挥铁路大动脉作用，助力畅通国内大循环和国内国际双循环。深入推进铁路运输供给侧结构性改革，开发更加符合市场需求的客货运输产品，创新运输组织模式，加快市场化经营和服务提质步伐，积极推动多种交通运输方式融合发展，不断提升铁路运营品质和效率效益。”

[http://www.china-railway.com.cn/xwzx/ywsl/202011/t20201118\\_110535.html](http://www.china-railway.com.cn/xwzx/ywsl/202011/t20201118_110535.html)

# 持续提升的“复杂性”

## Complexity

### 日益严苛的规范要求

#### Stricter regulatory requirements

- 安全性 Safety
- 互操作性 Inter-operability

### 日益增长的业主需求

#### Increasing customer demands

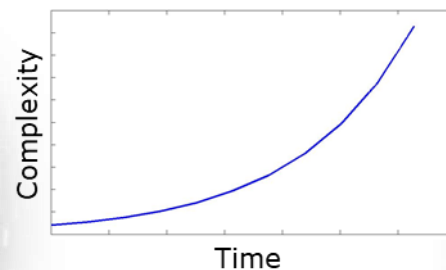
- 效率 Efficiency
- 维护与可服务时间 Maintenance & uptime

### ■ 复杂性提升

#### Increasing Complexity

- 大量增加的电子设备使得嵌入式软件显著增长

Increasing amount of Electronics leads to more Embedded Software



### ■ 更多的关注

#### Increasing Concerns with

- 软件质量与认证 Software Quality & Certification
- 上市时间 Time to Market





# 为什么进行“数字转型”

Why Digital Transformation?

做得“更好”

Do things better

优化

Optimization

- 对业务/系统的运行进行优化  
Optimize design performance in-operation
- 对系统的维护需要进行预测  
Predict when system needs maintenance
- 对连接在一起的“群”进行管理  
Manage a fleet of connected systems

创造新事物

Do new things

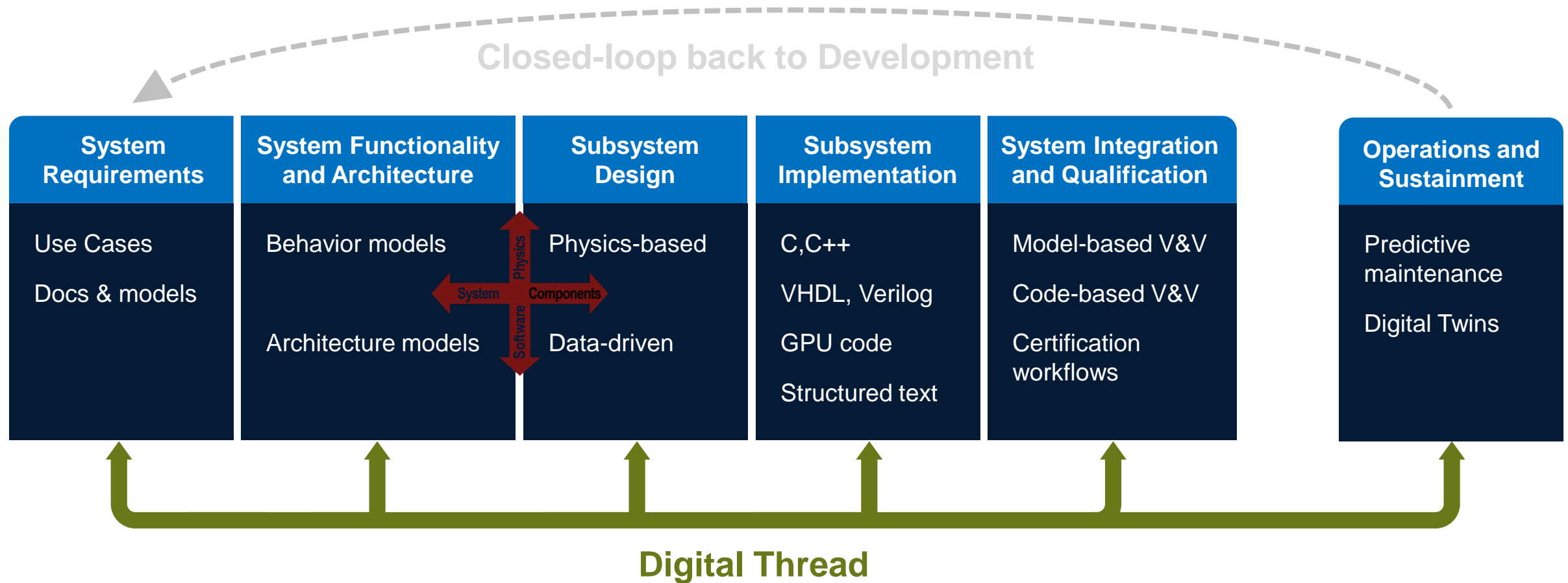
转型

Transformation

- 进入新领域和市场  
Go into new industries and markets
- 将业务扩展到整个平台的服务周期范围  
Expand into an entire platform service
- 为客户提供独特的价值  
Provide unique value to your customer

# 数字转型的关键 – 之模型

Key Factors - Extending Through the System's Lifecycle



# 数字转型的关键 – 之数据

Key Factors - Data centralization

现场数据  
Field  
data



系统数据  
System  
data



用户数据  
User  
data



环境数据  
Environment  
data



大数据  
Big Data



云平台  
Cloud Platforms



## 数据种类繁多带来复杂性提升

### Data diversity complexity

- 工程数据、科学数据和现场数据  
Engineering, Scientific, and Field
- 商业数据 & 交易数据  
Business & transactional
- 噪声，异常，数据遗失  
Noisy, Outliers, Missing data
- 时间序列数据的同步  
Time series synchronizing

## 当前的数据管理加重了这种“复杂性”

### Modern data management multiplies complexity

- 种类繁多的数据来源  
Proliferation of data systems, more siloes
- 需要权限访问的云端数据、异构数据  
Cloud, on-premise, hybrid
- 越来越多的数据——“大”数据  
Big Data

# 阿尔斯通在产品开发中使用自动代码生成技术

## ALSTOM

### Alstom Generates Production Code for Safety-Critical Power Converter Control Systems (2004)

#### Challenge

Design and implement real-time power conversion and control systems for trams, metros, and railways

#### Solution

Use MathWorks tools for Model-Based Design to design, simulate, and automatically generate production code for safety-critical transportation systems

#### Results

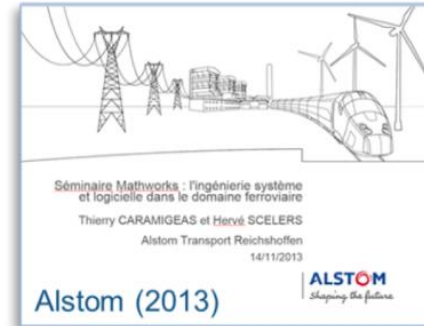
- Development time cut by 50%
- Defect-free, safety-critical code generated and certified
- Common language established



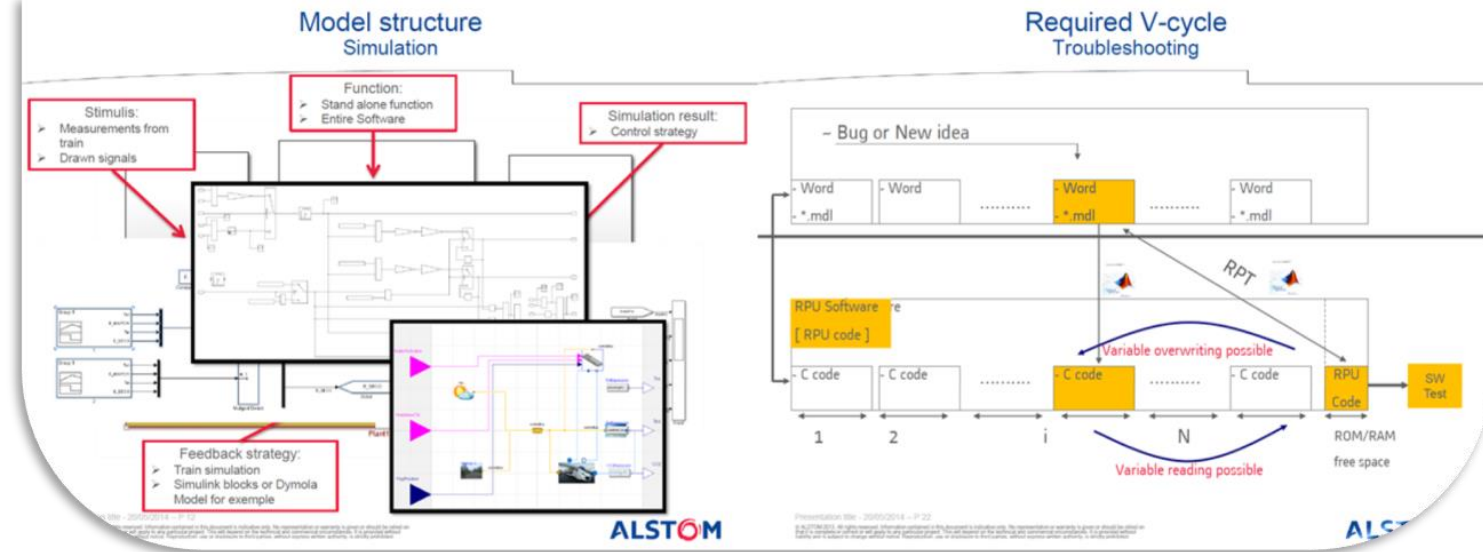
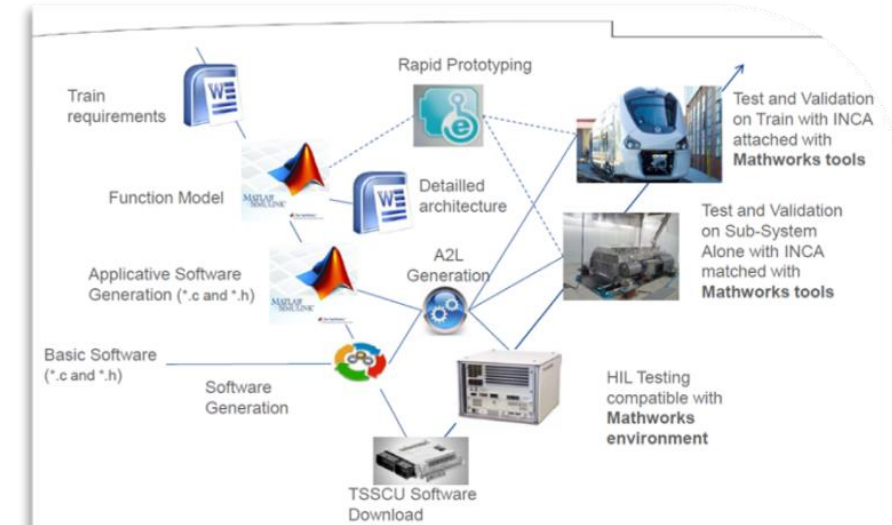
Pendolino tilting train.

"When Alstom delivered a Pendolino train to Czech Railways, the railway application was the first with automatically generated code to receive T certification (for EN 50128)"

Han



Alstom (2013)



Présentation 10h - 10h30/2014 - P.22

# 庞巴迪部署MBD降本增效

## Bombardier

### The First Steps

#### Exploring MBD

2013: 120 hours prestudy as part of a process improvement work package

- We learned that we can detect and correct design errors earlier and more quickly
- We learned that Matlab/Simulink is a strong contender
- A seminar arranged by Mathworks introduced MBD to

2014: 1 MSEK investment

- 60% spent on creating "base" models, 15% on training
- 10% spent on mitigating identified risks in a real customer project
- Results
  - One electrical design issue was located ahead of first train test
  - Iterated a complete system design early, saving lead time for
  - Altogether the savings were larger than the investment (ROI)

### First attempt to truly adopt MBD was a failure

#### Remember to change project planning

2017-2018: We chose a small project, rationale being

- Software is generated from model
- Electrical main circuit is defined by the model

### Lessons learned:

- The project must actually plan for early verification (i.e. update requirements, test strategies, functional safety etc.)
- Underestimated the work going from a quick & dirty model, to a model fulfilling all formal requirements (configuration management, debug on target, test strategies, functional safety etc.)
- Main Circuit Design: The electrical part of the model has to „look & feel“ like a traditional electrical schematics if you want the electrical and system teams to embrace the new method.

## An MBD Adoption Story from Bombardier Transportation

Matlab Expo 2018

Erik Simonson

Head of Propulsion Control

23<sup>rd</sup> May 2018

VAGSCNE1E18007

Public

BOMBARDIER

Erik Simonson – ROQ/PME – May 23<sup>rd</sup> 2018 – Rev. \_draft\_  
PRIVATE AND CONFIDENTIAL  
© Bombardier Inc. or its subsidiaries. All rights reserved.

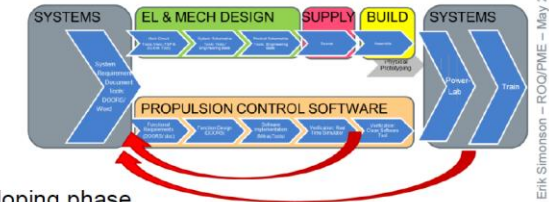
### Status 2018

#### Work in Progress & Outlook

Update of the software process is in the works

First alpha-baseline of model

- Tested in February in PowerLab
- Launch in real order project planned second half of 2018
  - Compliant with Safety Integrity Level 2 according to safety norms



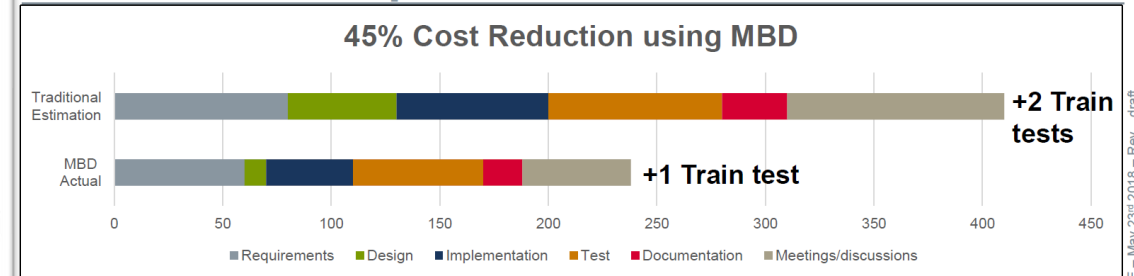
### System Modelling & Verification

- We expect the largest gains here
- Including all three departments is in a developing phase
- 10 Different teams must coordinate their efforts and define a joint process

### Result from 2017

#### Use Case: New Complex Function

35 % Lead Time Reduction



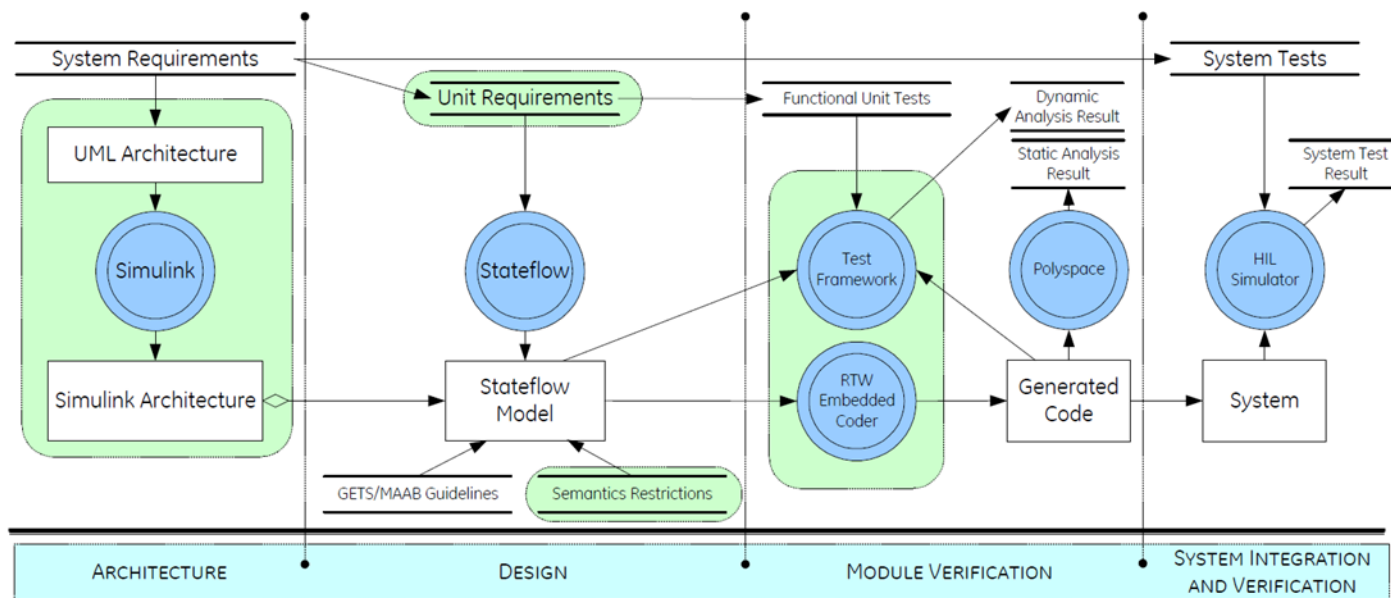
Workflow Step	# MBD Iterations (Actual)	# Traditional Iterations (Estimated)
Requirements	4	4
Design	1	3
Implementation	1	3
Test	1	3
Documentation	1	3
Train Test	1	2

Erik Simonson – ROQ/PME – May 23<sup>rd</sup> 2018 – Rev. \_draft\_  
PRIVATE AND CONFIDENTIAL  
© Bombardier Inc. or its subsidiaries. All rights reserved.

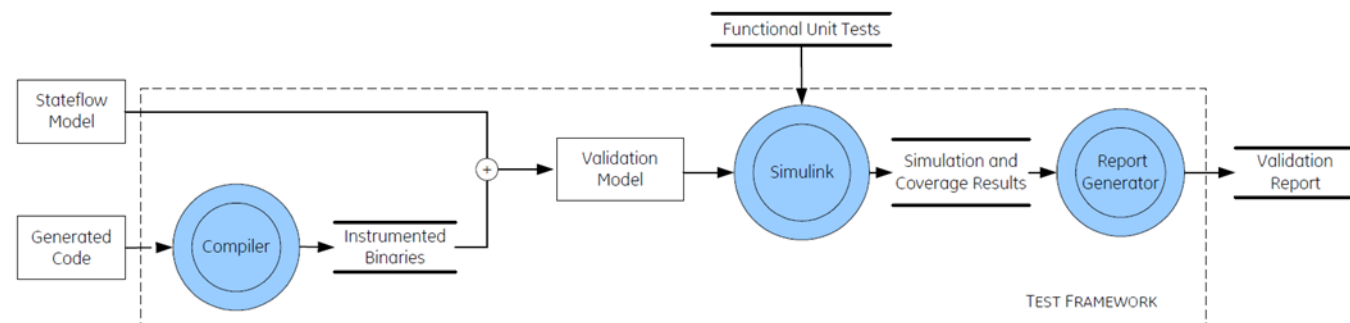


# 原GE轨道交通的基于模型架构设计和系统实现

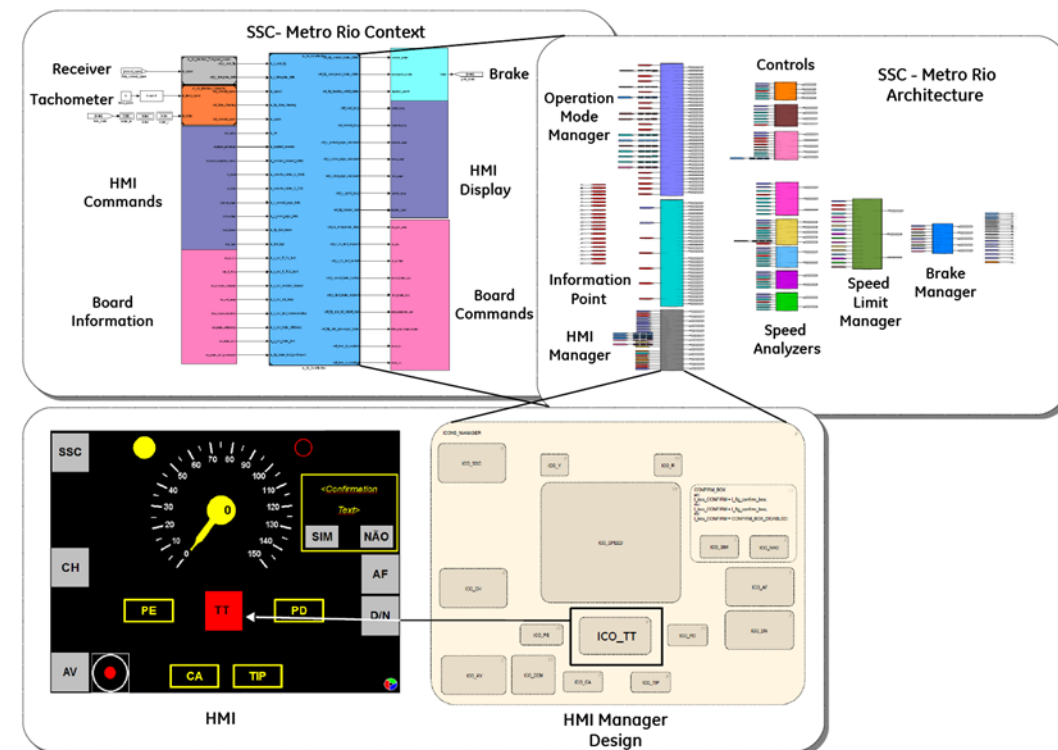
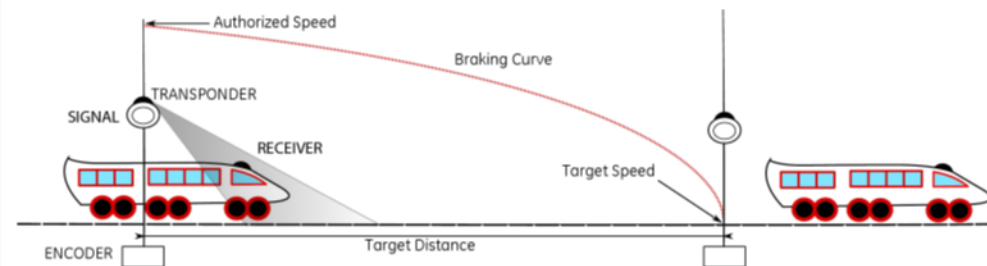
GETS use model-based engineering workflow



工作流 Workflow



测试框架 Test Framework : 2M-TVF



# SNCF开发预测性维护系统

## Productionalization of a predictive maintenance system for railways

### PRODUCTIONALIZATION OF A PREDICTIVE MAINTENANCE SYSTEM FOR RAILWAYS

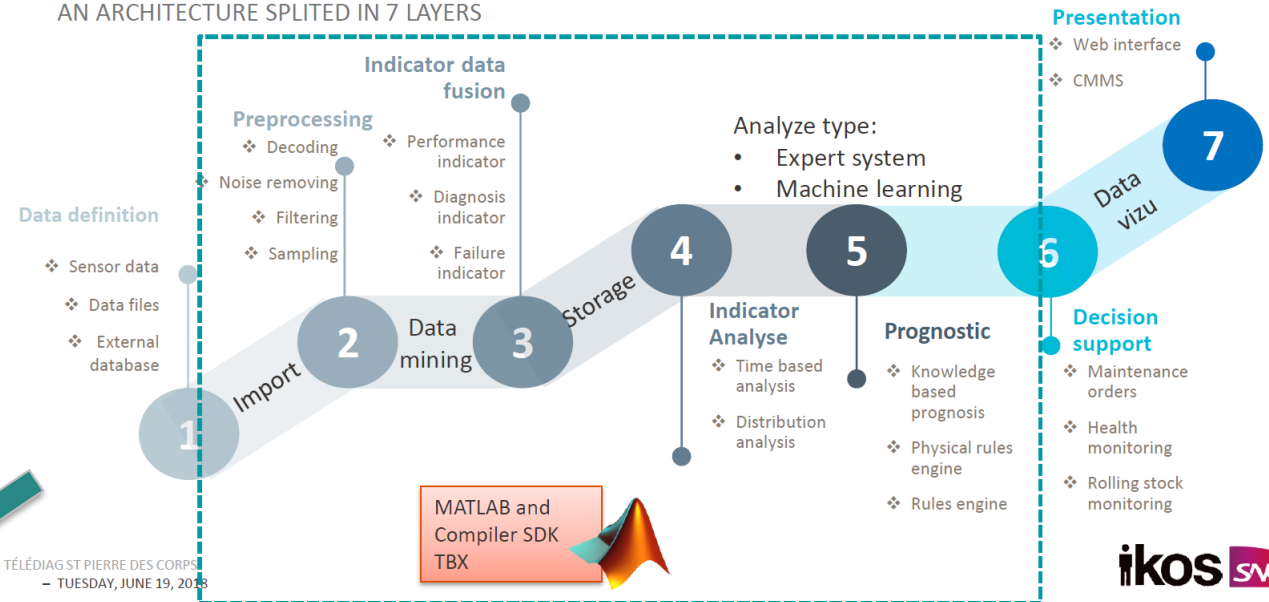


TÉLÉDIAG ST PIERRE DES CORPS  
- TUESDAY, JUNE 19, 2018

ikos SNCF

### CBM DATA WORKFLOW

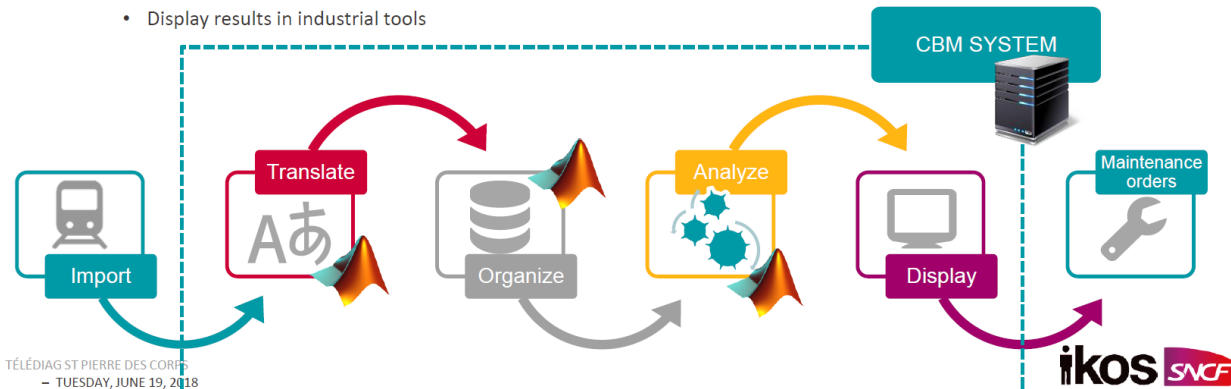
AN ARCHITECTURE SPLITTED IN 7 LAYERS



### CBM SYSTEM

CBM system is a software tool created to organize predictive maintenance task. It is composed by several function :

- Gather data from on board train systems and sub-systems
- Order and link data from studied systems
- Analyze data
- Translate data from analyzed data to obtain maintenance orders
- Display results in industrial tools



### ALL OUR USE CASES

FEW EXAMPLES OF OUR USE CASES

#### Compressor

Performance

#### Battery

Capacity ratio

#### Pantograph

Taring and up/down time

#### HVAC

Performance

#### Doors and Steps

Performance and adjustment

#### Traction

Engine performance

#### Brake

Brake performance

#### Toilette

Reservoir levels



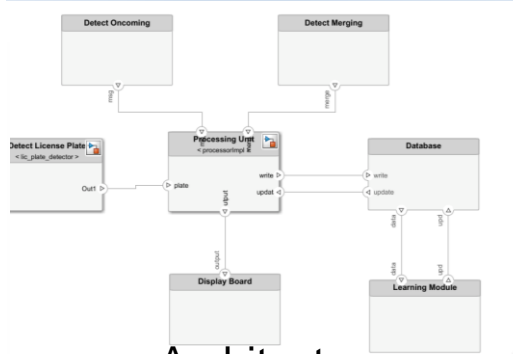
ikos SNCF

DIAG ST PIERRE DES CORPS  
- TUESDAY, JUNE 19, 2018

# 围绕模型开展数字化设计

MathWorks Solution

## MBSE

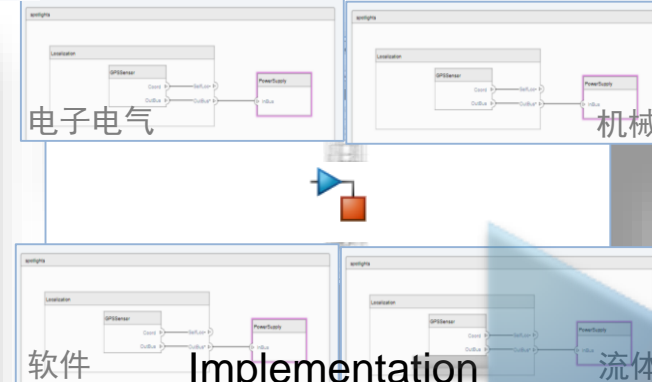


Architecture

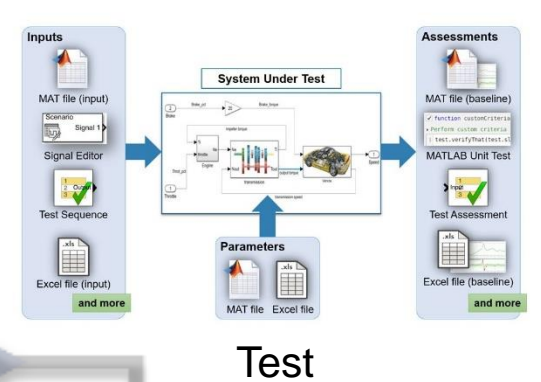
nce	latency(ms)	dataRate	resources	queueDepth
0	100	1		
1	100	1		
1	100		0	
1	100		0	
0.34843205575	287		0	
1		100	0	
2.8571428571	35	1		
1	100	1		
1	100	1		
0.00313469797	1387	23		
1.03	100		3	
1	100	1		
4	25	1		

Trade Analysis

## MBD



Implementation



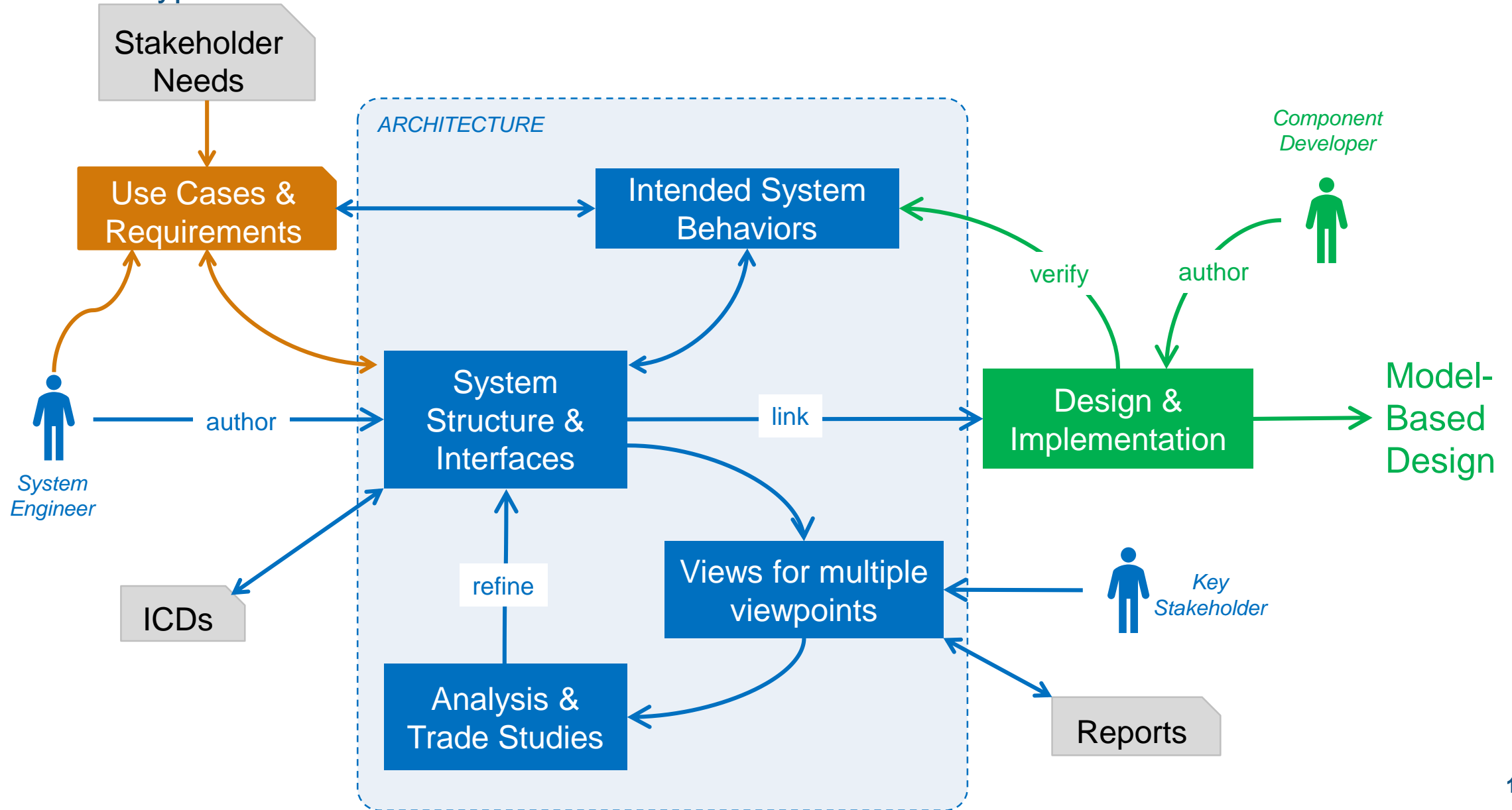
Test

Continuous Validation and Verification



# 典型的工作流程

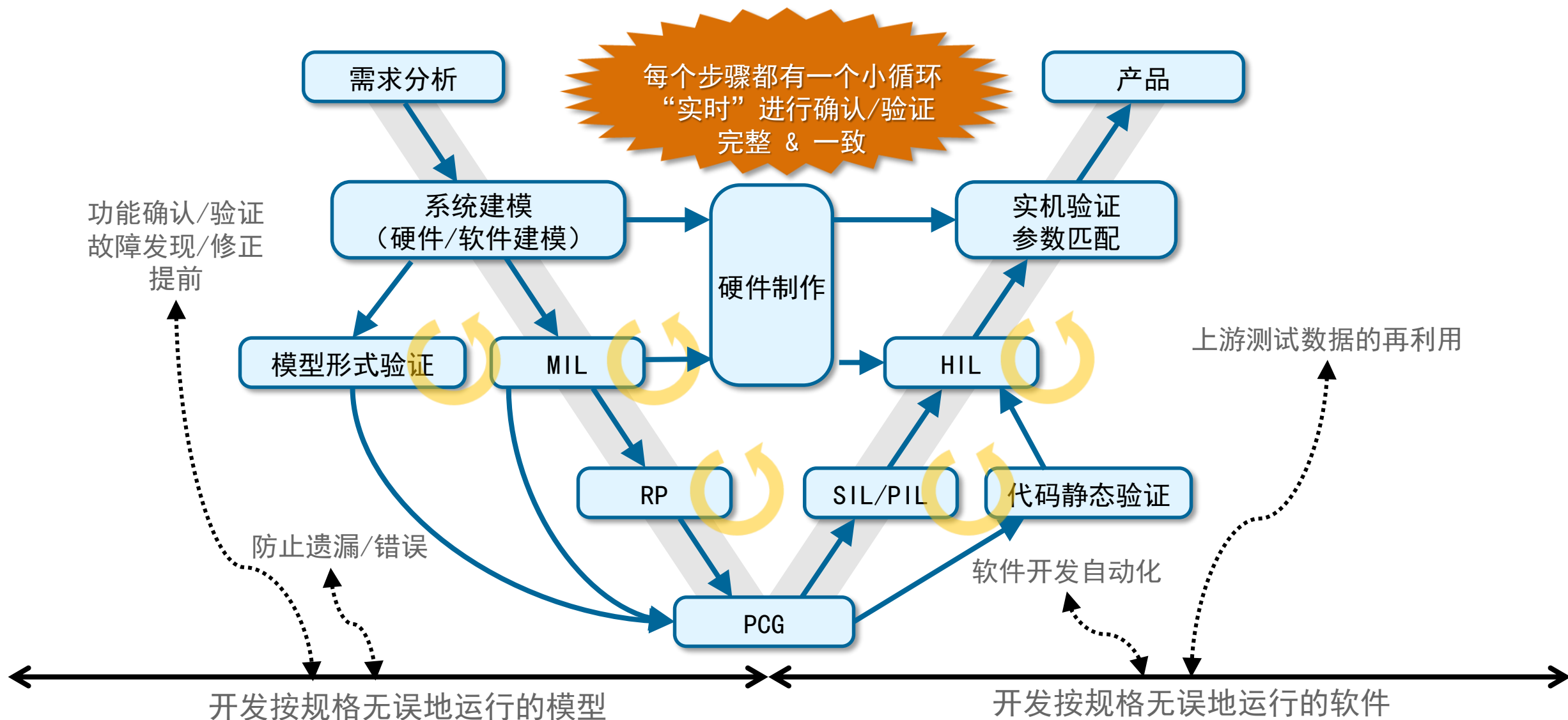
What does a typical workflow look like?





# 基于模型的设计

Model-based Design



# 系统建模及仿真

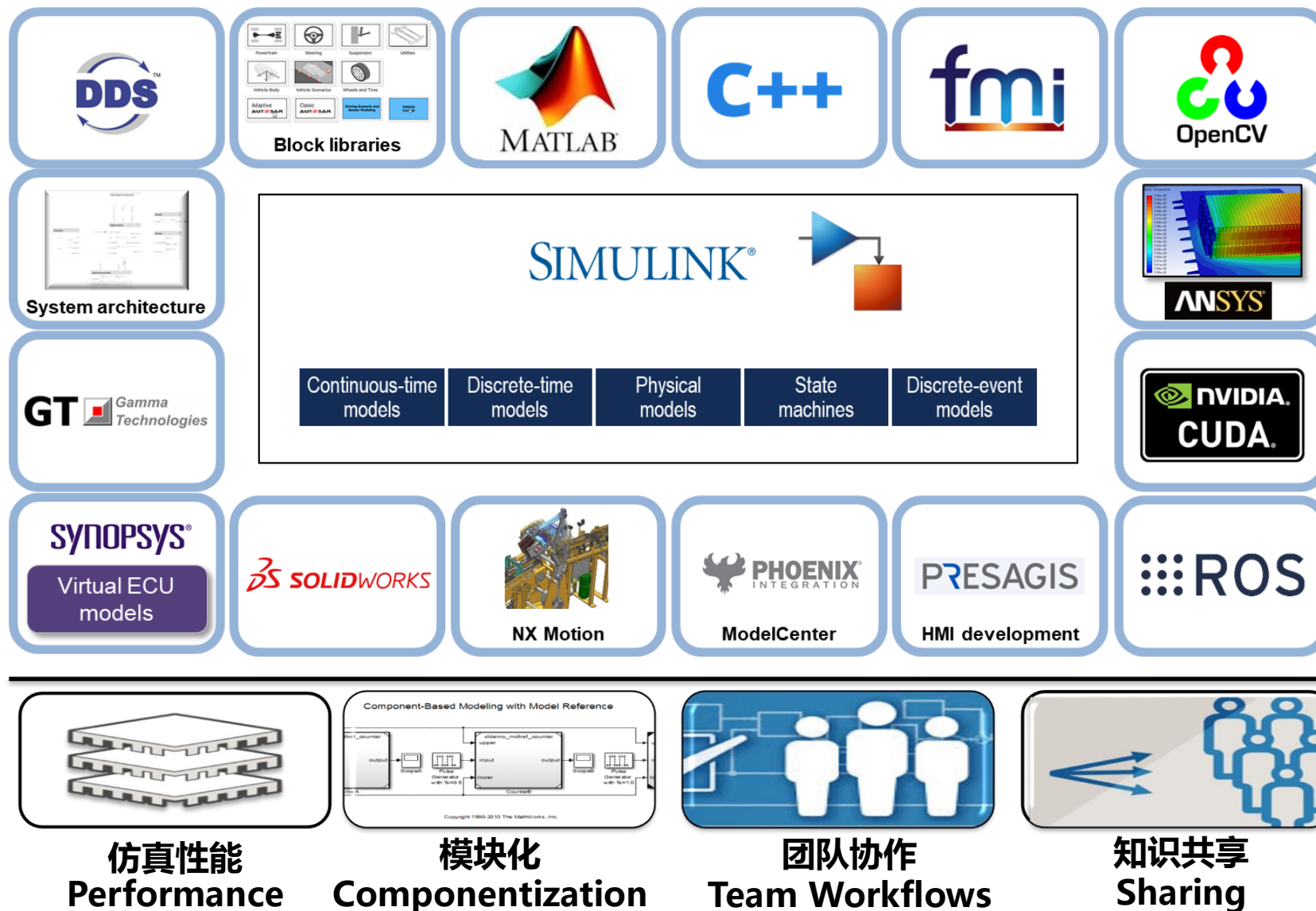
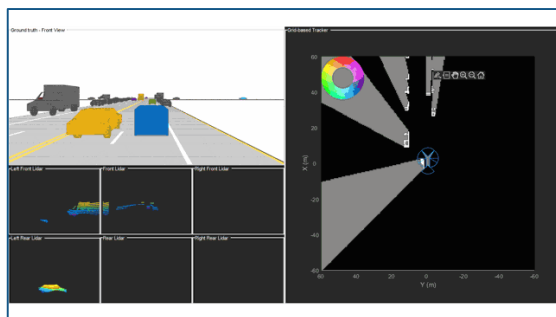
System model and simulation

系统级模型往往涉及多个物理域：机械、电气/电子、软件...

**MULTI-DOMAIN**

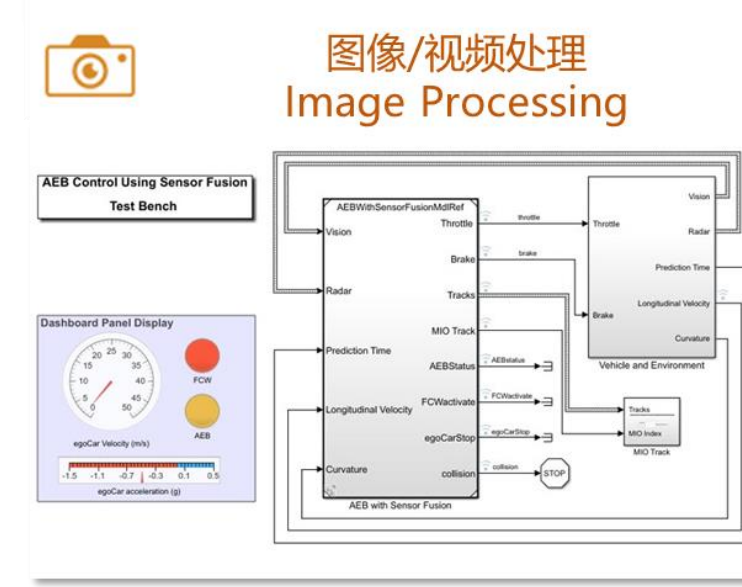
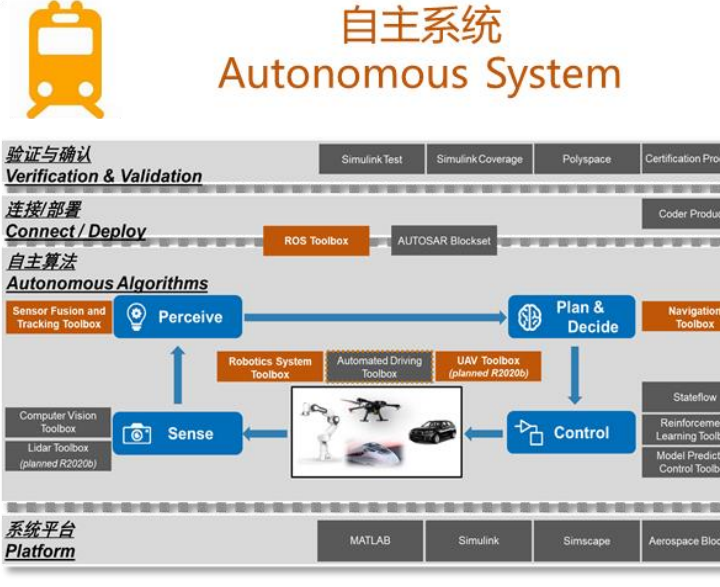
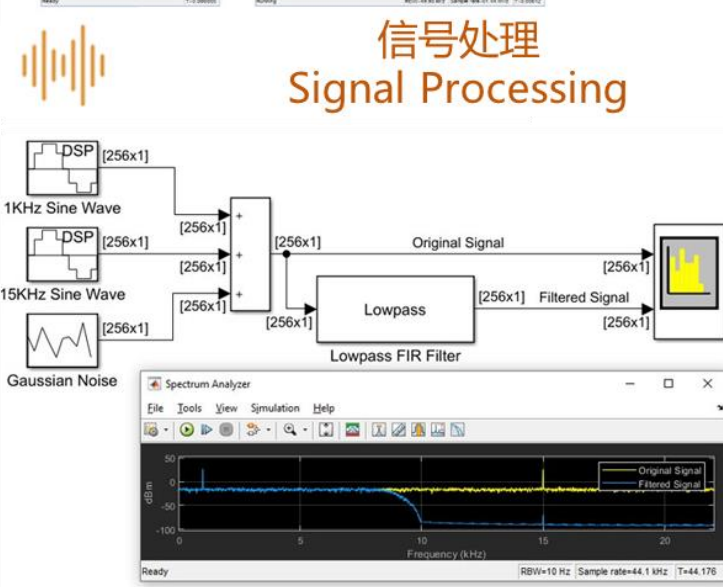
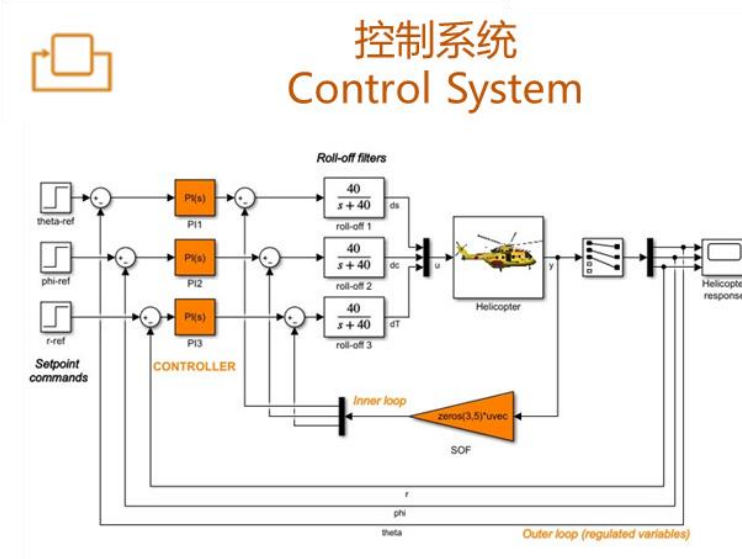
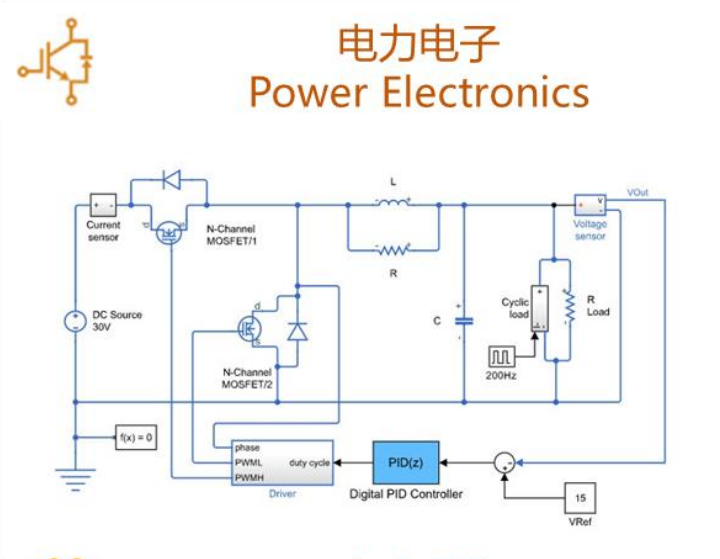
系统仿真往往涉及连续系统，离散系统，状态机，消息，异步事件...

**MULTI-SIMULATION MECHANISM**



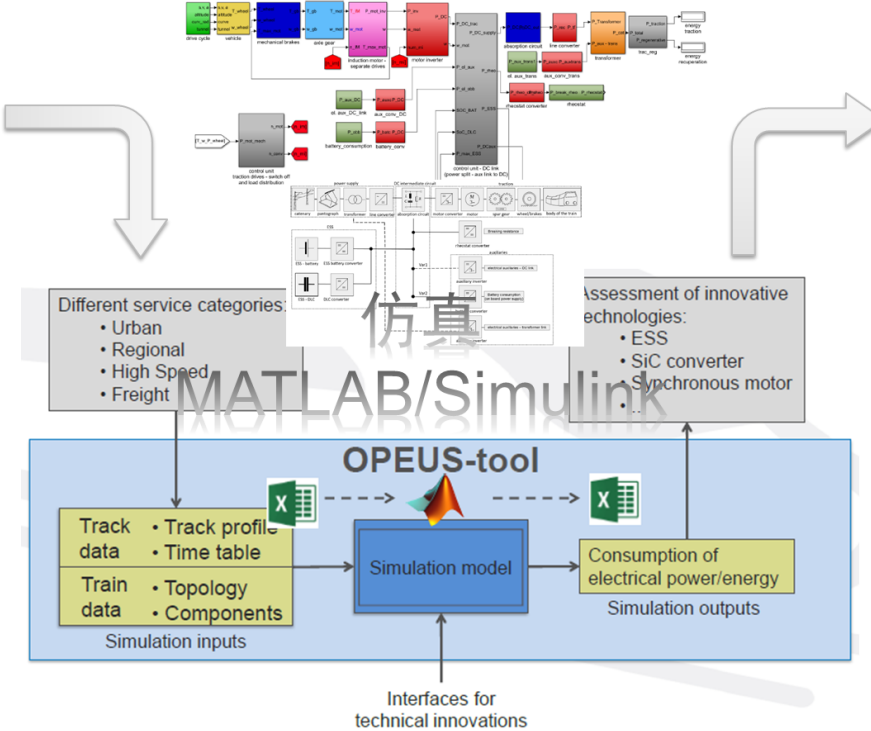
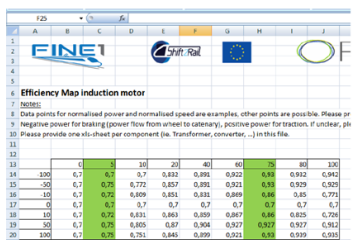
# 系统建模及仿真

## System model and simulation

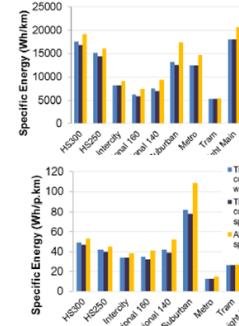


# Shift2Rail 的 OPEUS Energy Simulation

```
% nominal speed
w_nom = xlsread(filename,'efficiencymap', 'B12:B13');
% nominal power
P_nom = xlsread(filename,'efficiencymap', 'B14:B15');
% efficiency
eta = xlsread(filename,'efficiencymap', 'B16:B17');
```

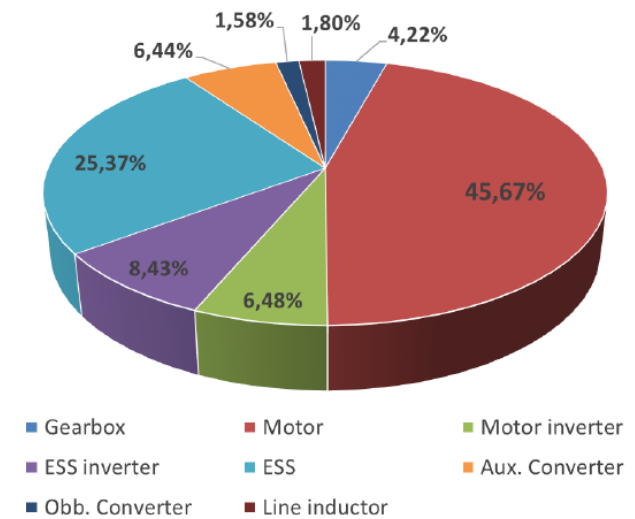


“The MATLAB/Simulink environment is utilized as it provides the user with some good degree of **flexibility** allowing to simply apply desired changes and to **integrate and simulate** other architectures. ”



可视化  
Excels  
& MATLAB

Tram with ESS energy losses % per component



Components EFFICIENCY	Axle Gear	Induction Motor	Motor Inverter	Auxiliaries	On board batteries	Absorption Circuit	Line Converter	Transformer
Reg160								
Traction Eff.	97%	81,12%	97,73%	-	-	98%	97,52%	92,19%
Reg. Eff.	97%	86,54%	97,28%	-	-	98%	98,04%	94,10%
Overall Eff.	97%	74,72%	96,85%	93,94%	94,02%	97,63%	97,14%	91,14%
Reg140								
Traction Eff.	97%	81,81%	97,76%	-	-	98%	97,64%	90,91%
Reg. Eff.	97%	87,24%	97,58%	-	-	98%	98,32%	93,02%
Overall Eff.	97%	64,12%	95,39%	93,93%	94,02%	97,07%	96,75%	87,93%
High Speed 300								
Traction Eff.	98%	90,24%	98,62%	-	-	98%	98,1%	92,33%
Reg. Eff.	98%	85,81%	97,00%	-	-	98%	98,06%	93,65%
Overall Eff.	98%	89,54%	98,51%	94,12%	94,02%	97,92%	98,03%	92,09%
High Speed 250								
Traction Eff.	98%	87,07%	98,39%	-	-	98%	98,07%	93,26%
Reg. Eff.	98%	89,24%	97,97%	-	-	98%	98,16%	94,33%
Overall Eff.	98%	84,60%	98,04%	94,07%	94,02%	97,73%	97,82%	92,53%

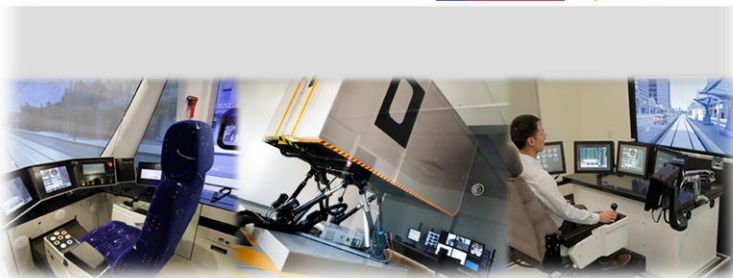


# 克诺尔SYDAC基于Simulink平台建立整车系统模型

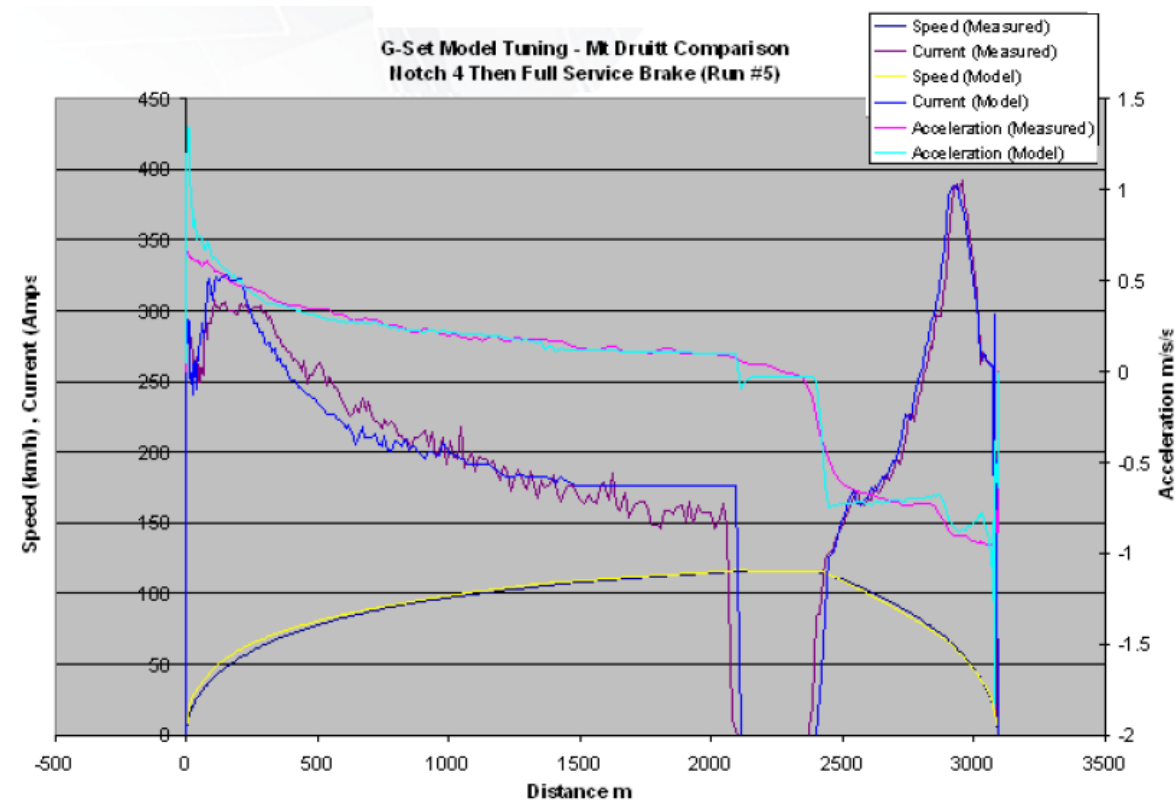
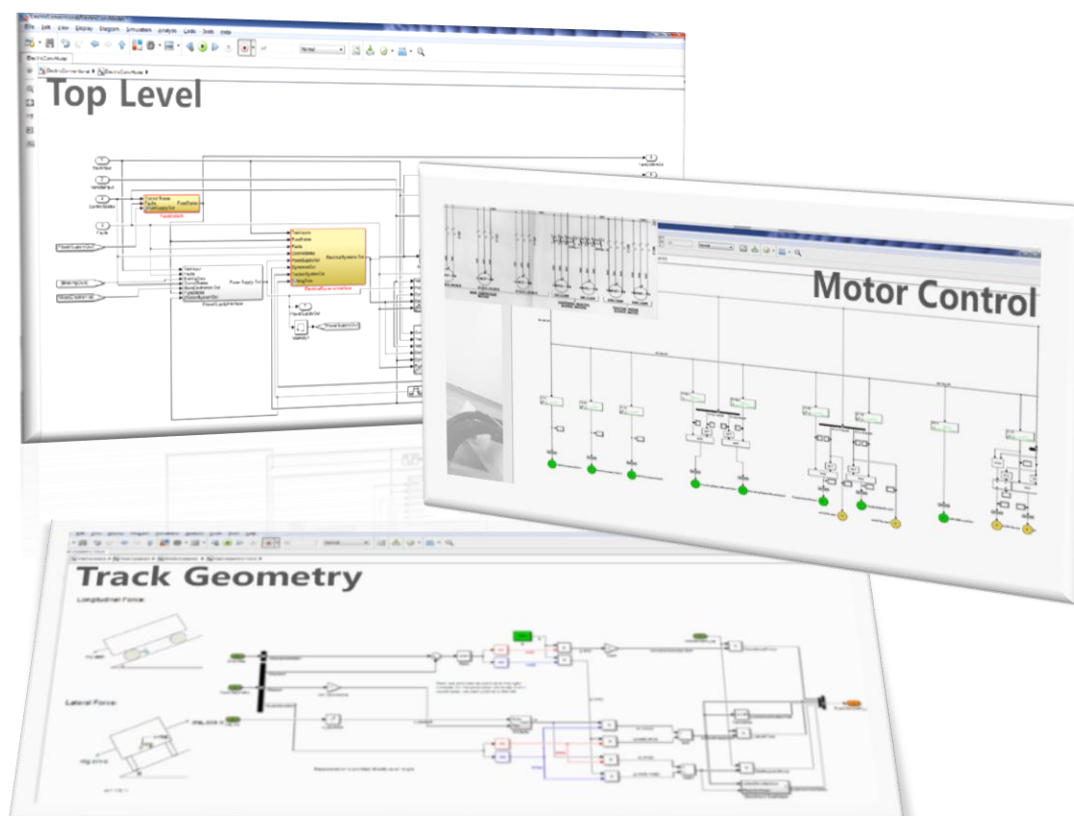
MATLAB CONFERENCE 2017

SYDAC

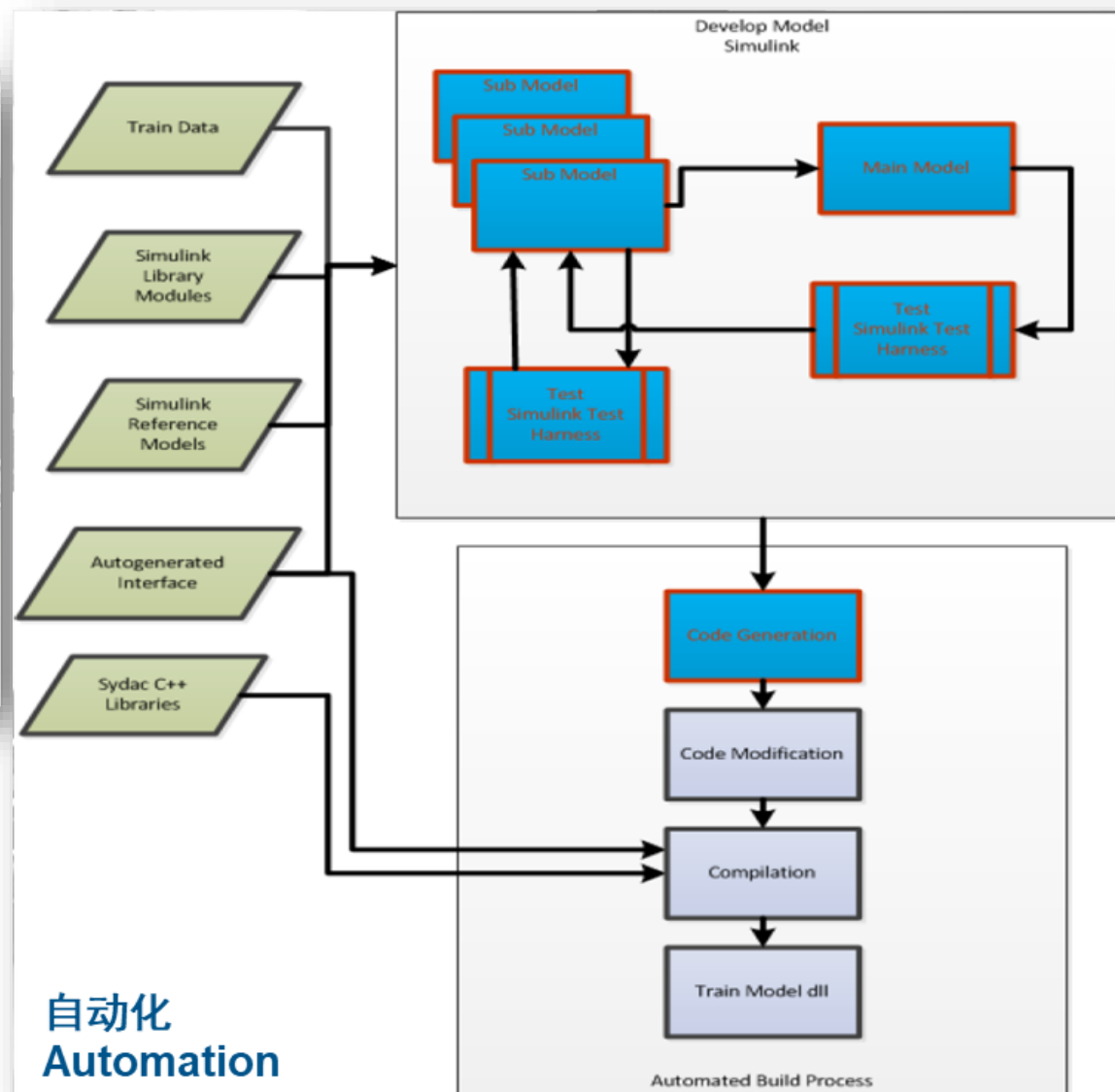
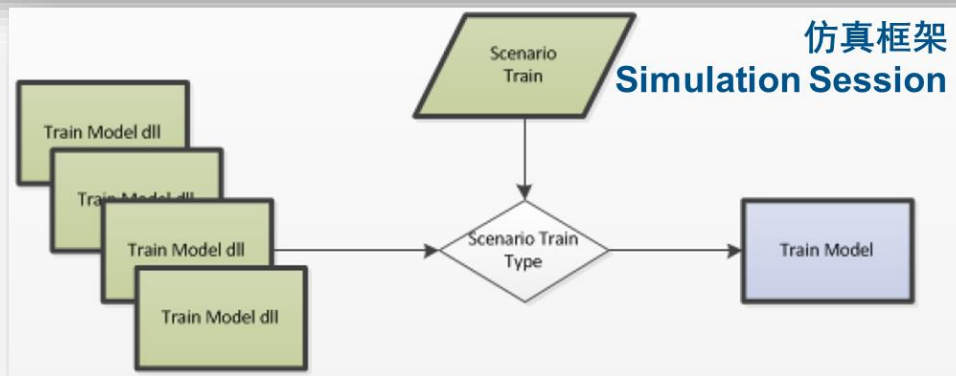
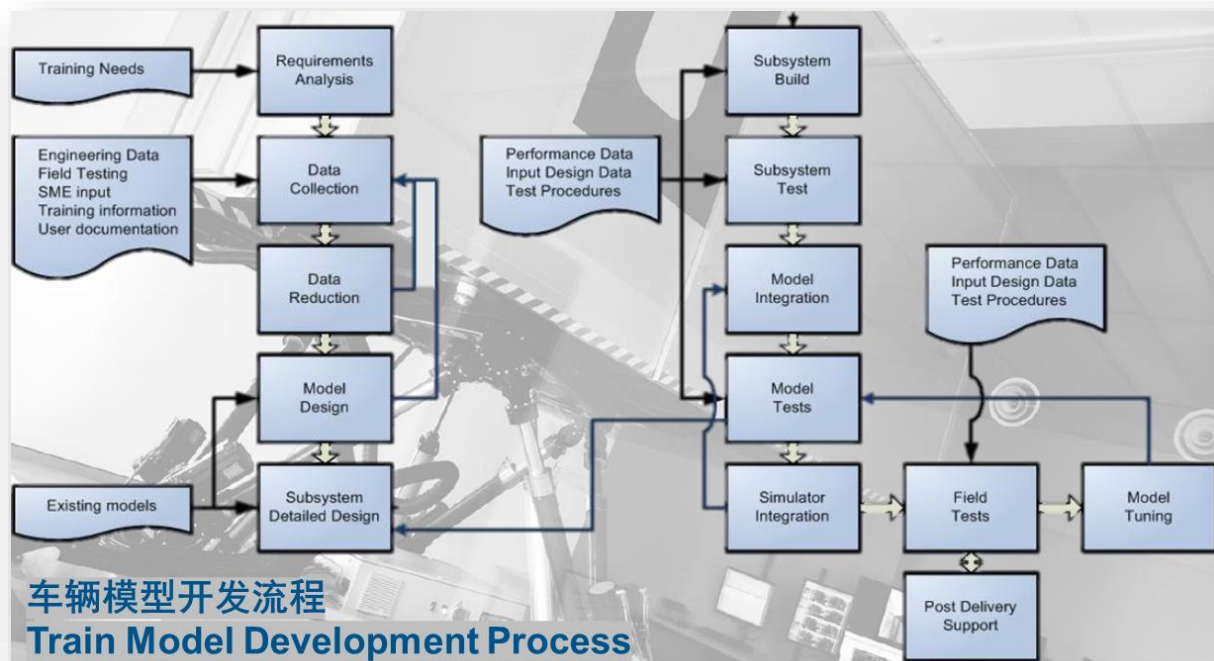
MathWorks®



- “
- Graphical modeling environment – modelers do not need to be programmers
  - Code-Generation – automated model deployment
  - Rich tool set
  - Mature user interface
  - Simulation and debugging environment
  - Large user base – resource availability
- ”

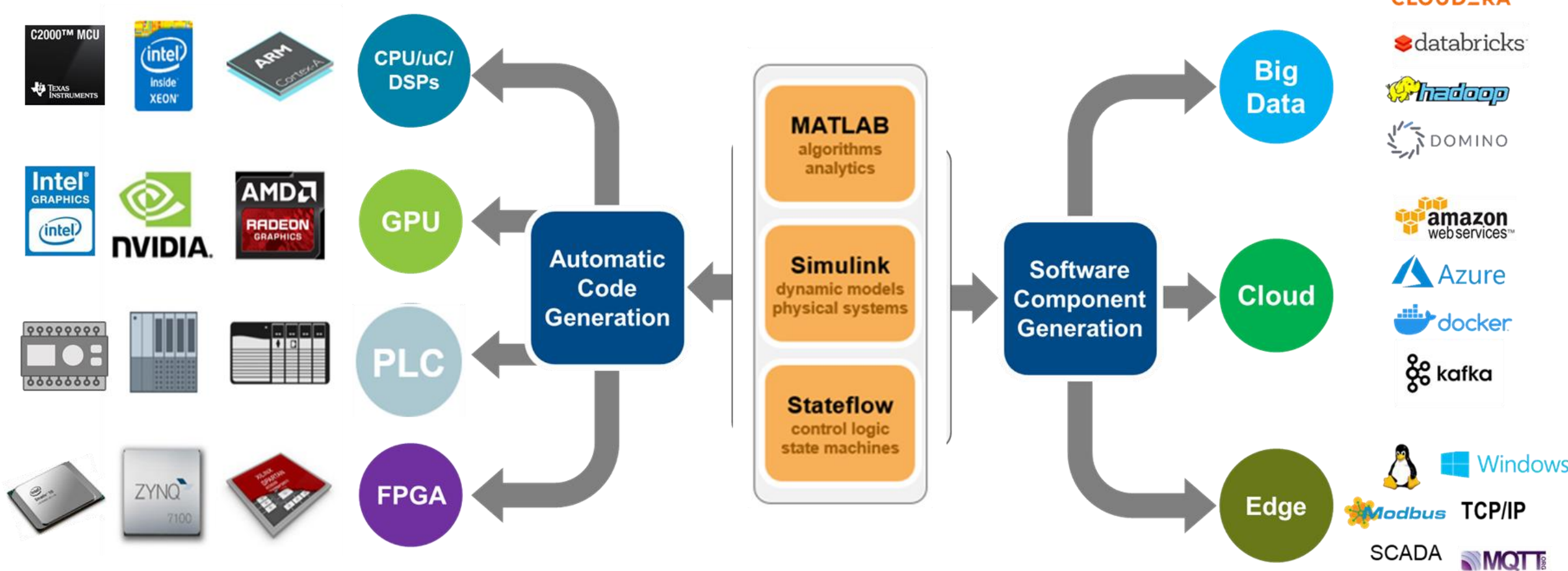


# 克诺尔SYDAC基于Simulink平台建立整车系统模型



# 核心能力——自动代码生成

Automatic code generation for choice of languages and targets



# ABB在变流器开发中使用代码生成技术

## ABB Traction

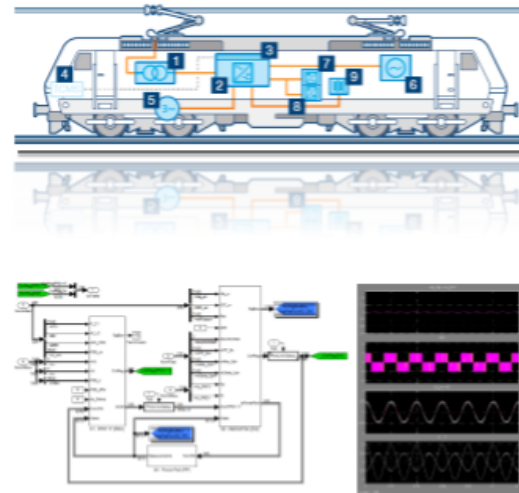
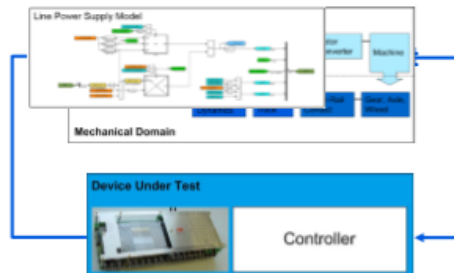
- 基于Simulink建立了超过50000个模型用于系统级仿真和控制软件设计
  - BMS模型、辅助电源系统控制模型、电机控制模型
  - 电机模型，车辆动力学模型等
- 基于自主开发的模型库，针对数字控制器的开发环境
  - 支持速率、多任务控制系统开发
  - 支持对系统需求变化的快速响应

### Where is Model-Based Design used?

From control of battery chargers, auxiliary power systems, to motor speed and wheel-slip control

- Large scale models with over 50,000 blocks

Simulation of the plant models e.g. motors, train dynamics



### Converter controller

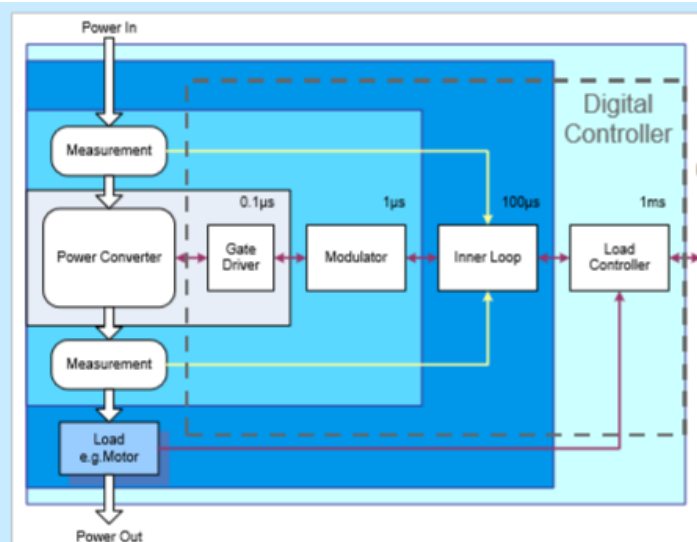
A controller is at the heart of the converter system

- Measure signals (speed, current, voltage, ...)
- Calculates new output voltages to reach desired operating point
  - multi-rate, multi-tasking control system

It is a digital controller, which provides

- Repeatable operation
- Performance complex operations
- Adaptable to system changes

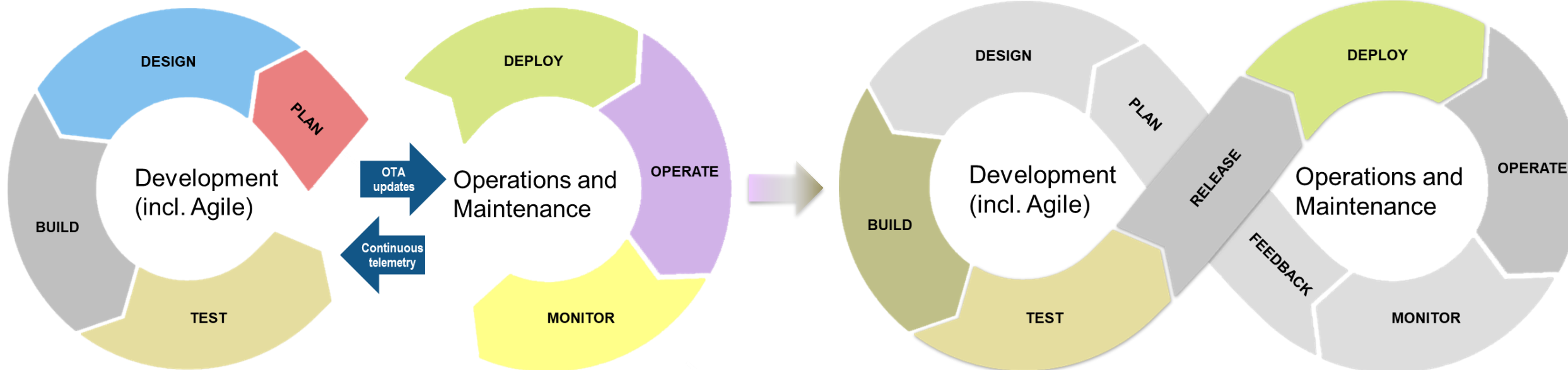
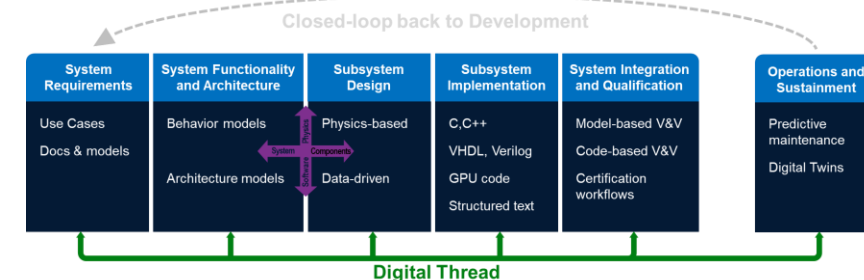
**Digital control technology is changing rapidly**





# 模型的使用贯穿系统全生命周期

## Systematic Use of Models throughout System Lifecycle



- ❑ Model DevOps使敏捷开发适用于数据驱动和物理模型驱动的项目实践

Model DevOps brings agile processes to both data-driven and physics-based models

- ❑ 基于模型的设计可以很好地映射到Model DevOps workflow

Model Based Design maps nicely onto the Model DevOps workflow

- ❑ 数据对于开发和运维都很重要

Data is essential for both development and operations

- ❑ 企业内各团队需加强协作以实现Model DevOps

Diverse teams across Engineering, IT, Line of Business, and Operations must collaborate to achieve success in Model DevOps

# 数字转型的关键 – 之数据

Key Factors - Data centralization

现场数据  
Field  
data



系统数据  
System  
data



用户数据  
User  
data



环境数据  
Environment  
data



大数据  
Big Data



云平台  
Cloud Platforms



## 数据种类繁多带来复杂性提升

### Data diversity complexity

- 工程数据、科学数据和现场数据  
Engineering, Scientific, and Field
- 商业数据 & 交易数据  
Business & transactional
- 噪声，异常，数据遗失  
Noisy, Outliers, Missing data
- 时间序列数据的同步  
Time series synchronizing

## 当前的数据管理加重了这种“复杂性”

### Modern data management multiplies complexity

- 种类繁多的数据来源  
Proliferation of data systems, more siloes
- 需要权限访问的云端数据、异构数据  
Cloud, on-premise, hybrid
- 越来越多的数据——“大”数据  
Big Data

# MATLAB使数据分析/机器学习工作流程无缝化

MATLAB makes the data analytics/machine learning workflow seamless

Access and  
explore data

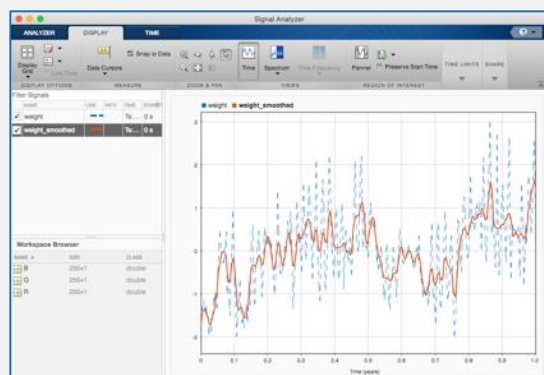
Preprocessing

Feature  
Engineering

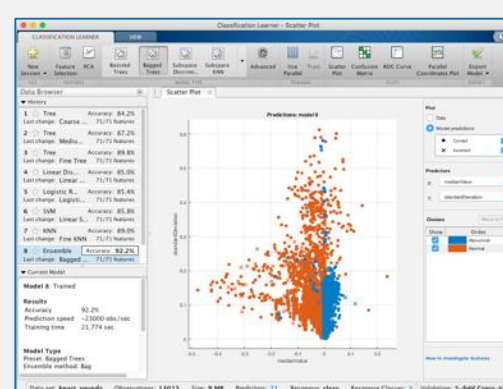
Model  
Training

Model  
Tuning

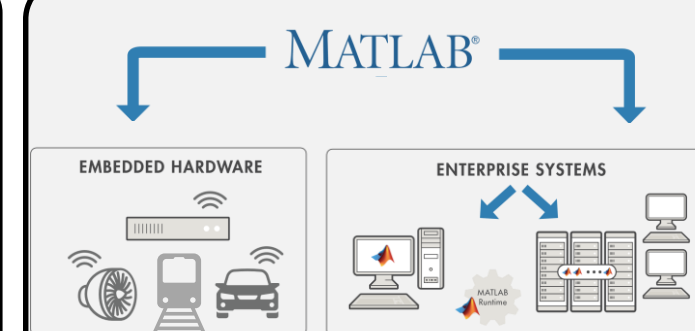
Integrate  
Analytics



Datatypes and tools for missing data, outliers, time-alignment, etc.



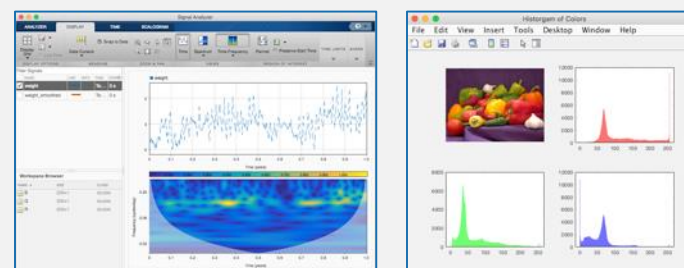
Machine Learning apps



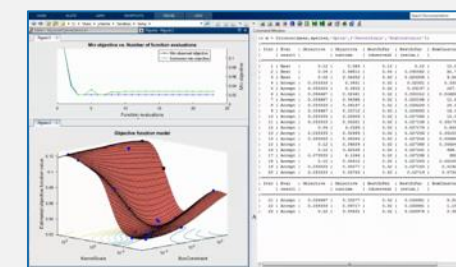
C/C++ Code Generation and  
Enterprise IT Integration

Region	OutageTime	Loss	Customers	RestorationTime	Cause
SouthWest	2002-02-01 12:18	458.972218	1820159.482	2002-02-07 16:50	winter storm
SouthEast	2003-01-23 00:49	530.1399497	212015.3001	2003-02-17 08:14	winter storm
SouthEast	2003-02-07 21:15	289.4035493	142938.6282	2004-04-06 06:10	equipment fault
West	2004-04-06 05:44	434.8053524	340371.0338	2004-06-18 10:54	attack
Midwest	2002-03-16 06:18	186.4167788	212754.0	2004-06-20 14:39	equipment fault
West	2003-06-18 02:49	0.0	0.0		
West	2004-06-20 14:39	231.2947226			

Text files, spreadsheets, databases, binary files, data feeds, web, cloud storage



Domain-specific techniques for  
Signals, Images, Video, Audio, and Text

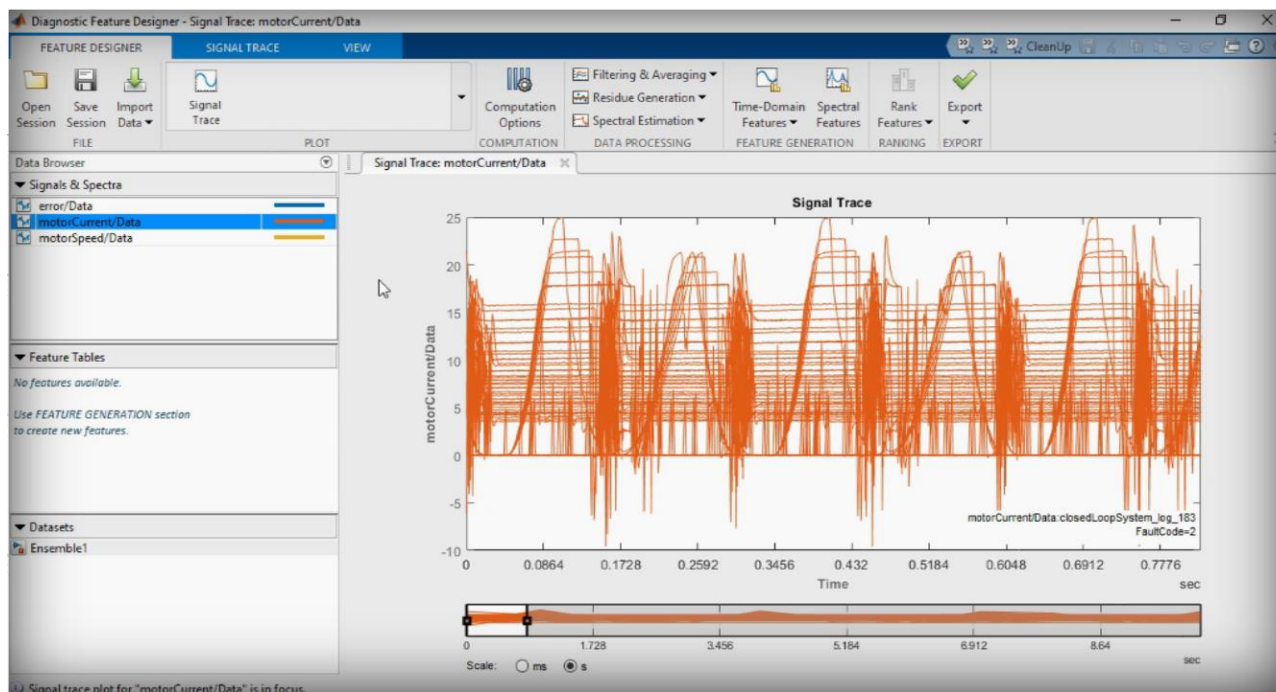


Automated Parameter Tuning

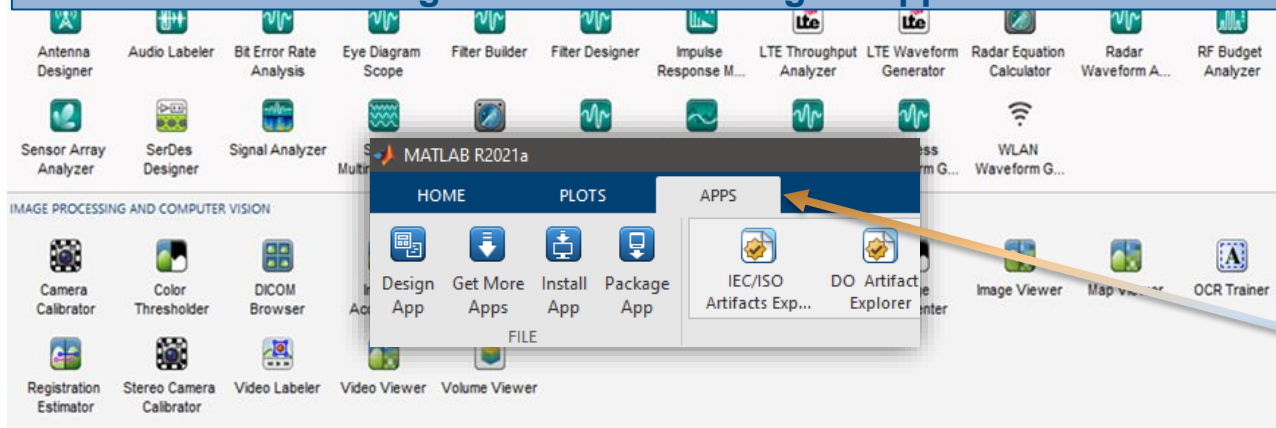


# MATLAB Apps提高生产力

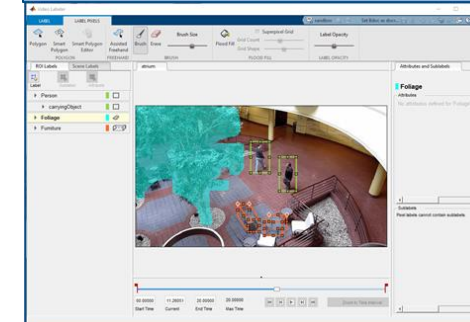
Apps increase the productivity



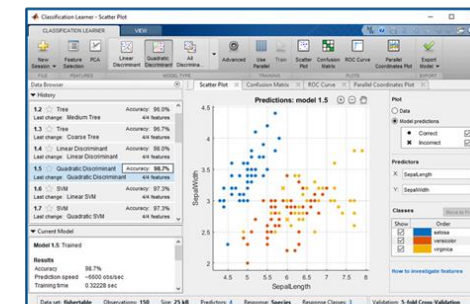
Diagnostic Feature Designer App



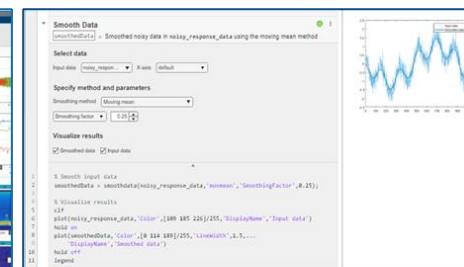
Signal Analyzer App



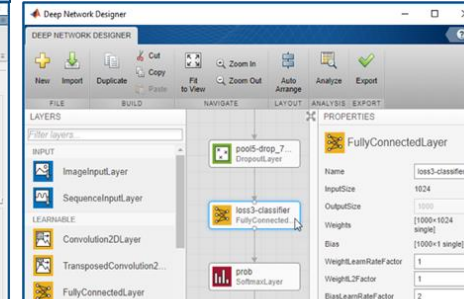
Image/Video Labeler App



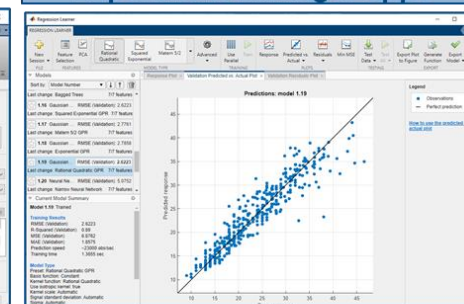
Classification Learner App



MATLAB Live Editor Tasks



Deep Network Designer & Experiment Manager Apps



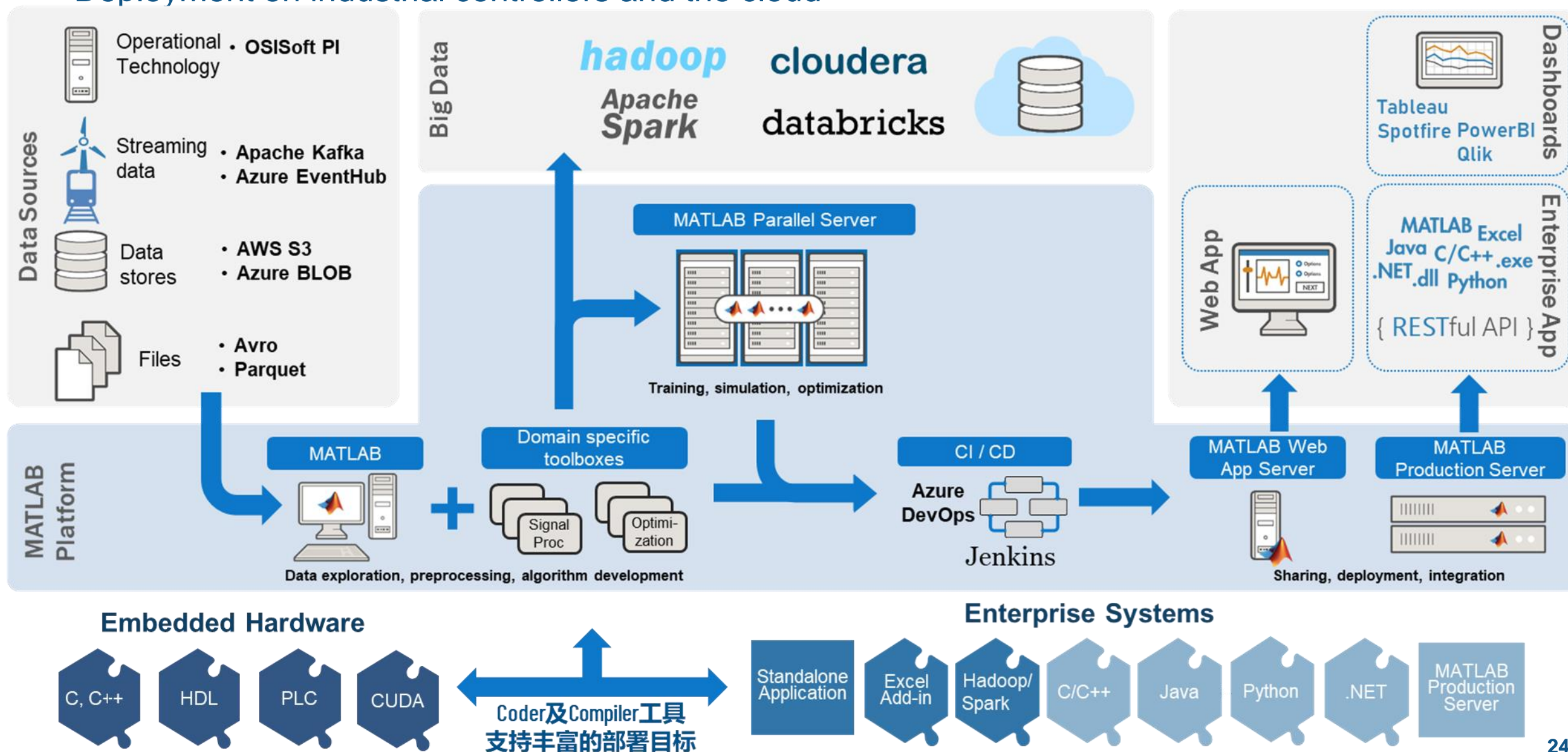
Regression Learner App

通过工具栏APPS访问更多的Apps  
explore more...



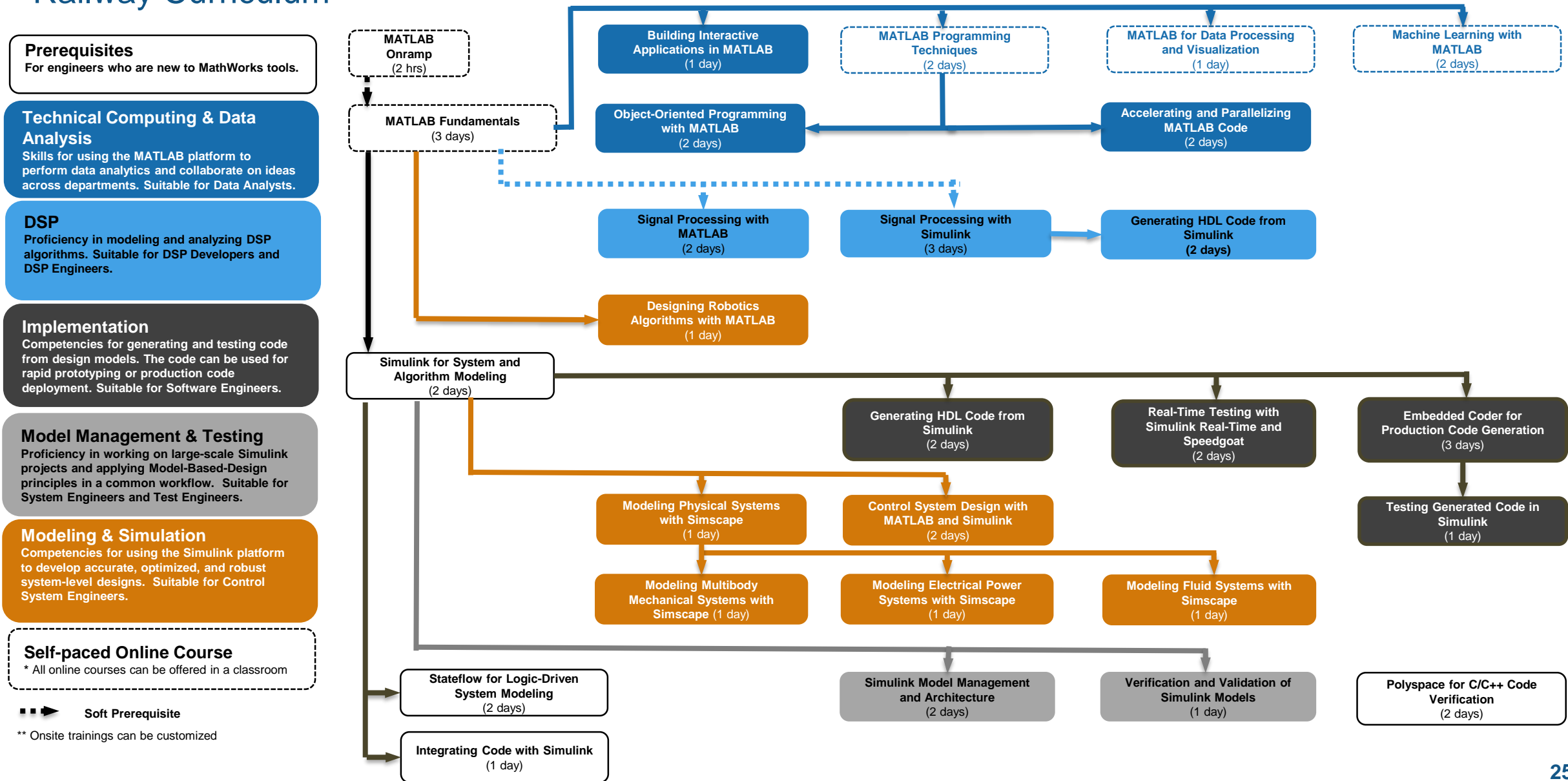
# 完整的工具链帮助基于数据应用的快速部署

Deployment on industrial controllers and the cloud



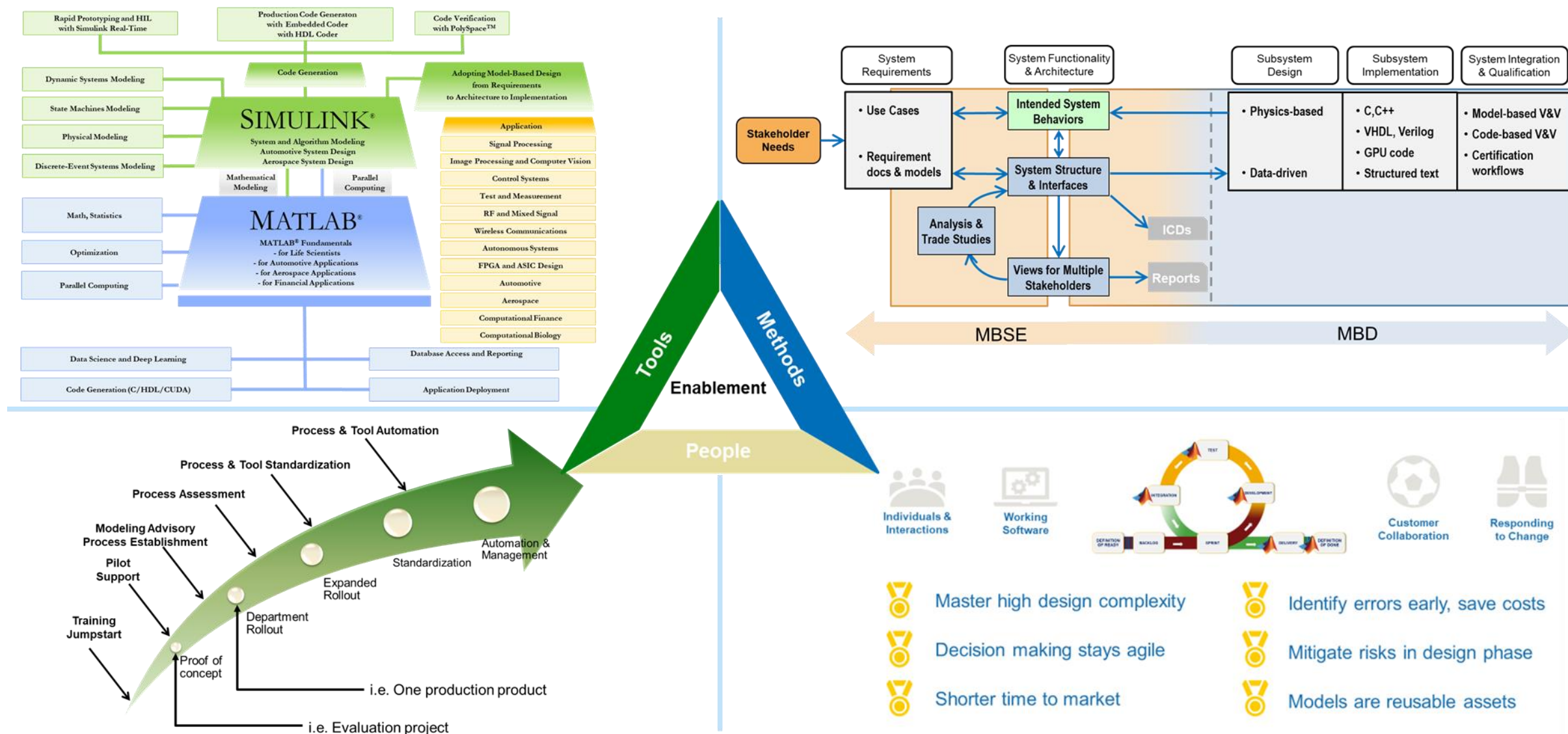
# 面向轨道交通行业的课程体系

## Railway Curriculum



# MathWorks助力您的数字转型

Accelerate the pace of digital transformation

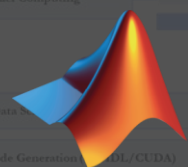




# MathWorks助力您的数字转型

Accelerate the pace of digital transformation

在 MathWorks，我们认为工程师和科学家具有举足轻重的地位。他们拓展了人类的知识，极大地提高了我们的生活水平。我们创造 MATLAB 和 Simulink 的意义便在于帮助他们把工作做到尽善尽美。



## MathWorks®

Accelerating the pace of engineering and science

更多信息，请访问 [www.mathworks.com](http://www.mathworks.com):

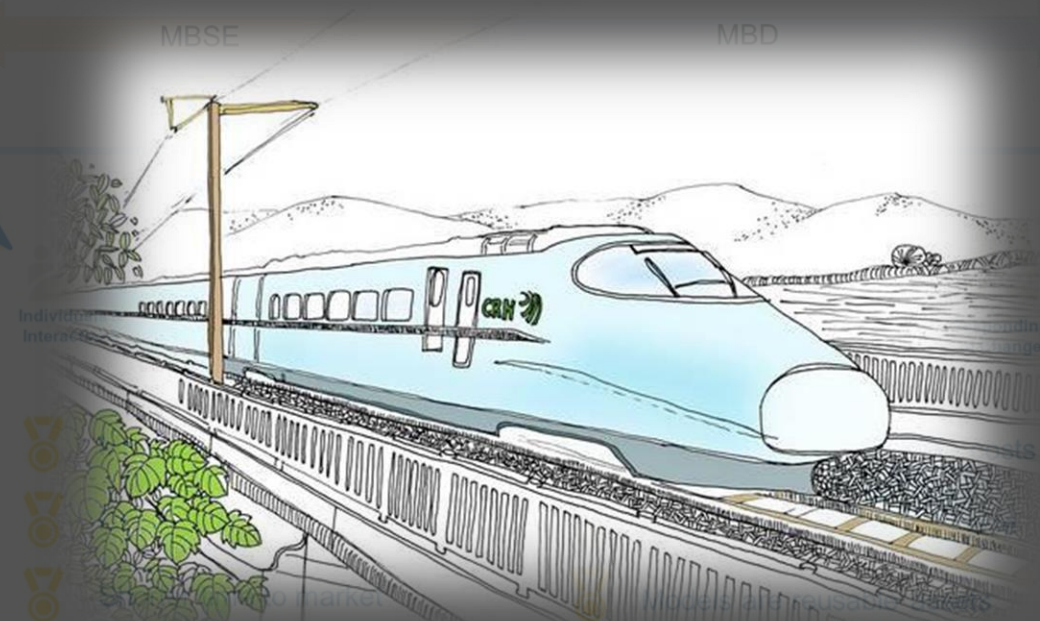
[Railway Systems](#)

[System Modeling and Simulation](#)

[Model-Based Systems Engineering](#)

[Agile System Development](#)

[Power Electronics Control Design](#)





# MATLAB EXPO

## 2021

谢谢！



© 2021 The MathWorks, Inc. MATLAB and Simulink are registered trademarks of The MathWorks, Inc. See [mathworks.com/trademarks](https://www.mathworks.com/trademarks) for a list of additional trademarks. Other product or brand names may be trademarks or registered trademarks of their respective holders.