ROUSH®

INGENUITY ON DEMAND

Advances in system monitoring: Lessons from the automobile industry

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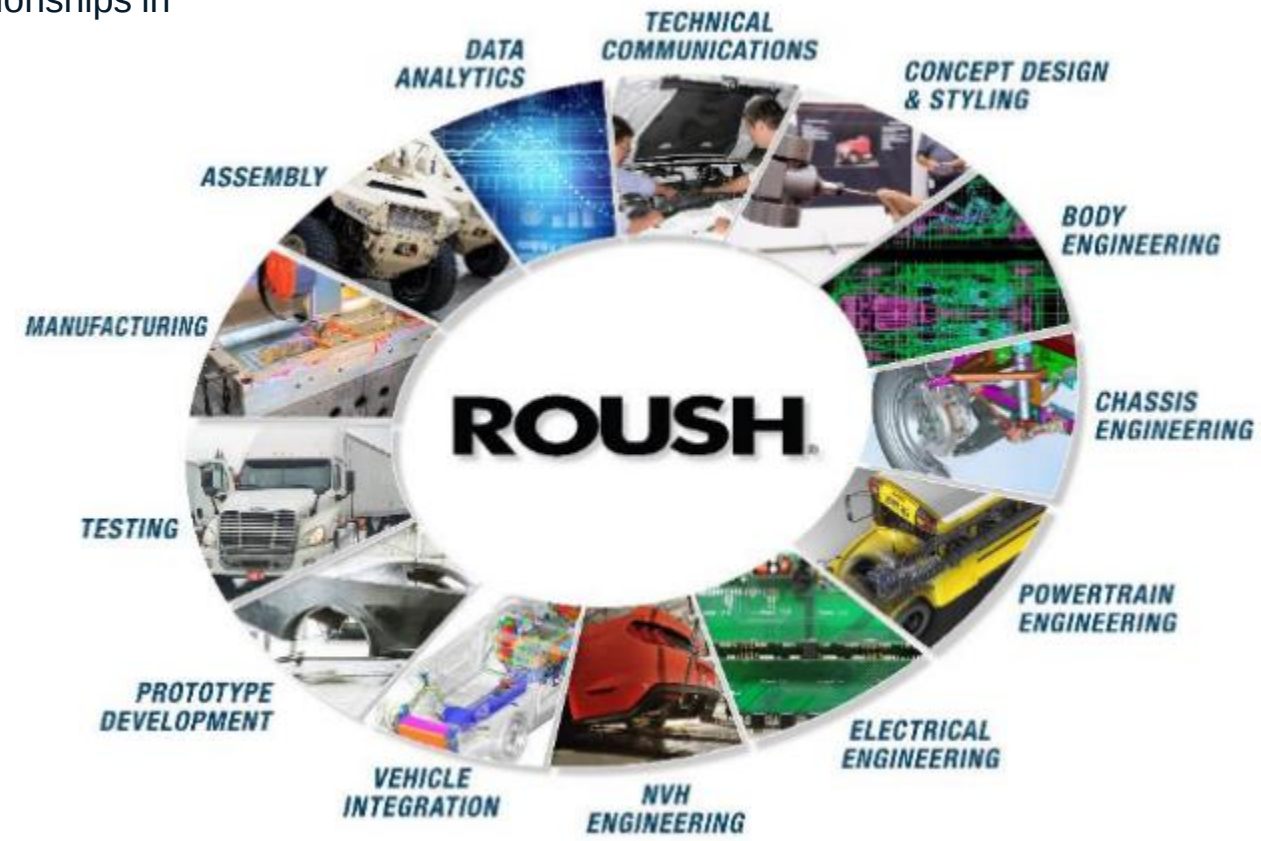
Roush Industries: More than NASCAR and Stage 3 Mustang?

Over 5,000 Engineers, Designers, Mechanics, Technicians and Support Personnel

Roush Fenway Racing is one of NASCAR'S premier racing teams, winning over 32 championships and more than 360 events including championships in NASCAR'S top three divisions.

Roush Performance Products develops and sells performance products ranging from crate engines, and kits to Roush Stage Mustangs, F150 and Ranger Pick-ups.



Roush On-Road Vehicle Testing (ORVT)

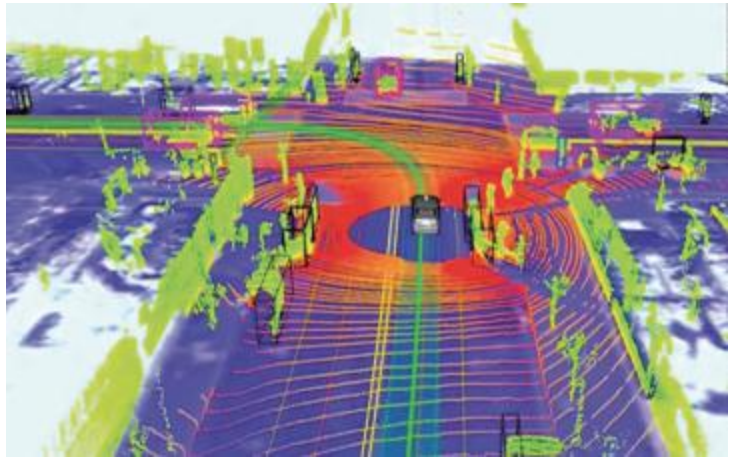
110 Million Miles Testing in 2018 – Over 1 Billion Miles Total

- Largest on-road testing operations in the US
  - Test labs in MI, FL, MN, CO, NV, CA, AK & WA
- 2000+ contract drivers, mechanics & test engineers
- Data-centric approach for collection, quality & engineering (performance and emissions)
  - All data are secured & customer proprietary
  - Unique exposure to preproduction issues across all OEM's and Tier 1 suppliers
- Support DFMEA, DV testing & functional safety analyses with broad issue experience.
  - Data Analytics supports quantitative data for DFMEA, DV & functional safety

Connectivity, ADAS, Autonomy

Electronics, Sensors, Network & Software Complexity

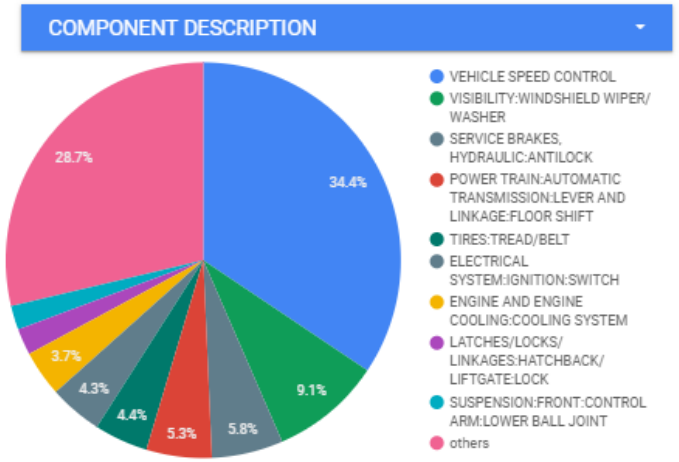
- Complex Infotainment System Testing
- Autonomy-map Development (sensor and vision)
- Algorithm Training (feature-based training routes, complexity)
- ADAS System Testing
  - Sensors: Vision, LIDAR, RADAR, etc.
- Over-the-air Software Updates
- Simulated and Real-Life Use Cases



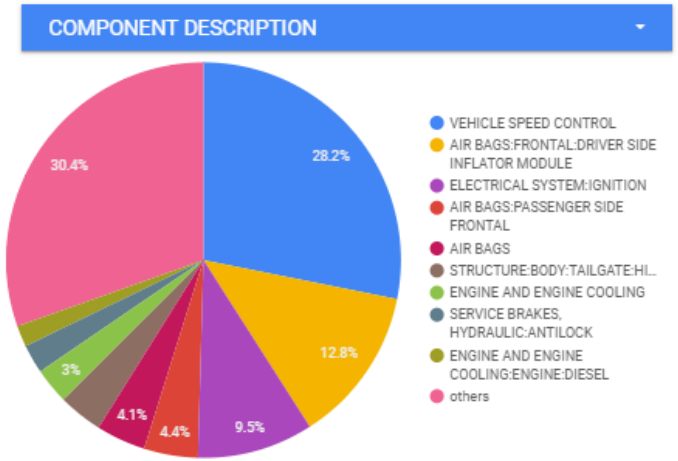
Technology Trends in Light-Duty Vehicle Recalls

Exponential Increase in Sensors, Network & Software Complexity

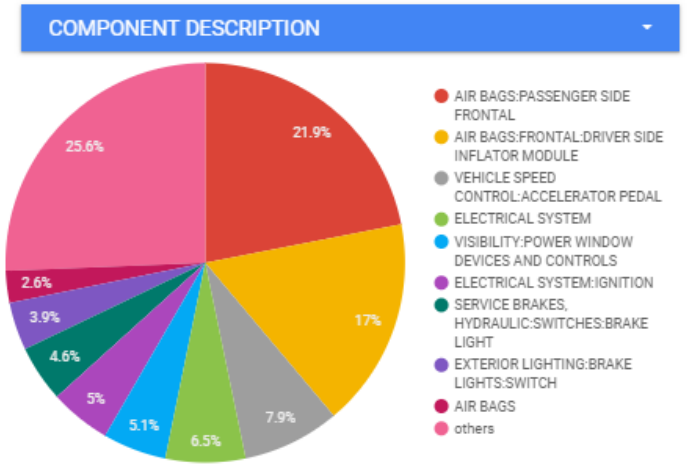
1995 – Speed control, Visibility



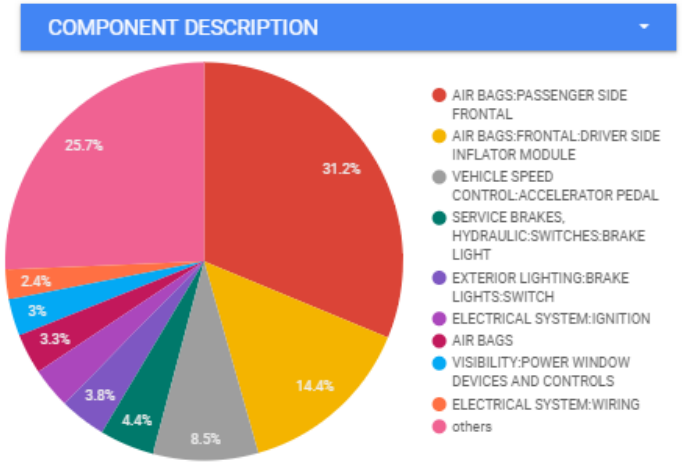
2002 – Speed control, Airbag (begins)



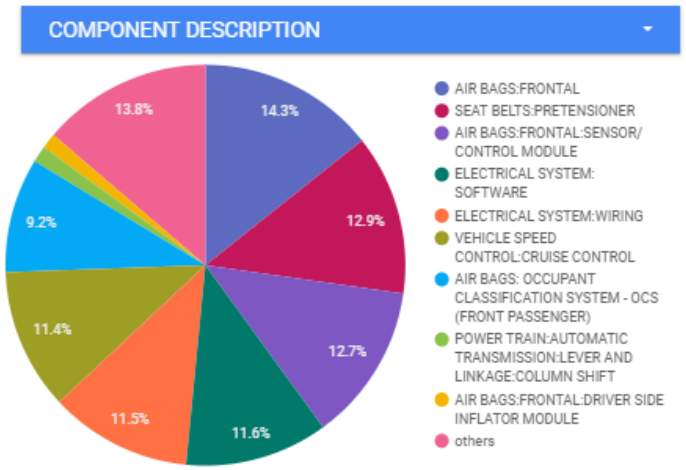
2008 – Airbag, Accelerator



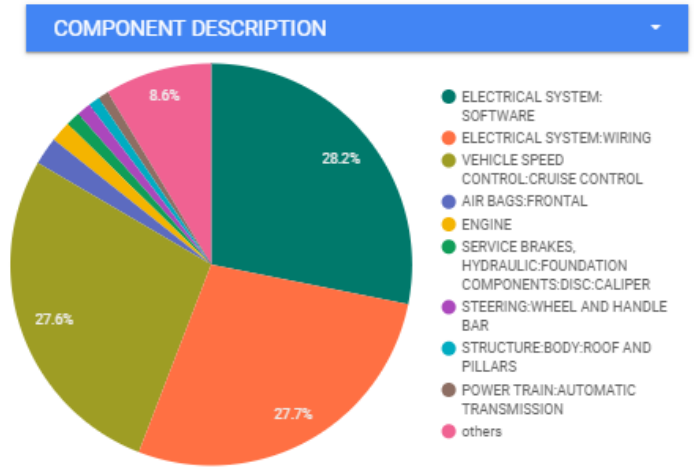
2010 – Airbag



2016 – Airbag. **Software** (begins). ADAS

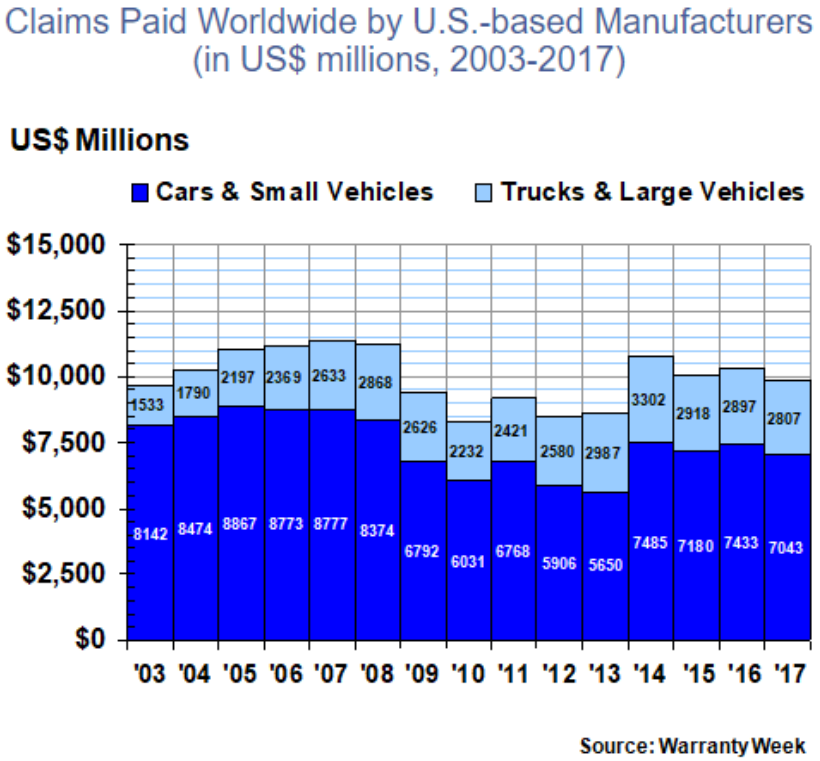


2018 – **Software. ADAS**



With Increasing Electronics and Software Content Comes Warranty Cost

Dramatic Increase in Recalls and Warranty Cost with Electronic Content



Cost of recalls is increasing

Per NHTSA, the **average** number of **recalls** per million US vehicles has risen steadily from 3.10 in 1980 to 11.79 in 2016.

Warranty costs have become severe

Annual, global automotive warranties are estimated to be **$40 Billion**

Technology Enablers: Feature-Based Routing

Need to Test and Monitor Electronic Hardware and Software

- Routing vehicles to capture road features
  - Autonomous Vehicle Development
  - Mapping Support
  - Vehicle Testing Support
- Development of predictive models
- Custom routes based on:
  - Drive time
  - Location
  - Time of day
  - Start and End points
  - Many more
- Billions of scenarios and potential failure modes

Commercial Vehicle In-Use Monitoring Example

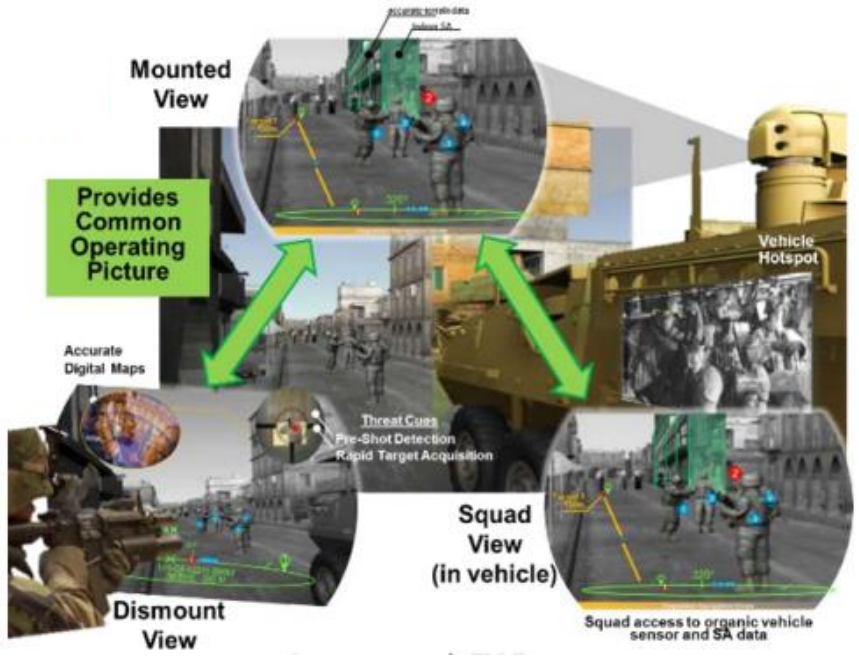
Cummins Connected Diagnostics

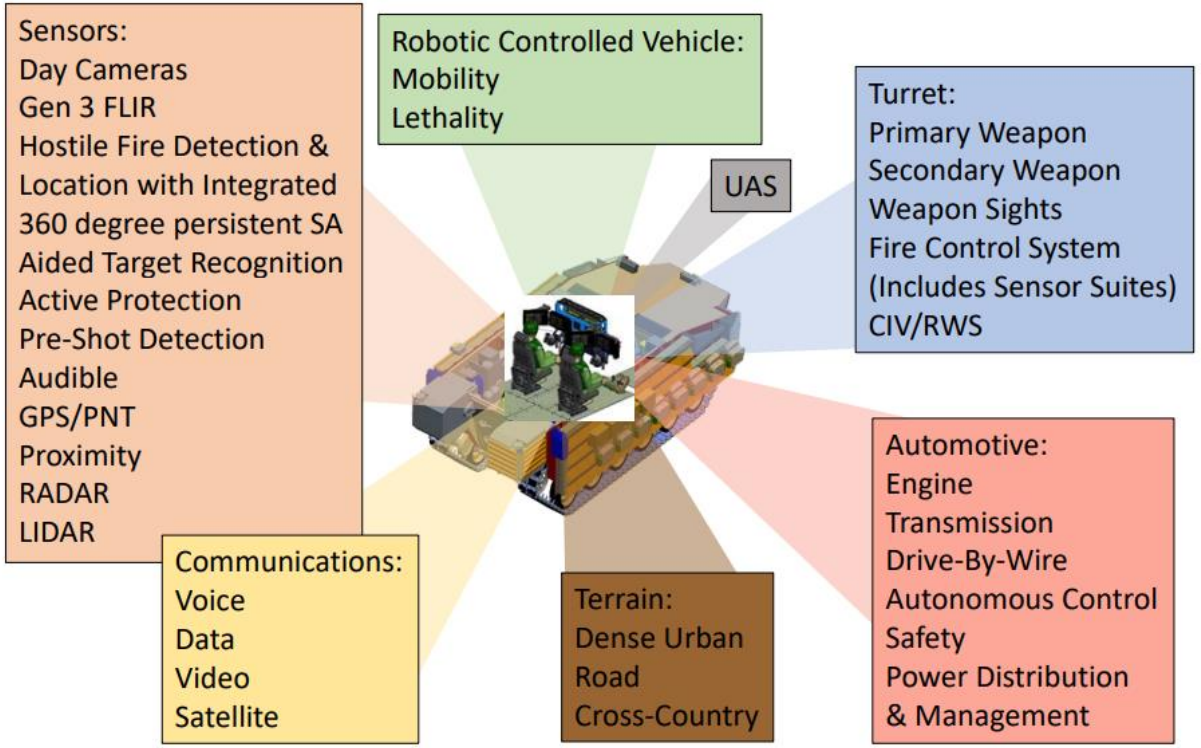
- Electronic control of ICEs has led to a highly complex network of sensors, processors and real-time control algorithms
- EPA and CARB emission regulations have led to intense monitoring of engine and aftertreatment systems (OBD)
- Development of predictive system models is being applied to electric drive & other vehicle systems

Ground Combat Vehicle System Overview

Next Generation Combat Systems (NGCV) will be complex networks

- Army vision for future is multi-domain, combined battlespace with broad network of sensor, maneuver, and tactical flexibility with combination of local (edge) compute and extensive data transfer.





- NGCV will support multi-domain battlespace with advanced sensor, vision, image, targeting, and threat detection systems.

Ground Combat Vehicle Overview

Combat Vehicle Systems and Sub Systems

- Ground Combat Vehicles pose unique challenges
  - Direct data feed to soldier
  - Space constraints
  - Vehicle temperature (no forced or water cooling)
  - Direct fire vulnerable
  - Small crew size
  - Monitoring of sensors and mission-critical systems
  - Ability to maneuver if electronic sensors are lost
- Ways to overcome these challenges
  - High speed backplane
  - Smaller, lighter, faster technology components
  - Adaptable self-healing software
  - Low heat rejection system without sacrificing performance
  - Offload crew effort to AI/ML components and systems
  - Autonomy systems

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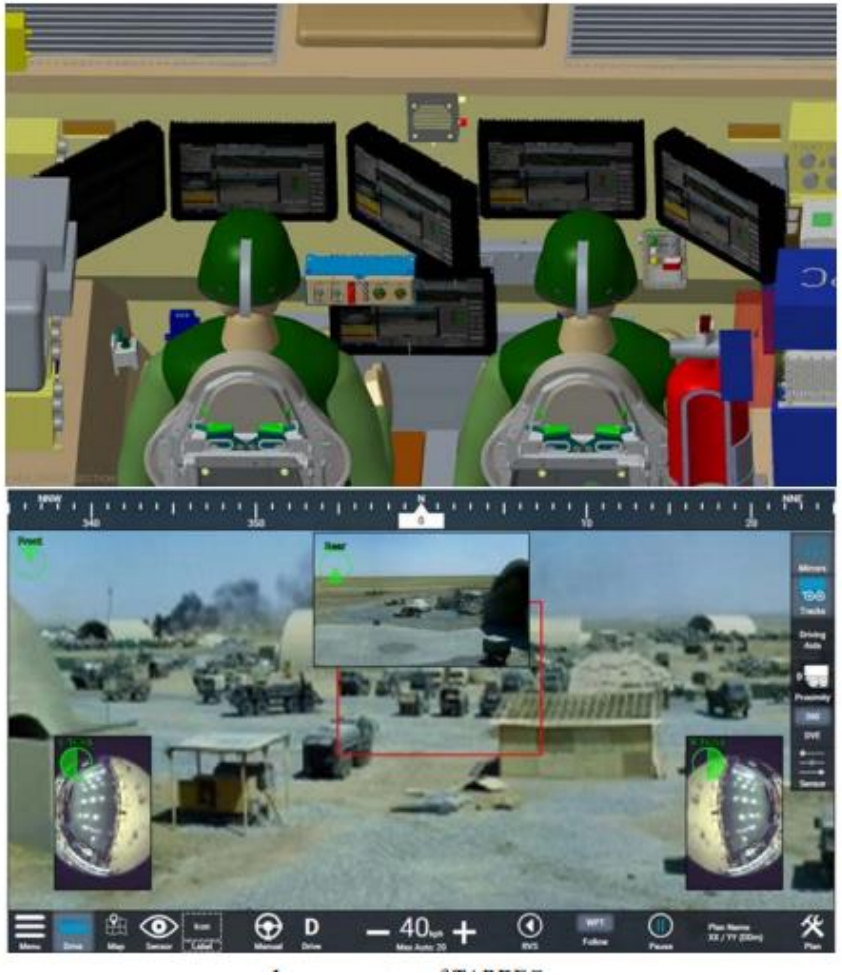
What will Future Combat Systems Include?

Onboard Processing with Human in the Loop

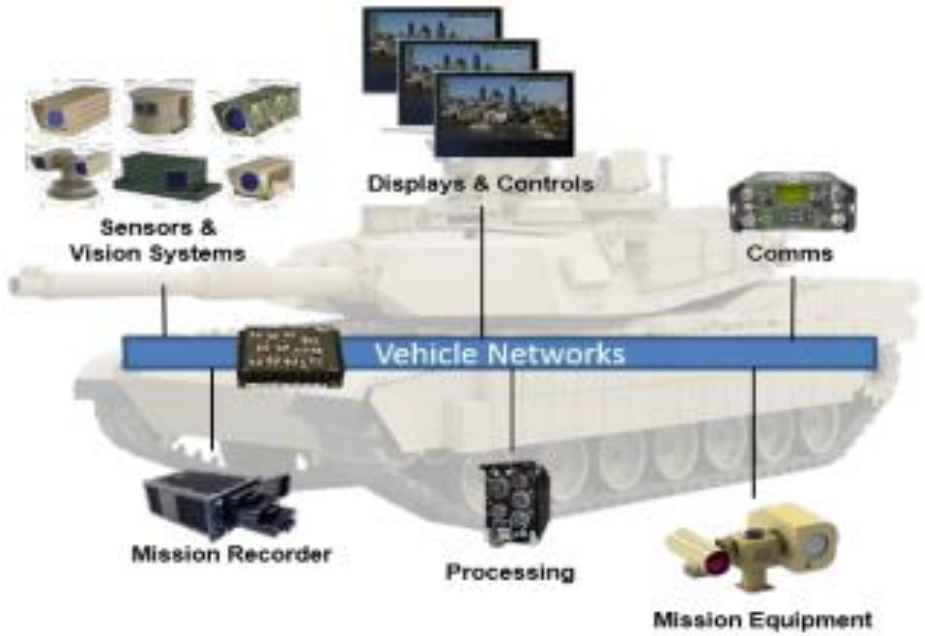
- Heavy focus on Modular Systems
  - Ability for onboard processing, plus robotic and autonomous functions
    - Data for local systems is not on google maps or street view
    - Organic battlespace requires monitoring and sending information off platform
      - Vision sensor data
      - Vehicle health data
      - Cross platform data
- System Reliability
  - Kiss analog systems goodbye
    - Forced reliance on software and digital systems
    - System integration & reliability is paramount
    - Get home safe under any circumstance
      - Be prepared for any situation



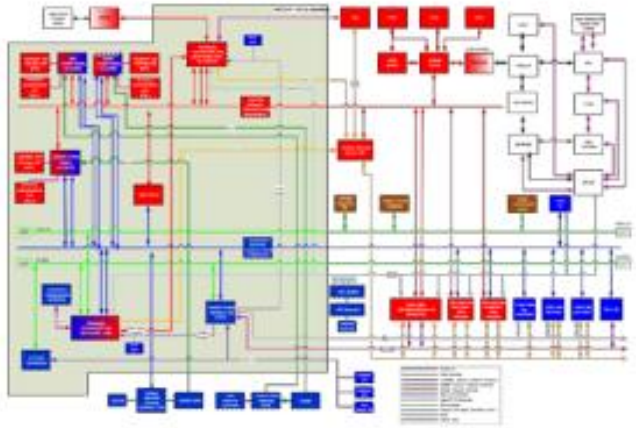
Needs of Future Combat Vehicles

Fast, Lightweight, Low Heat & Modular

- Fast System Processing Speed
  - Increased data throughput
  - Reliance on AI/ML system compute
- Lightweight
  - Lightweight, small form factor to maximize performance under armor
- Heat Dissipation
  - Smaller systems in enclosed spaces
  - Sandy, Dusty, hot, and humid environmental conditions
- Shock & Vibration
  - All terrain vehicle traveling at speed
  - High impact and weapon recoil
- Modular Open Network Architecture
  - Flexibility across vehicle platforms and combat missions
- Agile Software Development Cycle
  - Features and functionality upgrades
  - Rapid technology integration



C4ISR Integration



Conclusions

- Automotive and commercial vehicles have increasing electronics and complex processor systems which require monitoring and feedback
- Increasing electronic content has caused dramatic increases in recalls, warranty cost, software complexity and functional safety issues
- Emission compliance, connectivity, ADAS and autonomy have shown the potential of ML and AI, but integration and reliability issues remain
- Transition of electronics, ML/AI, connectivity and system monitoring has great potential for combat vehicles, but function under attack is critical
- NGCV systems must have edge compute and integrate into battlespace where latency and data throughput are critical
- Modular, self-learning, ML/AI-enabled systems will be critical for functionality and adaptability in combat scenarios