AUTOMOTIVE

Automotive Software: Trends, Importance & Opportunities

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Automotive software: Big picture

Software-defined car era
- Driverless car fleet mobility
- Self-driving & driverless car SW
- Always connected cars
- Cloud-centric software & service
- Cybersecurity & OTA updates

Software platform era
- Software platform ecosystems
- Software development savings
- Software royalty opportunities
- Cloud & SW-service opportunities
- SW connections to many devices

Embedded software era
- AUTOSAR as crowning success
- Auto industry proficiency
- Relatively small programs
- ECUs with embedded software

SOURCE: IHS Markit

Automotive software overview

Software is purely digital and has different characteristics than hardware!

Create	Make	Market/Sell	Car use
• Very expensive	• No SW BOM cost	• SW=car features	• Bug-fixing needed
• Long development	• Some royalty costs	• Features sell cars	• SW maintenance
• Difficult testing	• Mfg.=SW loading	• SW → connected car	• Connected car growth
• New technologies	• Loading flexibility	• SW is upgradable	• OTA SW updates
• Never bug-free		• SW → apps & cloud	• Cybersecurity defense

Software and applications impact all phases of most auto systems.

BOM=Bill of Material; SW=Software; OTA=Over-the-Air

SOURCE: IHS Markit

Software life stages

	Key information	Comments
Software design	▸ SW architecture based on specs ▸ Specify language, performance	▸ Effort is about **30%** of total ▸ Key to get reliable program
Software coding	▸ Program is coded as per design ▸ Object-oriented design needed	▸ Effort is about **30%** of total ▸ Error check tools emerging
Software testing	▸ Hardest part ▸ Automated tools emerging	▸ Effort is about **40%** of total ▸ Key to software reliability
SW release	▸ Software is ready for deployment	▸ Usually gets a version #
Software mfg.	▸ Object code loaded into memory ▸ Wi-Fi loading emerging	▸ During car manufacturing ▸ Wi-Fi provides flexibility
Software maintenance	▸ Find and correct errors ▸ Re-release program; Version #X	▸ Based on field usage ▸ OTA update emerging
Software update	▸ Update latest version ▸ Repeat all steps above	▸ Improved functions ▸ Usually for a new project

OTA=Over-the-Air

SOURCE: IHS Markit

Software life cycle example: Infotainment

Software create phase

SW Design	SW Coding	SW Testing
• 30% of total • $9 million	• 30% of total • $9 million	• 40% of total • $12 million

Infotainment software development cost=$30 million
About three-year development time
Assume production volume of 200,000 units

Production
- BOM=$60 range
- Royalty & IP
- Total=$12 million
- 200,000 units

Use phase
- Bug fixes: 2%/year
- $0.6 million/year for five years
- Or $3 million total
- Bugs+Updates: 10%
- $3 million/year for 5 years
- Or $15 million total
- SW recall estimate:
- $200 per car or
- $20 million for 200,000 cars
- OTA: < $10 million

Note: Typical software development cost is up to $30 per line of code and has not changed much in last 40 years

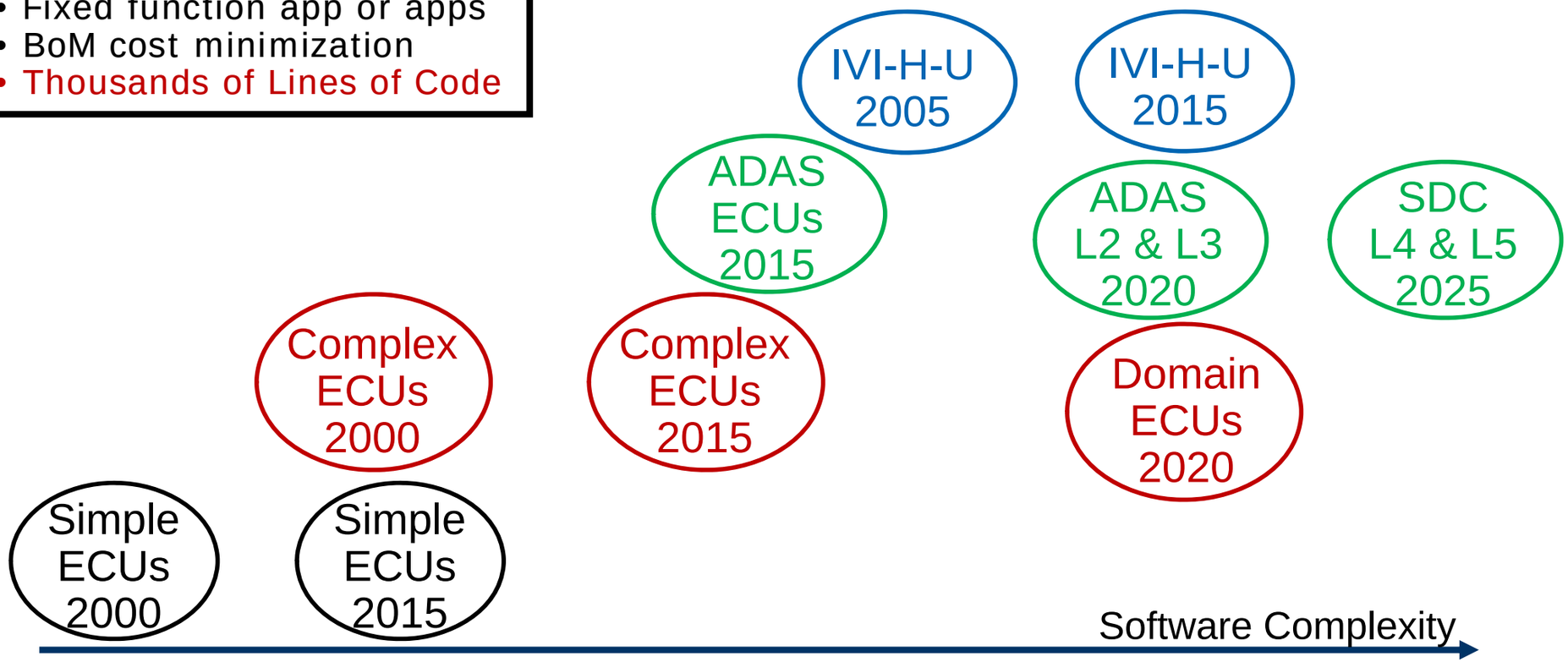
SOURCE: IHS Markit

Auto software complexity path

"Embedded Controllers"
- Simple SW control program
- Fixed middleware
- Fixed function app or apps
- BoM cost minimization
- Thousands of Lines of Code

10X-100X Complexity

"Apps Computers"
- Complex operating system
- Computer middleware
- Industry-specific middleware
- Multiple changeable apps
- Millions of Lines of Code



BoM=Bill of Material; SDC=Self-Driving Car; ECU=Electronic Control Unit; IVI=In-Vehicle Infotainment

SOURCE: IHS Automotive

Four factors are increasing high-tech impact

	Key information	Comments
Software complexity	▸ Advanced OS for infotainment ▸ Re-usable software platforms ▸ Agile SW development ▸ Deep-learning software ▸ Driverless car software	▸ Mostly high-tech expertise ▸ Decades of use in high-tech ▸ Pioneered by high-tech ▸ High-tech industry leads ▸ Google is leader; start-ups
Connected car eco-system	▸ Communication networks ▸ Apps and content ▸ Cloud content & interactions ▸ Remote software update ▸ Cyber-security (HW & SW)	▸ From telecom industry only ▸ Android & iPhone HMI wanted ▸ Mostly Internet industry ▸ Mostly high-tech expertise ▸ High-tech expertise only
Electric vehicle	▸ Electric motor skills are common ▸ Battery is high-tech expertise ▸ BEV opens door for new OEMs	▸ ICE dominated by auto OEMs ▸ Minimal auto OEM advantages ▸ ICE too costly for new OEMs
Maturing high-tech	▸ New big opportunities needed ▸ Want new segments to disrupt	▸ Slow growth in most segments ▸ Few big high-tech opportunities

ICE=Internal Combustion Engine; SW=Software

SOURCE: IHS Markit

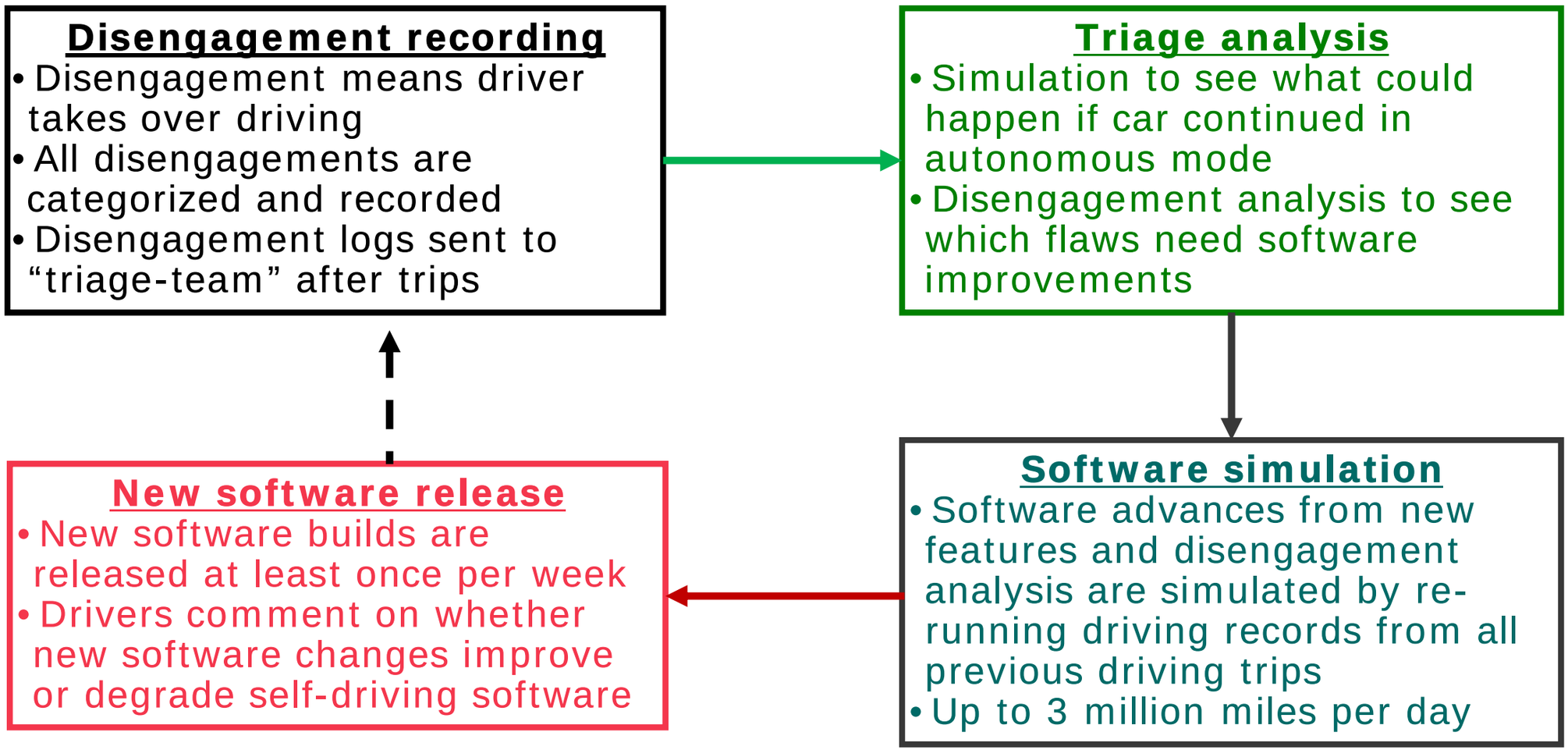
Google SDC-DLC software

	Key information	Comments
Estimated status	▶ Better than nearly all drivers—at least in fair-weather driving ▶ Fewer emergencies ▶ Know common driver weaknesses	▶ Faster reaction time, never tired, never distracted, superior object tracking capabilities ▶ From 2M miles in SDC mode
Next focus	▶ Finding and learning the once in a million events (Edge cases)	▶ Google has active projects to identify such events
Key problems	▶ Other drivers' perplexed reaction ▶ Other cars run into SDC-DLCs ▶ Computer ethics?	▶ SDC-DLC follow all laws ▶ SDC driving style too different ▶ Different views on its impact
Future steps	▶ More testing (Detroit likely) ▶ Software qualification path ▶ "Driver license" test for software	▶ Rain, snow, and bad weather ▶ NHTSA released first rules ▶ Included in NHTSA proposal

Key questions: How much better than the average driver will DLC software need to be for deployment? What is the acceptable ratio for lives saved vs. lives lost owing to imperfect software? **10?**

SOURCE: IHS Markit

Google's DLC software advances



SOURCE: IHS Markit

Deep learning advances

	Key information	Comments
Deep learning advances	▶ Deep learning applications ▶ Deep learning software platforms ▶ Deep learning hardware platforms	▶ Based on algorithm innovation ▶ Tools to develop and run apps ▶ Increased speed via SOC
Apps	▶ Most apps written in C, C++, Python ▶ Can be ported between HW platforms	▶ Most optimized for Nvidia ▶ With some effort
Software platforms	▶ Dominated by open source SW ▶ Major cloud players have donated their SW platforms to OSS ▶ Most SW optimized for Nvidia GPU ▶ Cloud service for DL emerging	▶ Rapid tech advances ▶ Google, Facebook, Microsoft, and others ▶ Strong development systems ▶ Nervana Cloud platform
Hardware platforms	▶ Nvidia GPU platform clear leader owing to high performance products ▶ CPU, DSP, and FPLA are also used ▶ Special purpose chips tailored to DL computational needs are ready to emerge and is likely long-term leader	▶ Nvidia Tesla* for data centers ▶ DrivePX for SDC projects ▶ Trying to catch up to GPU ▶ Such DL-tailored processing cores could be added to any: GPU, DSP, or CPU

SOC=System on Chips; SDC=Self-Driving Car; OSS=Open Source Software; FPLA=Field Programmable Logic Arrays; DSP=Digital Signal Processor

*Note: Nvidia Tesla is their GPU platform

SOURCE: IHS Markit

AI vs. human capability

	Key information	Comments
Turing test	▸ Test for nearly all AI problems ▸ Subject matter Turing test is emerging	▸ All solutions have failed! ▸ Smaller, specific problems
Subject matter Turing test results*	▸ Optimal: not possible to perform better ▸ Strong super-human: performs better than all humans ▸ Super-human: performs better than most humans ▸ Par-human: similarly to most humans ▸ Sub-human: performs worse than most humans	▸ Checker AI program ▸ Watson defeated 2 greatest Jeopardy champions-2011 ▸ Deep Blue beat world chess champion in 1997 ▸ Optical character recognition ▸ Crossing a room without bumping into something
DLC software	▸ Super-human in normal driving? ▸ Sub-human in unexpected events ▸ Sub-human in winter-driving	▸ Is Google there today? ▸ When super-human? 202x ▸ When super-human? 202x
DLC SW question	▸ What is needed for DLC software? ▸ Super-human or strong super-human?	▸ DLC at super-human level would have fewer accidents!

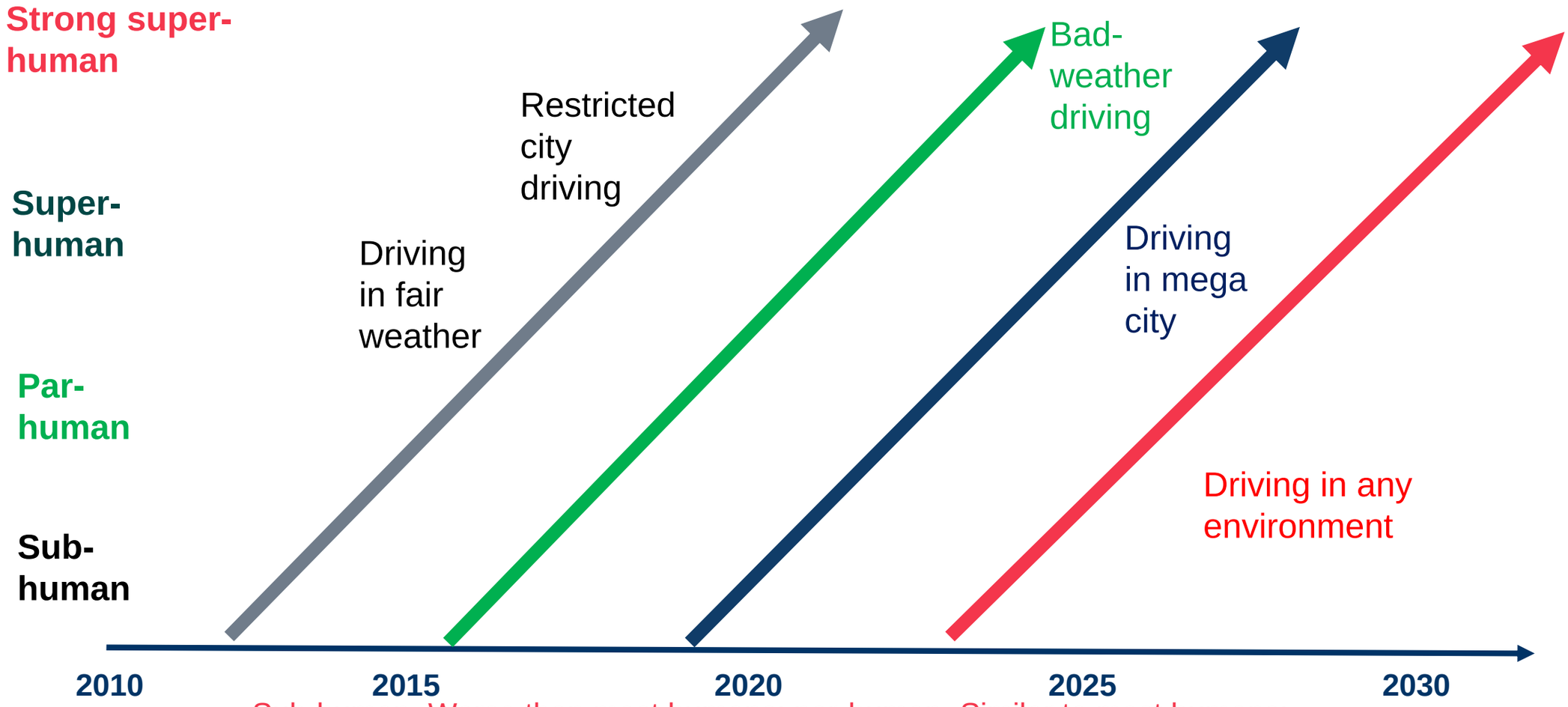
When to do driverless car volume deployment?

Is super-human good enough? Or is strong super-human needed? By climate areas?

*Source: Wikipedia: Progress in artificial intelligence

SOURCE: IHS Markit

Driverless car vs. subject matter Turing test



Sub-human=Worse than most humans; par-human=Similar to most humans;
Super-human=Better than most humans; strong super-human=Better than all humans

SOURCE: IHS Markit

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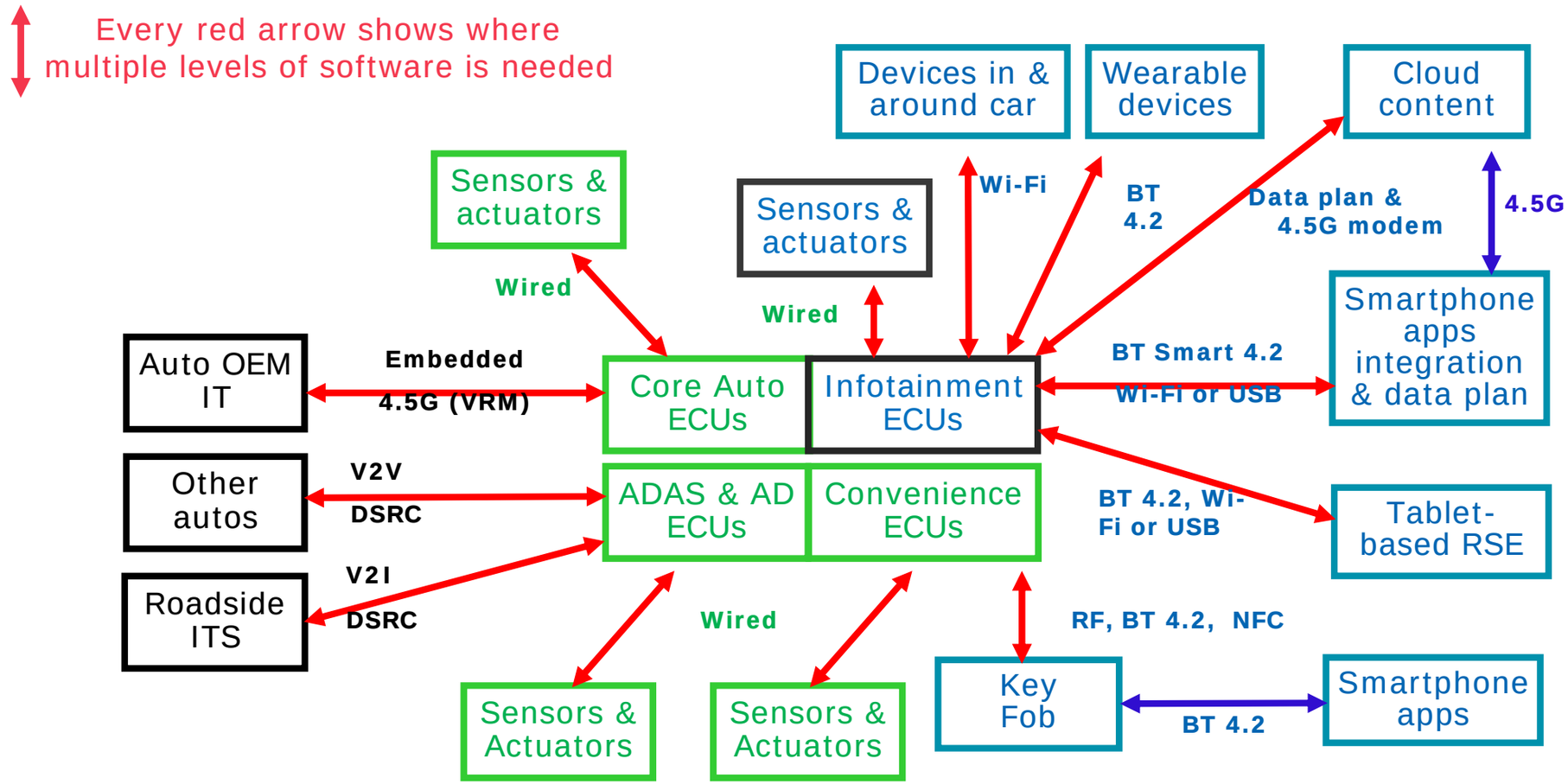
Software and connected cars



ITS=Intelligent Transportation Systems; VRM=Vehicle Relationship Management; BT=Bluetooth; RSE=Rear Seat Entertainment; RF=Radio Frequency

SOURCE: IHS Markit

Software opportunity perspectives

	Software opportunities	Comments
Software suppliers	▸ Software royalties per car sold ▸ SW development revenue ▸ SW maintenance service ▸ Services to connected cars	▸ $1–3/car to $20 range per car ▸ SW “tailoring” to OEM auto model ▸ Bug fixing and SW feature updates ▸ OEM IT server software (SaaS)
Tier 1 suppliers	▸ SW development revenue ▸ SW maintenance service ▸ Services to connected cars ▸ SW expertise to retain business ▸ Expertise to gain new business	▸ SW “tailoring” to OEM auto model ▸ Bug fixing and SW feature updates ▸ OEM IT server software (SaaS) ▸ Retain HW manufacturing business ▸ SW tech is key to win new business
Auto OEMs	▸ SW development savings ▸ Operational cost savings ▸ Cost avoidance ▸ Software functional updates ▸ New software capabilities ▸ SW functionality sells cars	▸ Re-usable software platforms ▸ Remote diagnostics, OTA, analytics ▸ Cybersecurity: avoid recalls & hacks ▸ New revenue opportunity via OTA ▸ To get new and/or retain customers ▸ Competition requires new features

SaaS=Software-as-a-Service; OTA=Over-the-Air, SW=Software

SOURCE: IHS Markit

Software suppliers' opportunities

	Software clients	SaaS and cloud SW
Features	▸ Software sold with cars ▸ Many different segments ▸ In every ECU: 1 or more	▸ Services to connected cars ▸ Via in-car modem & smartphone ▸ New segments emerging
Connected car and infotainment	▸ Operating system (OS) ▸ OS & auto middleware ▸ Speech recognition ▸ Navigation & map database ▸ OTA & cybersecurity	▸ Telematics: car-centric ▸ Telematics: driver-centric ▸ Smartphone apps-based ▸ Big data analytics ▸ OTA & cybersecurity SaaS
ADAS and autonomous driving	▸ Operating system (OS) ▸ OS & auto middleware ▸ ADAS applications ▸ OTA & cybersecurity ▸ SDC-DLC software	▸ Sensor big data analytics ▸ OTA software update SaaS ▸ Big data analytics; Cloud sensor fusion ▸ Cybersecurity SaaS ▸ Rapid functionality updates
ECUs for driving control	▸ AUTOSAR software ▸ ECU applications ▸ OTA & cybersecurity	▸ Remote diagnostics analytics ▸ Mostly OEM & T1 opportunities ▸ OTA & cybersecurity SaaS

SaaS=Software-as-a-Service; OTA=Over-the-Air; SW=Software

SOURCE: IHS Markit

Software cost overview

	Key information	Other info
Development cost	▸ $20M–$50M for hardware and software ▸ Two-year project with 50–100 people ▸ Includes testing and design verification	▸ Vary by region & car class ▸ Software platform re-use will lower these figures
Royalty costs (BOM)	▸ OS & system MW: $1–$20 per copy ▸ Smartphone apps integration: $1–$5 ▸ Bluetooth, Wi-Fi, Others: $1–$2 ▸ Navigation: $1–$10 per copy ▸ Speech recognition: $1–$20 per copy	▸ OTA: $1–$2 per copy ▸ Music: $1–$5 ▸ Echo cancellation:$1–$3 ▸ Map: $8–$40 per copy ▸ Multimedia: $4–$7 per copy
Mid-life upgrade	▸ IVI system feature update is common ▸ Cost is 1/3 of original development	▸New functionality ▸$6M to $15M
Software maintenance	▸ Bugs only maintenance: 2% of development cost per year ▸ Bugs & feature updates: 10% of development cost per year	▸$0.4M to $1M per year ▸Usually 3–5 years ▸$2M to $5M per year ▸Usually 3–5 years

OTA=Over-the-Air; MW=Middleware; IVI=In-Vehicle Infotainment; BOM=Bill-of-Material

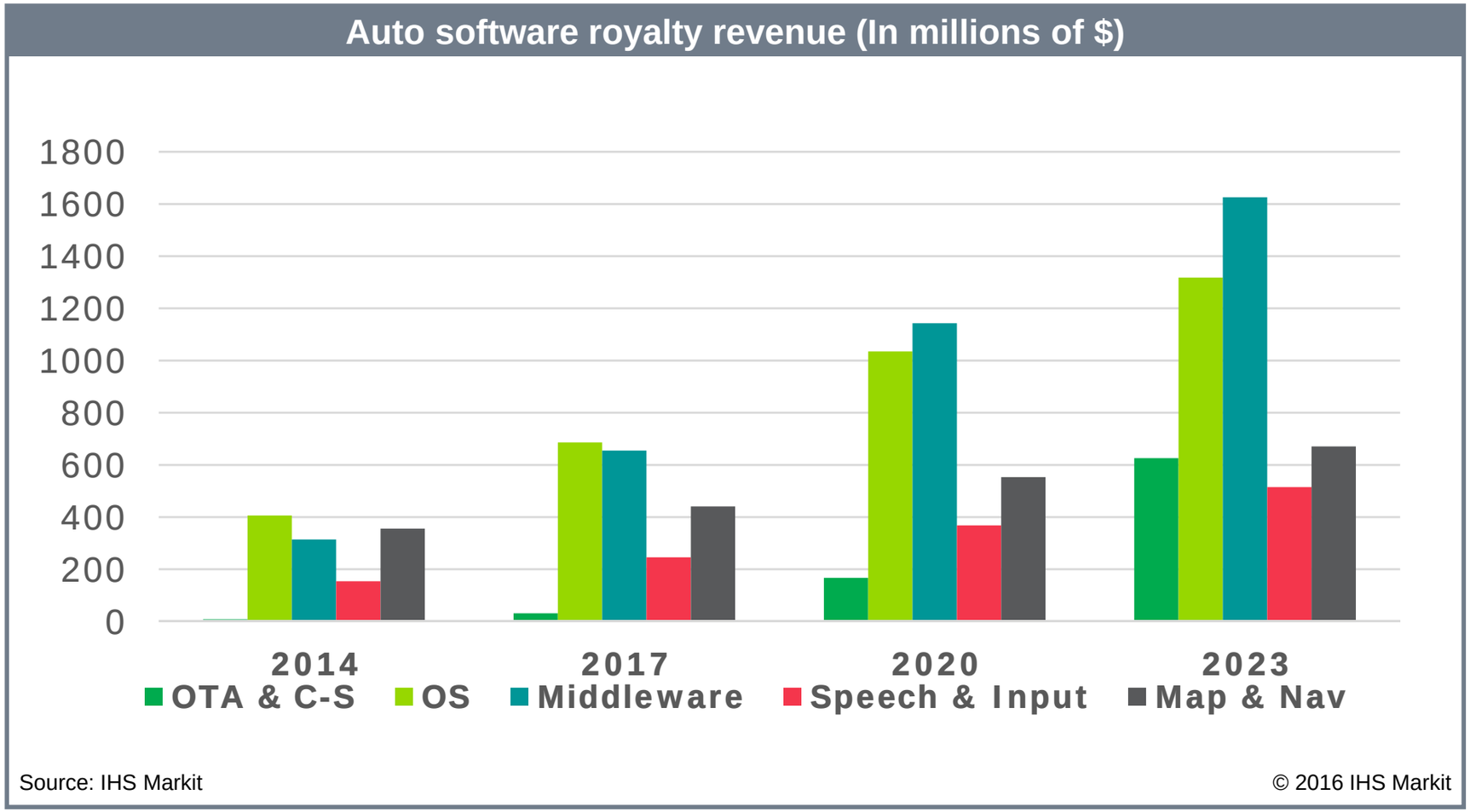
SOURCE: IHS Markit

Software platform cost savings potential

	Key information	Other info
IHS Markit data	▸ 2016 new or updated models: 401 ▸ Infotainment SW development costs per model range from $15M to $30M	▸ IHS Markit production database ▸ Varies by region and by class of vehicle
No platform sharing	▸ Software development cost for all 401 models is more than $6.5 billion	▸ Not real, since software platform sharing is common
Assumptions	▸ 271 models are candidates for software platform sharing ▸ Software saving larger for two models in the same country-region ▸ Four scenarios for software platform cost savings were estimated	▸ Based on how many models from OEMs and by regions ▸ Due to language and other cultural differences ▸ Software cost saving is 20% higher for same region
SW cost savings results	▸ Savings: 50%-same; 30%-different ▸ Savings: 60%-same; 40%-different ▸ Savings: 70%-same; 50%-different ▸ Savings: 80%-same; 60%-different	▸ $1.91B or 29% ▸ $2.33B or 36% ▸ $2.75B or 42% ▸ $3.18B 0r 49%

SOURCE: IHS Markit

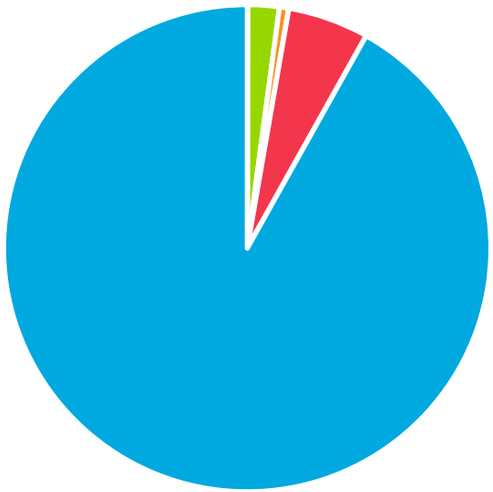
Software royalty opportunity scenario



SOURCE: IHS Markit

Cloud-based service opportunity scenario

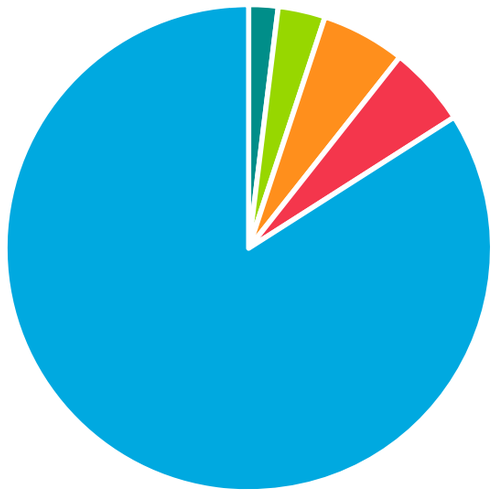
2016 Cloud SW & Services



Cloud C-S
Inet Radio
SP Apps Int
Traffic-Related
Telematics

2016=$8.2 billion

2023 Cloud SW & Services



Cloud C-S
Inet Radio
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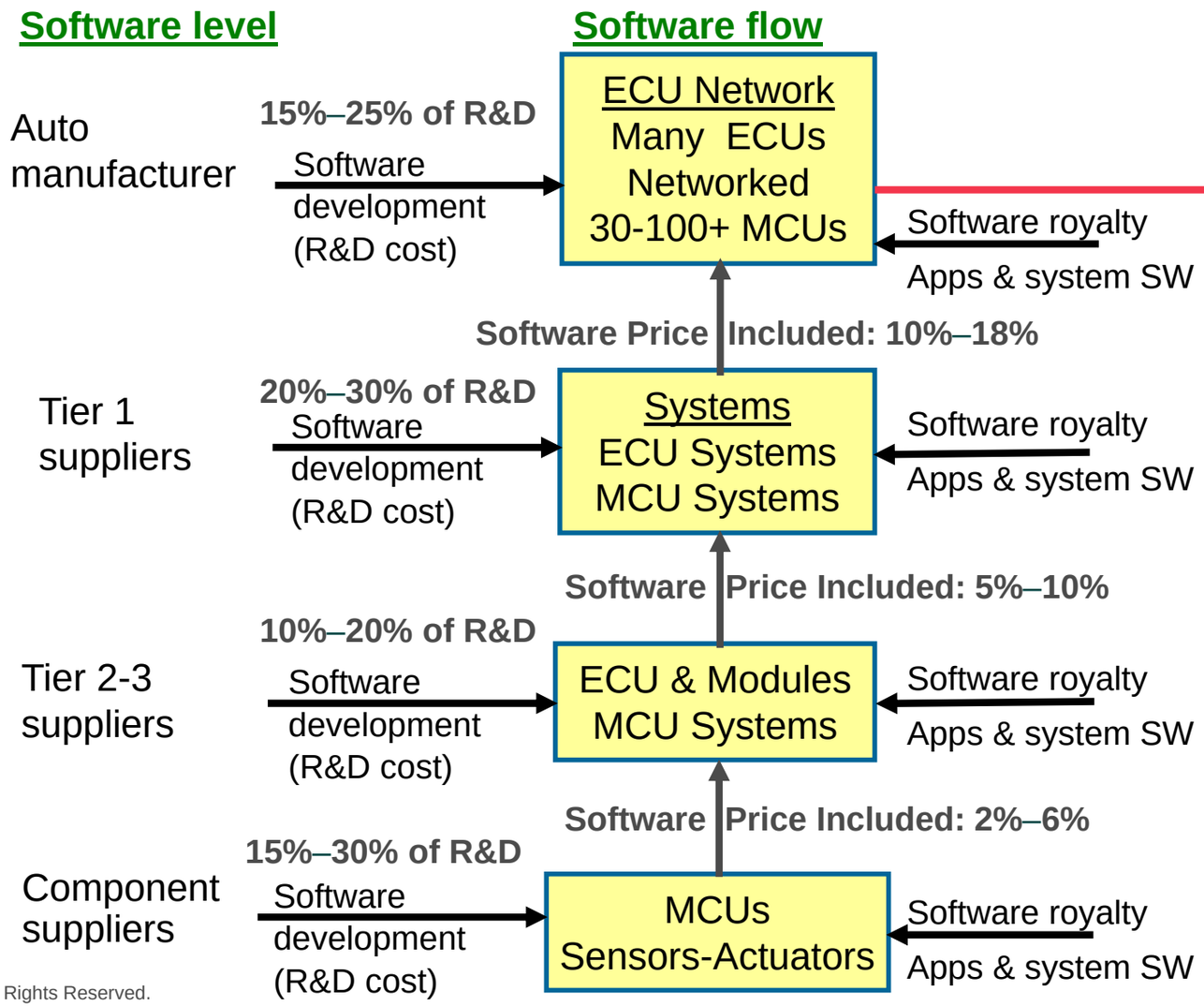
Telematics

2023=$20.2 billion

SOURCE: IHS Markit

Auto software market value flow



SW direct value per auto

Production cost: $100–$300
Development cost: $200–$500
Maintenance: $50–$250
SW-dependent Hardware: $2,000–$6,000

Software market

- Difficult to estimate
- Includes SW products:
- OS & driver software
- Application software
- SW products: Royalty
- Includes SW development
- At multiple levels
- Part of R&D budget
- SW R&D not specified

SOURCE: IHS Markit

Software phases: Big picture

Software is purely digital and has different characteristics than hardware.

SW create	Make	Market / Sell	Car use
• Very expensive	• No SW BOM cost	• SW=car features	• Bug-fixing needed
• Long development	• Some royalty costs	• Features sell cars	• SW maintenance
• Difficult testing	• Mfg.=SW loading	• SW → connected car	• Connected car growth
• New technologies	• Loading flexibility	• SW is upgradable	• OTA SW updates
• Never bug-free		• SW → apps & cloud	• Cybersecurity defense

Software and apps impact all phases of most product

Good SW creation tools are required	Minimal software cost for manufacturing	New features are primarily via software	High-tech influence
Better SW testing tools are needed	SW make function can be re-done at low cost	Good/bad HMI is mostly based on software skills	Cyber-security threat SW recall growth SW features updates

Take-away: Lower software development cost is key

- **Re-usable software platforms are needed to lower development costs**
- **Over-the-air software updates needed for bug fixes & cyber-security**

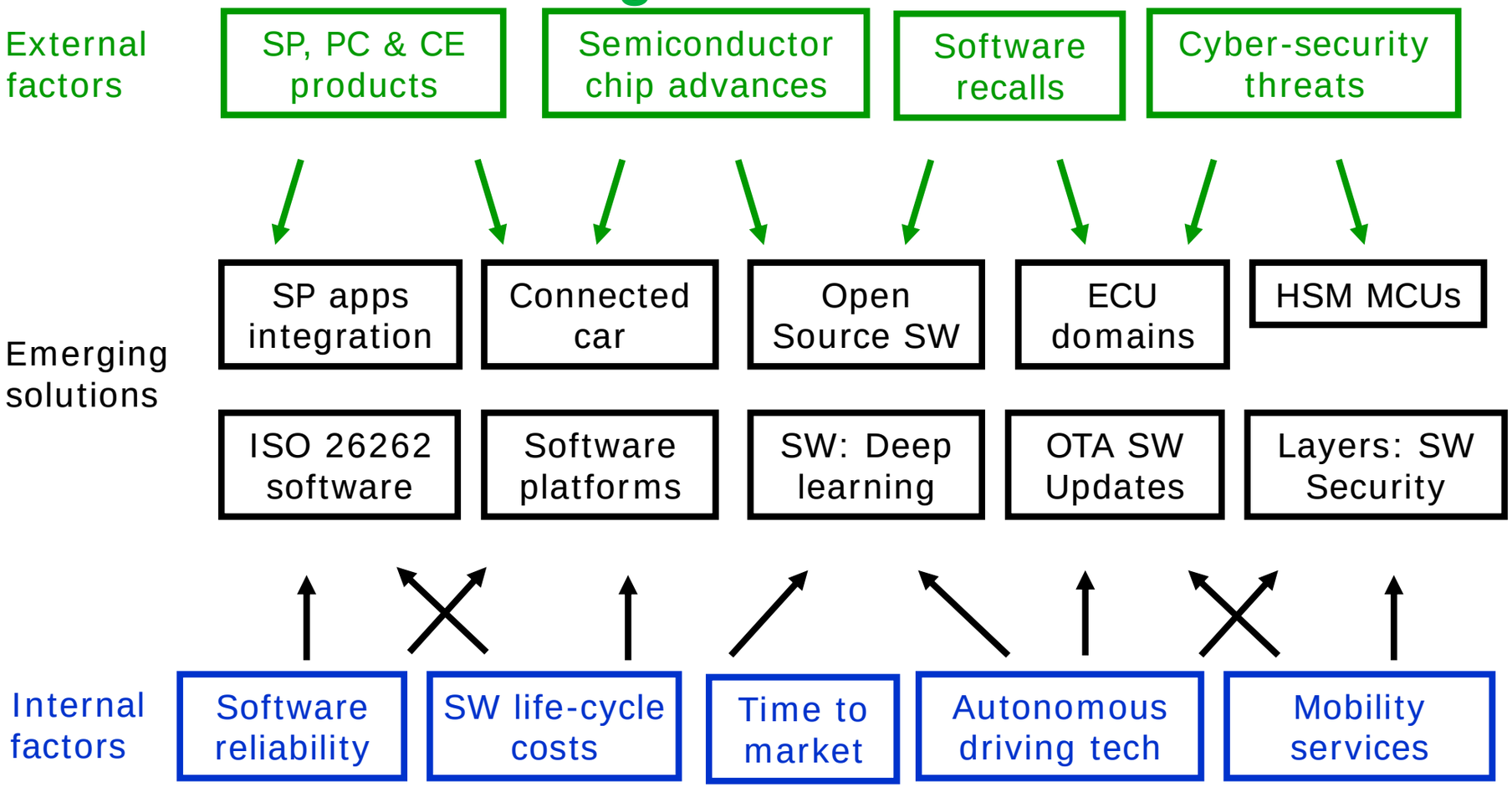
Re-usable software:

- **Software platforms that are modified / updated for use with other car models**
- **Saves development cost and time and has fewer bugs, benefits of platforms**

BOM=Bill of Material; SW=Software; OTA=Over-the-Air

SOURCE: IHS Markit

Automotive software mega-trends



SP=Smartphone; CE=Consumer Electronics; HSM=Hardware Security Module; SW=Software; OTA=Over The Air

SOURCE: IHS Markit

Automotive software summary

For OEMs:
- Platforms: Development cost savings
- OTA-CS: Operational cost savings
- Connected car & smartphone apps use
- Path to autonomous driving: SDC-DLC
- SW: Key to retain its auto leadership

For Tier 1s:
- Platform: Development cost savings
- SW: Key to retain business
- SW: Key to get new business
- SW: Key to keep HW mfg. business
- SW expertise decides future success

Automotive software market
- SW platforms → Dominant technology
- Standalone software → Cloud-centric
- Software as product → Software as service
- SW Dev. Method: Waterfall → Agile
- Connected SW: OTA, CS, BD Analytics
- Tech: Deep learning & cloud-based platforms

For software suppliers:
- Platform: Ecosystem & more business
- SW royalty: Steady business model
- SW-cloud-service: Better business model

For high tech:
- Auto SW: New opportunities
- Auto SW: Cloud-based SaaS
- SW: Business model disruption

OTA=Over-the-Air; CS=Cybersecurity; BD=Big Data; SW=Software; SaaS=Software-as-a-service

SOURCE: IHS Markit

THANK YOU!

ありがとうございます

謝謝

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