USE OF PHM IN NON-TRADITIONAL GROUND VEHICLES

NASHVILLE, NOVEMBER 1, 2022

TOM TASKY

PREPARED FOR

PHM SOCIETY

14TH ANNUAL CONFERENCE OF THE PROGNOSTICS AND HEALTH MANAGEMENT SOCIETY

PANEL PRESENTATION

Your Engineering and Consulting Partner – Strong, Competent and Reliable

GLOBAL REACH – ONE FACE TO THE CUSTOMER

~645 M€
Revenue in 2021

~200
Patent applications per year

40+
Subsidiaries on five continents

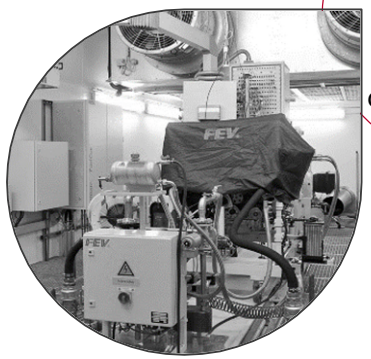
7,000
Employees globally

300+
Test cells for engines, T/M, e-drives, fuel cells & batteries

>40
Years of experience

>70%
Academics

>50
Different nations



FEV is Part of the Industry Ecosystem and acts as an Integrator of Different Industry-Specific Capabilities for its Clients

FEV ECOSYSTEM

TECHNICAL KNOWLEDGE

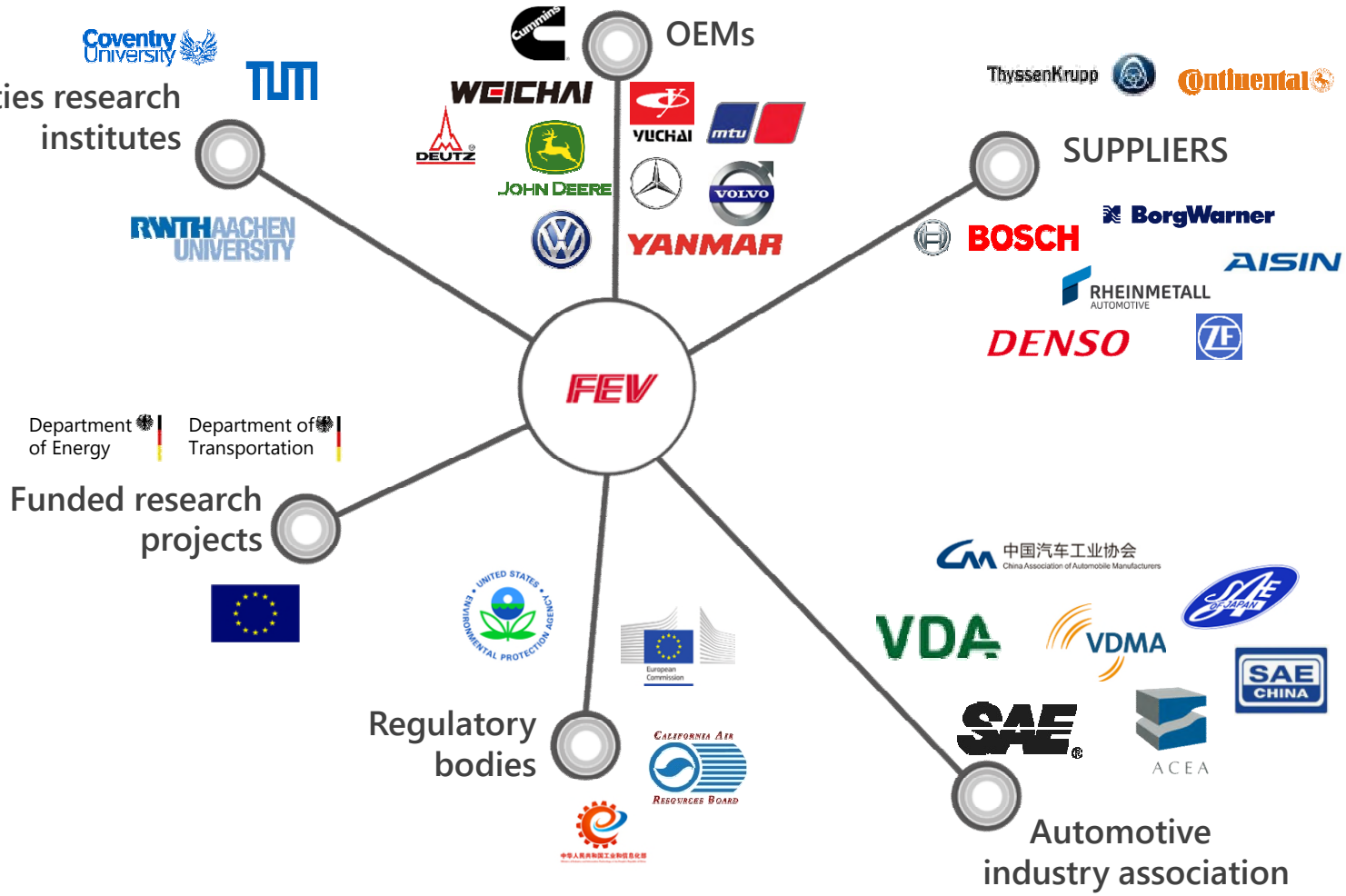
Access to over 4,000 engineers and subject matter experts and close ties to engineering and operations research

INDUSTRY EXPERIENCE

Experience from thousands of projects delivered for major players and organization from different industries

GLOBAL REACH

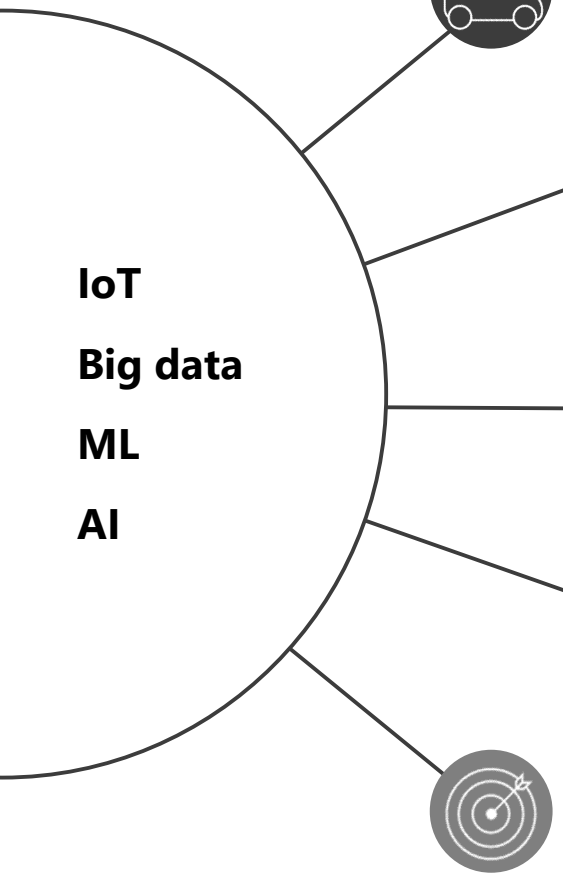
Global company and customer network with 40+ subsidiaries on four continents



Note: 1) OEM = Original Equipment Manufacturer

Relevant trends are based on IoT, big data, artificial intelligence, and machine learning

CONNECTIVITY IS BOTH A FUNCTION AND A KEY ENABLER



Autonomous vehicles & robots enable autonomous vehicle actions, e.g., driving, drilling, hauling, excavating… **IEEE802.11p & 5G/C-V2X** are key enablers for collaborative functions

Remote operation systems let workers control machines from a small distance or from control centers several miles away – **5G and MEC solutions** are enablers to achieve low latencies

Connected & predictive asset management track current state of machines continuously by transmitting data from connected sensors – enabled by **mobile broadband**

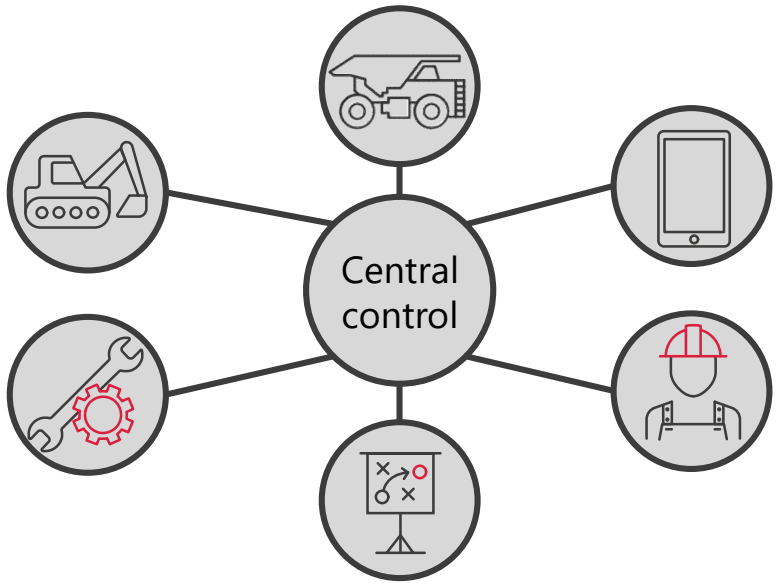
Image recognition includes detecting, analyzing, and interpreting images – conducted by computers – to enhance decision-making for humans; **4G/5G** is a key enabler to offload processing into the Cloud

Industry specific innovation disrupting traditional business processes

MEC = Mobile Edge Cloud; C-V2X = Cellular Vehicle-to-Anything

Connecting assets leads to high potential in improving overall productivity, with tools available in all three industries

CONNECTED & PREDICTIVE ASSET MANAGEMENT – NRMM MARKET TRENDS

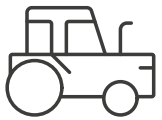


CONNECTED ASSETS:

Asset, workers, and tools are equipped with IoT-enabled sensors. Data is continuously sent to a computing unit, where their future performance is predicted by ML-based algorithms.

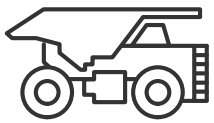
CONSTRUCTION – MEDIUM to HIGH RELEVANCE

- **MARKET PENETRATION:** Adoption in large/ complex construction projects; predictive maintenance is easy to implement
- **TIMELINE:** Construction industry slowest adopter of IoT, fast adoption of predictive maintenance expected



AGRICULTURE – HIGH RELEVANCE

- **MARKET PENETRATION:** Connected field relevant to areas with good network conditions; predictive maintenance is easy to implement
- **TIMELINE:** field monitoring products already in market; fast adoption of predictive maintenance expected



MINING –HIGH RELEVANCE

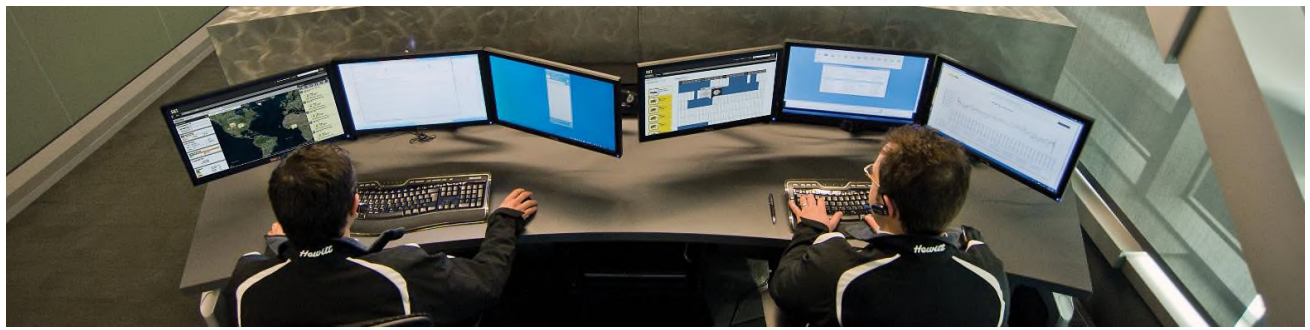
- **MARKET PENETRATION:** Connected assets provide good potential for mine operation optimization; predictive maintenance is easy to implement
- **TIMELINE:** Already used to track extraction performance on mine and vehicle level; fast adoption of predictive maintenance expected

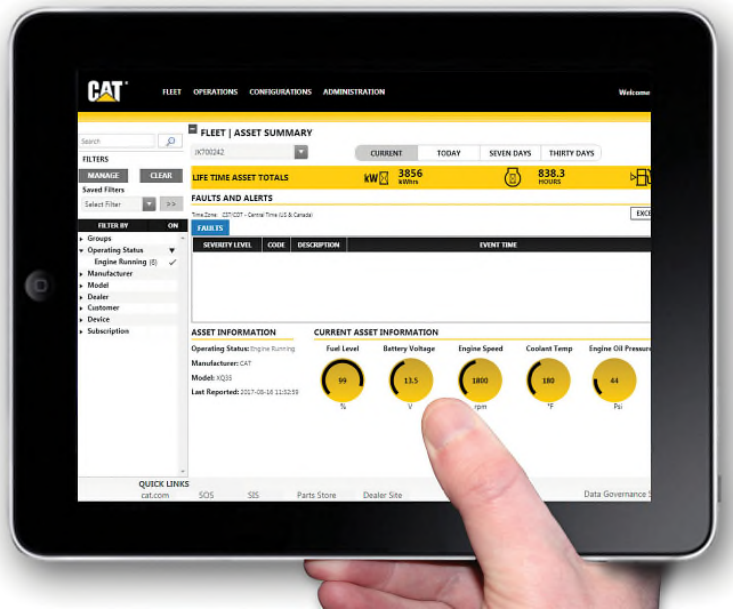
Notes: PC – passenger car
Source: FEV, Volvo

Caterpillar invests in digital solutions for condition and performance monitoring as well as predictive maintenance

CAT DIGITALIZATION STRATEGY

- Cat Connect services for generator set customers
  - **Digital technologies to anticipate, prevent and solve customer problems**
  - **Condition and performance monitoring, predictive maintenance**
  - **Remote control systems**
- Advantages for the customer: **Help to control costs, reduce risk and improve business / system performance**
- Advantage for Caterpillar: **More insights into equipment performance and operations → customized solutions**
- Plans on visualization of information and development of specific reports, remote start/stop, augmented reality





Source: FEV, CAT

Connectivity was highlighted by Bobcat at CES 2022 with a 5G-based Remote Control demonstration between Las Vegas and Denver

EXCAVATOR OPERATOR REMOTELY CONTROLLED A LOADER OVER 5G THROUGH AN IMAGE STREAMING INTERFACE

Screenshot from CES 2022

Real-time tractor data available through a smart connector application for simplified compact utility tractor maintenance

CONNECTIVITY IN AGRICULTURE

» CASE STUDY

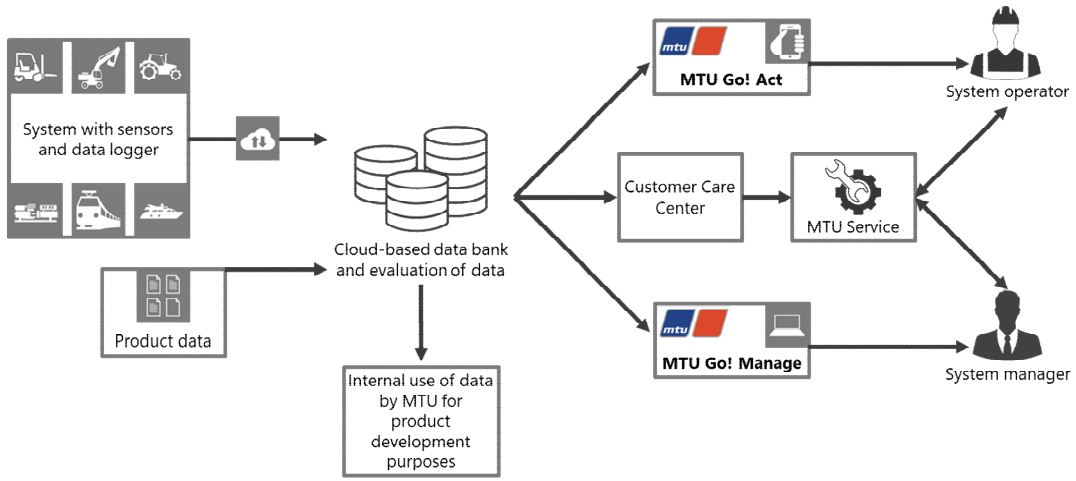
JOHN DEERE SMART CONNECTOR

- John Deere smart connector and the John Deere application allows for **simplified tractor maintenance**
- Smart connector is plugged into the service advisor port and establishes a **connection to the smartphone application via Bluetooth**
- This connection allows for **easy access to tractor data like service intervals, diagnostic codes, engine hours, vehicle usage, maintenance notifications, and fuel level**
- Application helps owners by providing easy access to manual, part diagrams, and ordering directly from the John Deere store
- **Real-time tractor information available through a dashboard** within the application
- Smart connector is compatible with both old and newer compact utility tractor models

Source: Media, John Deere, FEV

Rolls-Royce Power Systems launched its customer care center and digital tools for mining vehicles

DIGITAL TRANSFORMATION OF MTU'S GLOBAL CUSTOMER SUPPORT



- Establishment of Customer Care Center in Friedrichshafen, Germany for advanced customer support
- Design of **digital analysis tools** GO! Manage and Go! Act for connecting customer systems (propulsion, power generation, etc.) to a database and **enabling communication between operator and service personnel**
- MTU GO! Manage is a **platform for remotely monitoring customer equipment, predicting and scheduling maintenance work, ensuring the availability of spare parts and analyzing operational data**
- MTU GO! Act is a smartphone application for the **identification of system irregularities and quick interaction with MTU service**
- Rolls-Royce offers Value Care Agreements guaranteeing reliability and availability of engines and systems
  - e.g. monitoring of drive system performance and maintenance supported by sensor data for Hitachi trainsets

Source: Rolls-Royce, FEV

HMI trends assist operators, solution providers, and manufactures with real-world data to continuously improve operations, comfort, and performance

5 HUMAN-MACHINE-INTERFACE TRENDS IN VEHICLES

Interactive Driver Displays

- Screen based interior focus for all functions & operator feedback

Voice Command

- Multi-language voice commands

Biometric Feedback

- Visual and tactile sensory feedback

Driver Monitoring

- Monitoring
  - Driver Habits, fleets

Automated Driving

- Improved controls for the driver or "passenger"
- Driver attention can be reduced

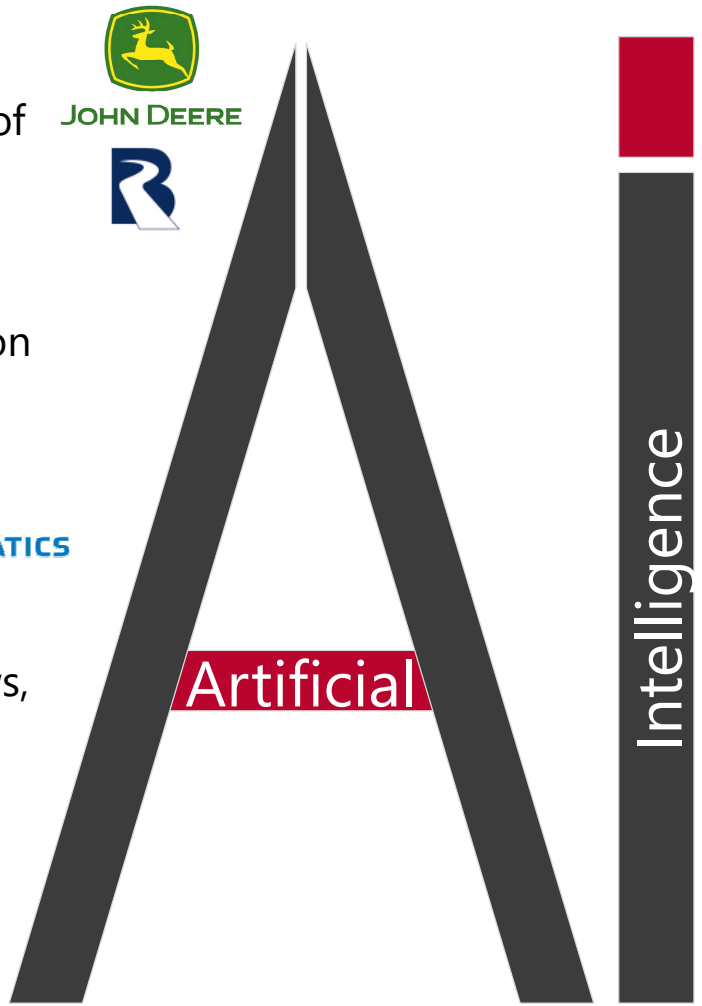
Source: FEV

AI and ML-based solution trends continue to be developed in various industries to reduce operating costs and increase vehicle availability

» NON EXHAUSTIVE

- Automated driving tractor
- Calculation of the optimal volume of herbicide (80-90% less herbicide)
- **Collecting user data to suggest machine improvements**
- Bought Blue River, an AI visualization start-up

- Telematics: Efficient fleet management
- Asset tracking: streamline workflows, identify inefficiencies and ensure transparent processes.
- **Diagnostics: detect malfunctions before they create extra expense**

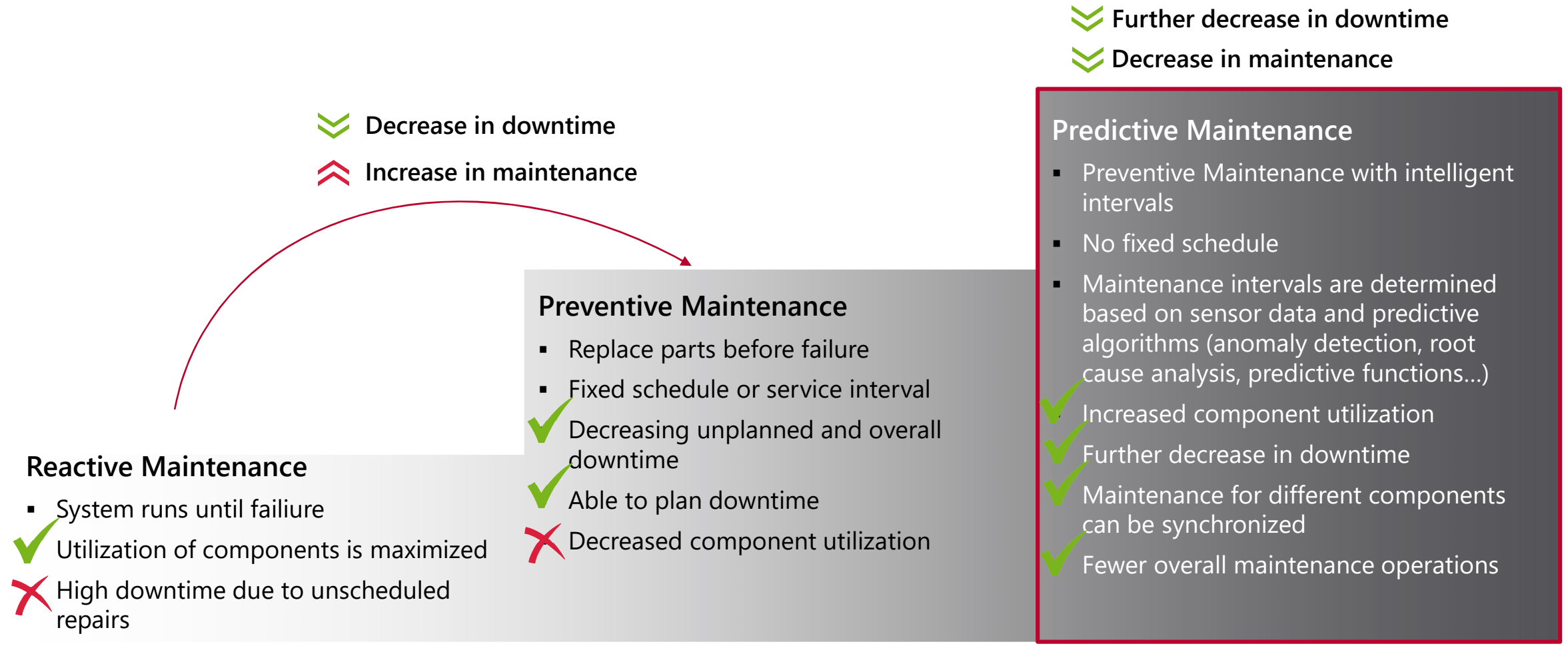


- Real-time analysis of engine data
- Recognize patterns of malfunctions in engines and ship equipment
- **Use machine learning to enable predictive maintenance**

- **Predictive maintenance**
- Reduction of costs for unexpected breakdown
- Optimization of periodic inspection
- Reduction of operation costs

Source: FEV, John Deere, Rolls Royce, Bosch, ZF

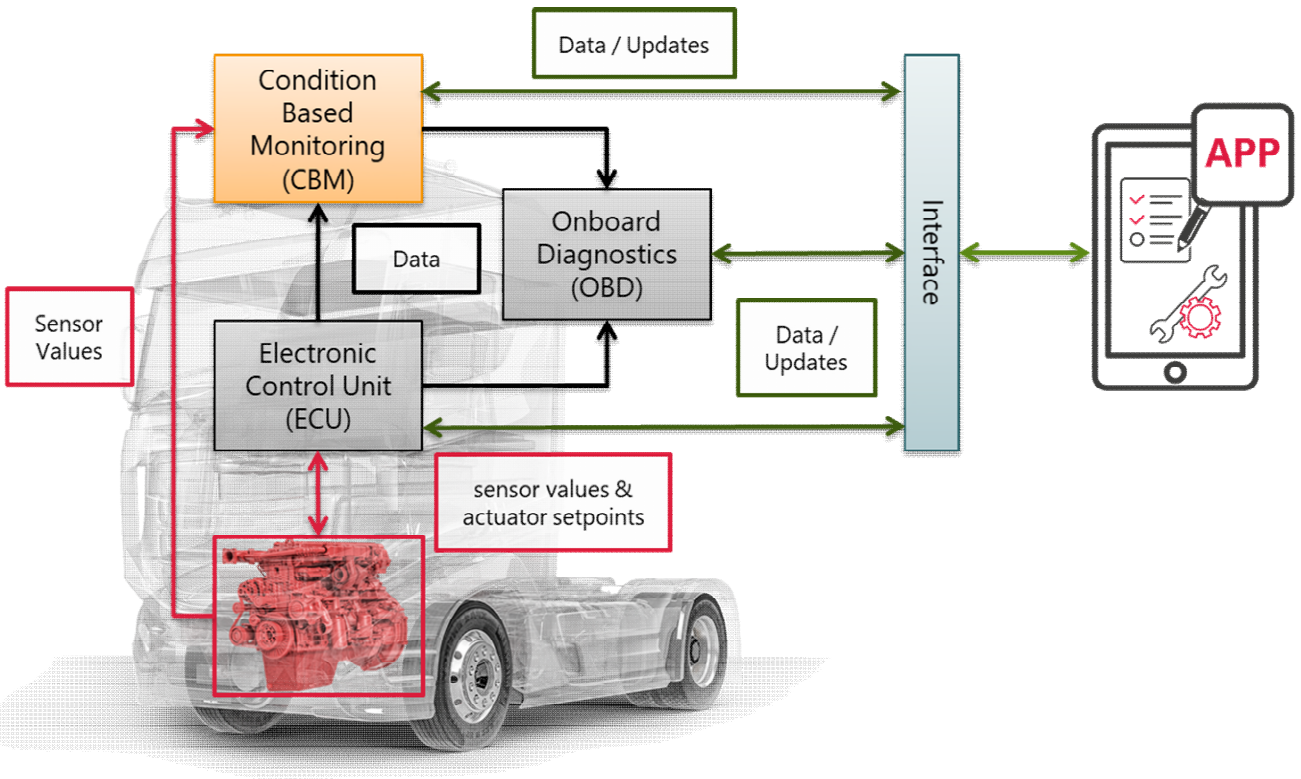
Maintenance strategies can provide new value based on Reactive, Preventive, or Predictive approaches



Source: FEV

Condition-based monitoring has different levels of implementation
Stage 1: On-board Condition Monitoring

SYSTEM OVERVIEW



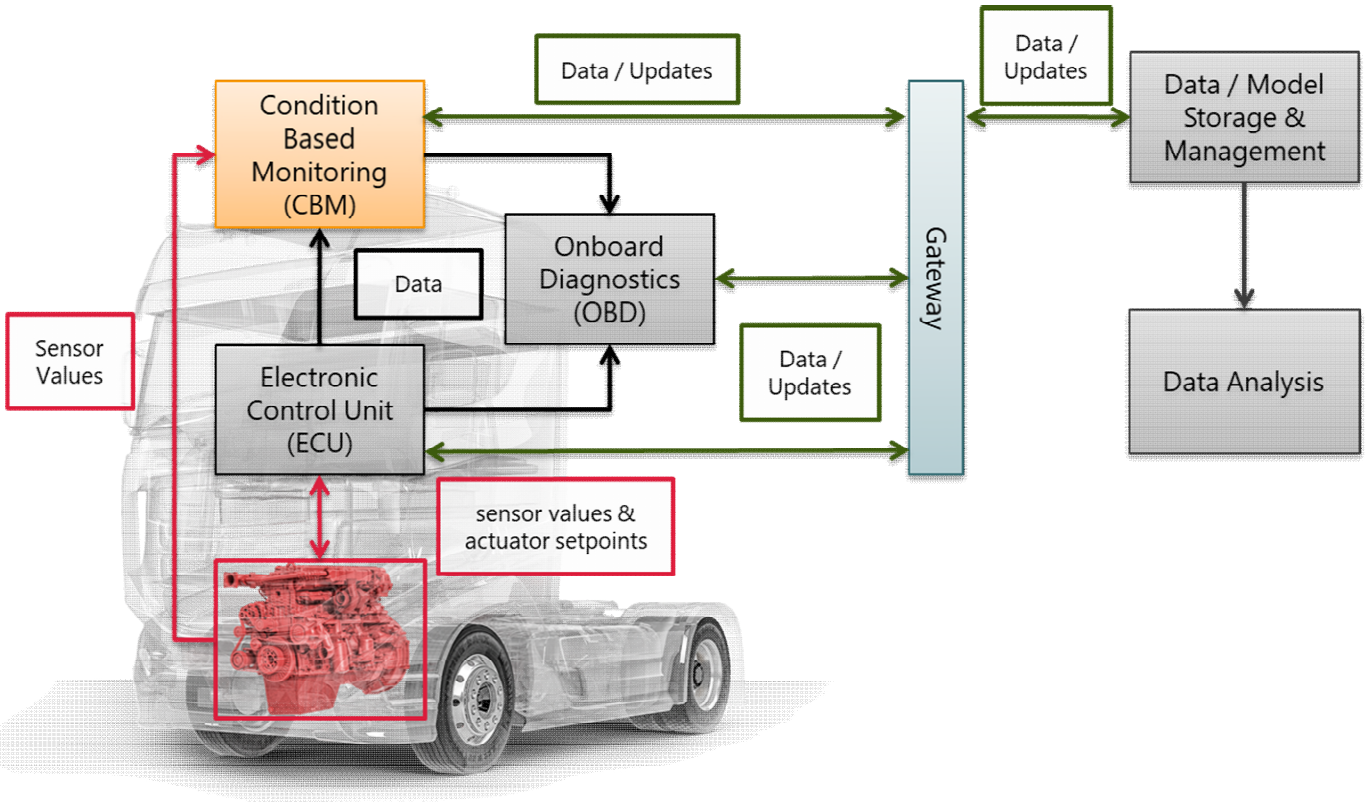
Stage 1

- Plant model and engine monitors run on-board using existing ECU HW
- Deviation between expected and actual behavior can be detected onsite

Source: FEV

Stage 2: On-board Condition Monitoring with Off-board Data Analysis

SYSTEM OVERVIEW



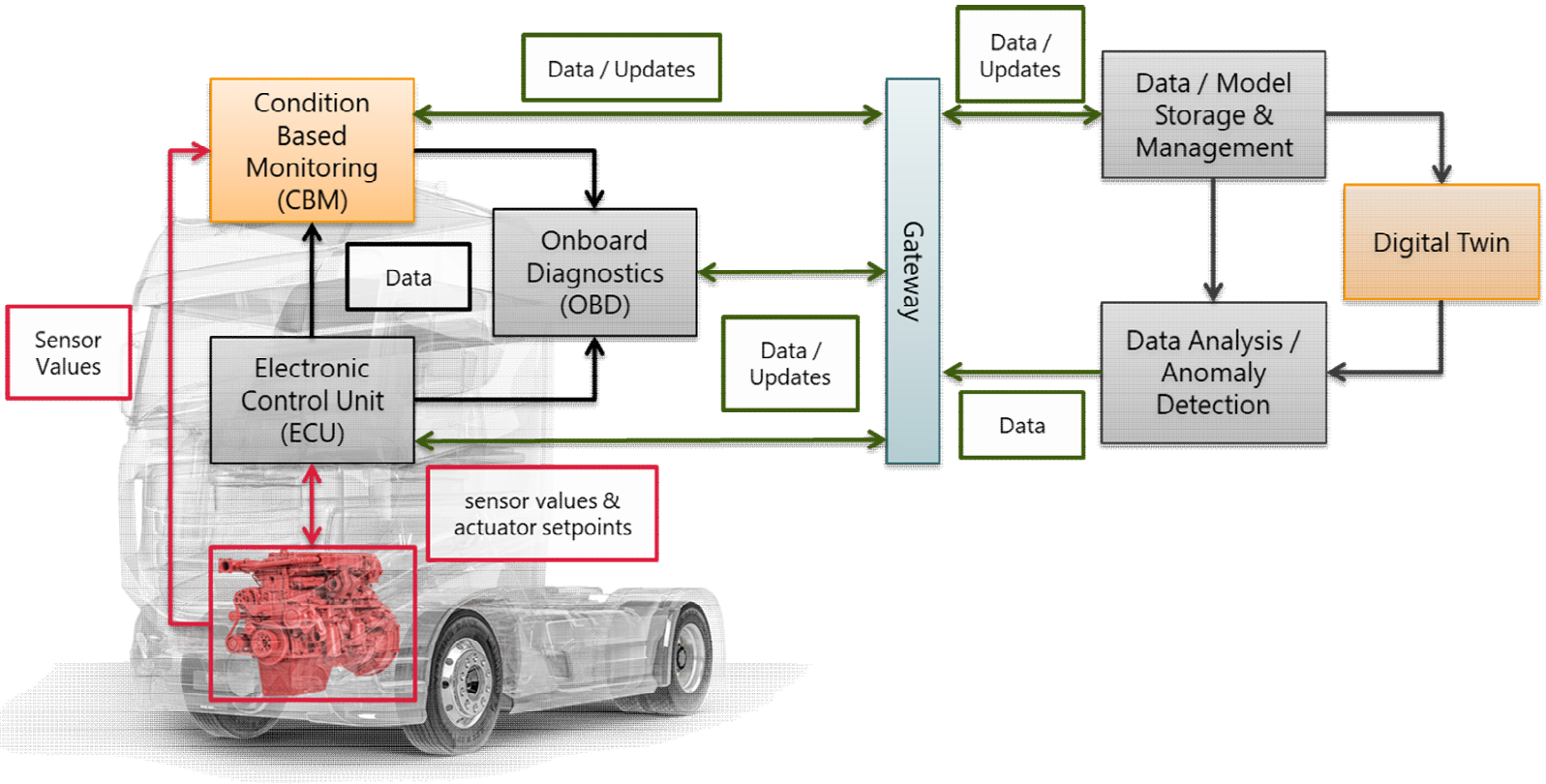
Stage 2

- Monitoring system runs on-board
- Data analysis unit runs off-board on e.g. central computation facility and collects relevant data from complete fleet
- Data is stored and can be visualized

Source: FEV

Stage 3: On-board Monitoring with Off-board Failure Analysis and Digital Twin

SYSTEM OVERVIEW



Stage 3

- Monitoring system runs on-board
- Data analysis unit runs off-board on e.g. central computation facility and collects relevant data from complete fleet
- Data is stored and can be visualized
- Digital Twin runs off-board and is fed with data from the fleet
- Potential failures are identified; pinpointing to potential root causes

Source: FEV

Case example of a fleet monitoring and proactive service/maintenance solution

» CASE EXAMPLE

MOBILE MEDIUM SPEED ENGINE APPLICATION

BACKGROUND

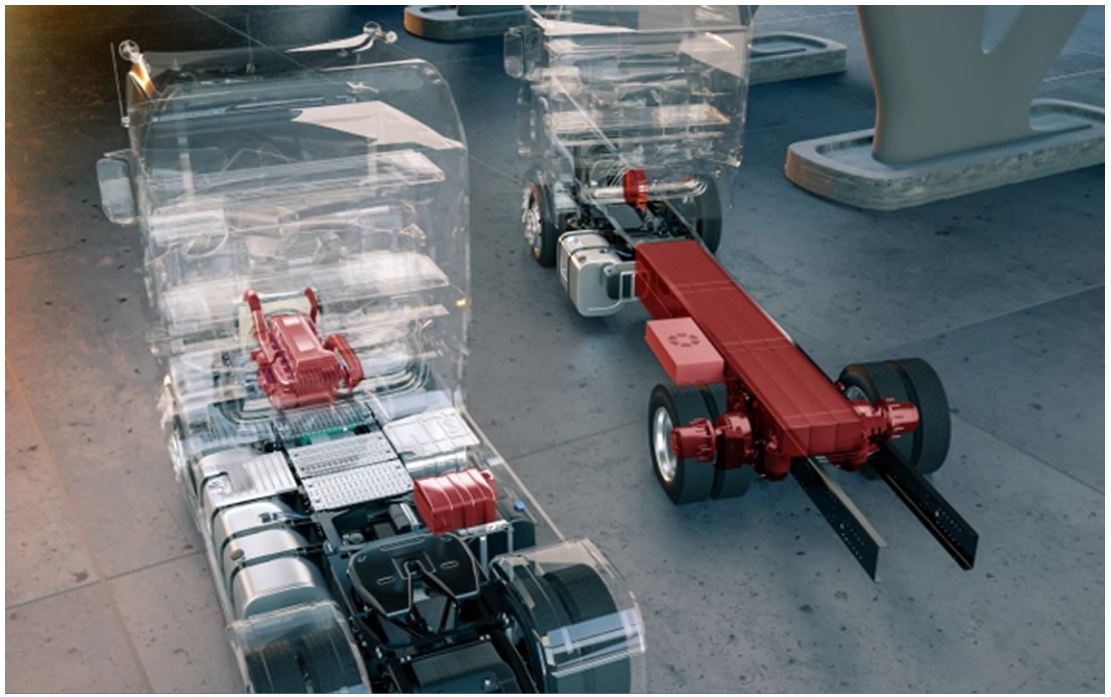
- Number of vehicles ~1000
- Remote data collection >100 parameter per vehicle
- Data packages (10ms – 1s sampling) transmitted at pre-defined triggers and routinely

PROJECT DESCRIPTION

- Scope:
  - **Develop algorithms to detected unhealthy engine systems** including verification & validation
  - Target: **predict breakdowns** ≤ 3 days in advance
  - Diagnostics and evaluation of incidents
  - Recommendation for intervention of service
- Key Results:
  - **Successful conversion of vehicle breakdowns into unplanned service/maintenance**
  - **Prevention of catastrophic engine failure**
  - **Increase overall fleet availability**
  - Prioritize proactive planned maintenance
  - Data saved in database and constantly evaluated by algorithm automatically

Source: FEV

Electrification based State-of-Health examples as well as functional safety (FuSa) development implications



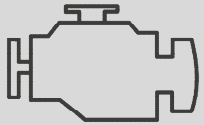
Examples

- Contactor State of Health:
  - Reliability of HV contactors
  - Studies to determine contactor aging and replacement prior to failure
- Battery Pack/Cell State of Health:
  - Understanding of cell limitations
    - Impacts on FuSa limits, performance, & range
- Cell Balancing:
  - Individual cell health monitoring
  - Better SOH -> better balancing strategy -> less exercising of ASIC -> lower risk of failures
- HW degradation & failures affect safety mechanisms

Source: FEV

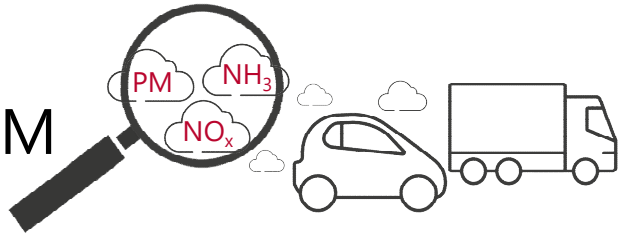
Proposed emissions regulations to make use of On-Board Monitoring (OBM)

CURRENT OBD



- **European Commission: OBD** is **not sufficient** to detect all high emitting vehicles
  - OBD system was not designed to monitor tailpipe emissions
  - Higher emissions with failures in RDE compared to WLTC
  - Detection of single point of failure at defined conditions (test cycle), multiple failures are not considered
  - Some systems with emission impact are not monitored at all
  - Tampering still possible
- **High effort:** More than 50 % of control functions of a typical ECU are for OBD

IDEA OF EU7 OBM



- **On-board monitoring** of **tailpipe emissions** under all relevant driving conditions for EU7
- Detect **any emission exceedance** and all possible failure modes of individual vehicles and vehicle types
  - Monitoring of overall tailpipe emissions impact by OBM instead of only monitoring the effectiveness of single emission reduction systems by OBD
- Long-term idea is that **tailpipe pollutant sensors** check the emissions, but **for some pollutants indirect monitoring approaches** will be needed

THANK YOU!

CONTACT DETAILS

TOM TASKY

VP

FEV.io
Phone: +1 248.724.3472
Email: tasky@fev.com