FROST & SULLIVAN



2018 Global In-Vehicle Infotainment Enabling Technology Leadership Award





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Background and Company Performance

Industry Challenges

Smartphones and tablets changed customer expectations for in-vehicle infotainment systems. Their interfaces and rapid pace of innovation led to just over 50 percent of consumers wanting equivalent technology from their vehicles. Automotive development, however, is very different from smartphones and tablets, involving much longer product cycles, harsher operating conditions, and more complex systems, with very little software reuse between systems, much less between automakers.

Between all their various systems, modern vehicles require upwards of 100 million lines of code. Smartphone operating systems, such as Android, run on 12 to 15 million lines of code, and a typical app runs on 50,000 to 100,000 lines of code. The average in-vehicle infotainment system requires 3 to 4 years to be developed, during which time 3 to 4 iterations of a smartphone will typically have been released to consumers. Automakers would like to speed the development of in-vehicle infotainment operating systems to roughly the same as smartphone and tablet development - 6 to 12 months.

The difficulty automakers and suppliers face in developing hardware and software as quickly as smartphone and tablet manufacturers is fragmentation. Most smartphones and tablets in 2018 run on Android, iOS, or KaiOS with significant backward compatibility between versions of the same operating system. Each automaker, however, uses custom versions of Linux, QNX, or Windows Embedded Automotive. Much as automakers attempt to standardize where they can, not only will each automaker use custom versions of each operating system, but each vehicle line within each automaker often uses different custom operating systems from different suppliers. The rapid release cycles of smartphones and tablets further changing customer expectations makes it increasingly difficult for automakers to keep pace on in-vehicle infotainment system development.

Along with the logistics of developing in-vehicle infotainment system software are the philosophy and corporate values behind the systems. Automakers want to differentiate themselves from competitors, yet not cede control of a user interface to more software-centric companies who typically develop operating systems, like Apple and Google. While this is a valid concern, many vehicle components are rarely seen by drivers, just like much of operating systems are rarely interacted with by drivers.

As long as the underlying functionality in terms of speed, security, and implementation is met, the user interface is the primary competitive differentiator. Some automakers want a proprietary operating system good for the situation, while others will opt more for an open-source approach ideally benefiting the industry as a whole. Corporate philosophy dictates whether or not to develop something proprietary versus using open standards and corporate values determine how much data will be collected about drivers, not to mention how that data will be collected and shared with ecosystem partners.

Technology Leverage and Customer Impact

To address the development time, fragmentation, and lack of code reuse, among other factors, Automotive Grade Linux (AGL) from The Linux Foundation hopes to serve as the de facto industry standard in-vehicle infotainment operating system, before addressing all the software needs of vehicles, including advanced driver assistance systems, autonomous driving, telematics, and other in-vehicle displays, such as instrument clusters and heads up displays.



Automotive Grade Linux

Over 133 industry participants, from automakers to suppliers to component producers, signed up to be part of the consortium that develops Automotive Grade Linux. This will be of benefit to traditional Tier 1 in-vehicle infotainment suppliers who develop similar products for multiple automakers and to automakers to keep pace with smartphone and tablet advances. By sharing a common platform, suppliers can reuse the same underlying core functionality while developing new applications and interfaces particular to each automaker to achieve the differentiation they all want to achieve, while bring in-vehicle infotainment systems to market faster and at a lower cost. Major AGL participants include Toyota, Honda, Mazda, Nissan, Mercedes-Benz, Aisin AW, Denso, Panasonic, Renesas, Amazon, Continental, Pioneer, and Qualcomm, among many others.

There are other custom versions of Linux already in use by BMW, Chevrolet, Honda, Mercedes, and Tesla. While each one only needs to work on the particular vehicle on which it is installed, the benefit to automakers is reusing as much of that code base as possible to speed future development. And software use in vehicles will get only more complicated as autonomous driving picks up momentum. Though each automaker and supplier is currently working on their own systems, the amount of code necessary to accomplish level 0 through 5 autonomous driving will not likely be done by any one company.

Commitment to Innovation

Of all the competing in-vehicle infotainment systems on the market, nearly all are about helping automakers, but also about gaining market share for themselves through innovation and providing desirable features at the best price. As part of a consortium, innovation is at the core of AGL. By collaborating on non-competitively differentiated technology, automakers are free to concentrate on what consumers truly want from their in-vehicle infotainment experiences rather than rewriting underlying code no driver ever experiences. The primary reason AGL exists is to facilitate this collaboration and thereby foster innovation where it truly matters, at customer touchpoints. Other industry consortiums promote different agendas. The Open Automotive Alliance strives to get Android into more vehicles, benefiting a proprietary operating system and by extension benefiting Google. The GENIVI Alliance has similar aims as AGL, but at a higher level than the operating system, which GENIVI pledges to be agnostic to AGL, Android, and QNX.

Stage Gate Efficiency

Open source software comprises 60 to 80 percent of modern applications. These software building blocks are reusable components that provide developers proven, reliable, community-tested ways to insert functionality and features without having to write new code from scratch. Though automakers will add their proprietary interface layers and any data collection processes, AGL strives to create a Unified Code Base (UCB) for developers to contribute for use by other participating automakers. This code sharing allows automakers to speed their development process by not having to rewrite underlying code. Toyota claims the flexibility of AGL allowed it to roll-out their in-vehicle infotainment system across their vehicle line-up at a pace more in-line with smartphone and tablet consumer technologies. According to Toyota, the open source approach of AGL enabled them to focus on developing innovative new features and bring them to market faster.

Commercialization Success

The first AGL-based in-vehicle infotainment system debuted in the 2018 Toyota Camry on the 3rd generation of their Entune system, and will roll-out to most Toyota and Lexus vehicles in North America. Along with their first mass market implementation, AGL released their Unified Code Base (UCB) 5.0 in 2018 with reference applications for a media player, tuner, navigation, web browser, Bluetooth, WiFi, HVAC control, audio mixer and

vehicle controls across a range of hardware support from major automotive component manufacturers Intel, NXP, Qualcomm, Renesas, and Texas Instruments, among others. AGL's UCB 5.0 also includes over-the-air (OTA) update capabilities to help future-proof the system by enabling updates to keep pace with changing smartphone and tablet consumer technologies. While not part of the AGL consortium, Tesla built much of its Model S and Model X vehicle's software using open source software and, as of mid-2018, is releasing some of the Linux source code for those models. Along with all the AGL members operating as part of the Linux Foundation, this is a testament to the open source process of contributing code back to the community working on the scale of major automakers.

Application Diversity

AGL is expanding beyond in-vehicle infotainment to telematics, instrument cluster and heads-up-displays with an eventual roadmap to advanced driver assistance systems, safety systems, and eventually level 0 through 5 autonomous driving. AGL is also more than an operating system. It is a complete software stack including the Linux kernel, middleware, application framework and APIs, software-development kit (SDK), and reference applications. The advantages of AGL over competing consortiums GENIVI and the Open Automotive Alliance is that AGL brings a common set of services and interfaces to in-vehicle infotainment that provide standard front ends to other in-vehicle systems that interface with infotainment, such as cameras and navigation systems.

Price/Performance Value

While the underlying Linux code is of no CAPEX licensing cost to automakers and suppliers, there is an on-going OPEX cost to maintain the software and contribute back to the AGL community. Each automaker and infotainment supplier will make the determination which approach is of greater benefit to them, but no upfront licensing cost represents a big price/performance value advantage that must be factored into the overall lifecycle costs of the infotainment system. Of further consideration for the price/performance value is the maintenance of data control and customer interface versus competing infotainment operating systems. AGL provides that choice to automakers.

Conclusion

Automotive Grade Linux is still in its infancy, achieving its first commercial deployment in a major original equipment manufacturer vehicle program in the 2018 Toyota Camry. Toyota also announced plans to roll out AGL to the remainder of Toyota and Lexus vehicles over the coming years. Such a high profile installation in mass market vehicles can only help AGL provided consumers react well to the system as it becomes more widespread. No other automotive operating systems have the enabling technology goals of 1) serving as a de facto industry standard through a collaboration of automakers, suppliers, and technology providers, and 2) fostering innovation and improving time to market for in-vehicle infotainment by reducing software fragmentation and reusing noncompetitive differentiated aspects of operating system's code base. There has been, and will be, growing pains as automakers determine how best to implement AGL into their infotainment systems and beyond. For its strong overall performance, Automotive Grade Linux has earned Frost & Sullivan's 2018 Enabling Technology Leadership Award.

Significance of Enabling Technology Leadership

Ultimately, growth in any organization depends upon customers purchasing from a company and then making the decision to return time and again. In a sense, then, everything is truly about the customer—and making those customers happy is the cornerstone of any long-term successful growth strategy. To achieve these goals through enabling technology leadership, an organization must be best-in-class in three key areas: understanding demand, nurturing the brand, and differentiating from the competition.



Understanding Enabling Technology Leadership

Product quality (driven by innovative technology) is the foundation of delivering customer value. When complemented by an equally rigorous focus on the customer, companies can begin to differentiate themselves from the competition. From awareness, to consideration, to purchase, to follow-up support, best-practice organizations deliver a unique and enjoyable experience that gives customers confidence in the company, its products, and

its integrity.

Key Benchmarking Criteria

For the Enabling Technology Leadership Award, Frost & Sullivan analysts independently evaluated two key factors—Technology Leverage and Customer Impact—according to the criteria identified below.

Technology Leverage

Criterion 1: Commitment to Innovation Criterion 2: Commitment to Creativity Criterion 3: Stage Gate Efficiency Criterion 4: Commercialization Success Criterion 5: Application Diversity

Customer Impact

Criterion 1: Price/Performance Value Criterion 2: Customer Purchase Experience Criterion 3: Customer Ownership Experience Criterion 4: Customer Service Experience Criterion 5: Brand Equity

Best Practices Award Analysis for Automotive Grade Linux

Decision Support Scorecard

To support its evaluation of best practices across multiple business performance categories, Frost & Sullivan employs a customized Decision Support Scorecard. This tool allows our research and consulting teams to objectively analyze performance, according to the key benchmarking criteria listed in the previous section, and to assign ratings on that basis. The tool follows a 10-point scale that allows for nuances in performance evaluation. Ratings guidelines are illustrated below.

RATINGS GUIDELINES



The Decision Support Scorecard is organized by Technology Leverage and Customer Impact (i.e., These are the overarching categories for all 10 benchmarking criteria; the definitions for each criterion are provided beneath the scorecard.). The research team confirms the veracity of this weighted scorecard through sensitivity analysis, which

confirms that small changes to the ratings for a specific criterion do not lead to a significant change in the overall relative rankings of the companies.

The results of this analysis are shown below. To remain unbiased and to protect the interests of all organizations reviewed, we have chosen to refer to the other key participants as Competitor 2 and Competitor 3.

| Measurement of 1–10 (1 = poor; 10 = excellent) | | | |
|--|------------------------|--------------------|-------------------|
| Enabling Technology Leadership | Technology Leverage | Customer Impact | Average Rating |
| | | | |
| Automotive Grade Linux | 10 | 9 | 9.5 |
| Competitor 2 | 8 | 8.5 | 8.25 |
| Competitor 3 | 7 | 8 | 7.5 |

Technology Leverage

Criterion 1: Commitment to Innovation

Requirement: Conscious, ongoing adoption of emerging technologies that enables new product development and enhances product performance

Criterion 2: Commitment to Creativity

Requirement: Technology leveraged to push the limits of form and function in the pursuit of "white space" innovation

Criterion 3: Stage Gate Efficiency

Requirement: Adoption of technology to enhance the stage gate process for launching new products and solutions

Criterion 4: Commercialization Success

Requirement: A proven track record of taking new technologies to market with a high rate of success

Criterion 5: Application Diversity

Requirement: The development and/or integration of technologies that serve multiple applications and can be embraced in multiple environments

Customer Impact

Criterion 1: Price/Performance Value

Requirement: Products or services offer the best value for the price, compared to similar offerings in the market.

Criterion 2: Customer Purchase Experience

Requirement: Customers feel they are buying the most optimal solution that addresses both their unique needs and their unique constraints.

Criterion 3: Customer Ownership Experience

Requirement: Customers are proud to own the company's product or service and have a positive experience throughout the life of the product or service.

Criterion 4: Customer Service Experience

Requirement: Customer service is accessible, fast, stress-free, and of high quality.

Criterion 5: Brand Equity

Requirement: Customers have a positive view of the brand and exhibit high brand loyalty.

Decision Support Matrix

Once all companies have been evaluated according to the Decision Support Scorecard, analysts then position the candidates on the matrix shown below, enabling them to visualize which companies are truly breakthrough and which ones are not yet operating at best-in-class levels.



Best Practices Recognition: 10 Steps to Researching, Identifying, and Recognizing Best Practices

Frost & Sullivan analysts follow a 10-step process to evaluate Award candidates and assess their fit with select best practice criteria. The reputation and integrity of the Awards are based on close adherence to this process.

| | STEP | OBJECTIVE | KEY ACTIVITIES | OUTPUT |
|----|--|--|--|---|
| 1 | Monitor, target, and screen | Identify Award recipient candidates from around the globe | Conduct in-depth industry research Identify emerging sectors Scan multiple geographies | Pipeline of candidates who potentially meet all best- practice criteria |
| 2 | Perform 360-degree research | Perform comprehensive, 360-degree research on all candidates in the pipeline | Interview thought leaders and industry practitioners Assess candidates' fit with best-practice criteria Rank all candidates | Matrix positioning of all candidates' performance relative to one another |
| 3 | Invite thought leadership in best practices | Perform in-depth examination of all candidates | Confirm best-practice criteria Examine eligibility of all candidates Identify any information gaps | Detailed profiles of all ranked candidates |
| 4 | Initiate research director review | Conduct an unbiased evaluation of all candidate profiles | Brainstorm ranking options Invite multiple perspectives on candidates' performance Update candidate profiles | Final prioritization of all eligible candidates and companion best-practice positioning paper |
| 5 | Assemble panel of industry experts | Present findings to an expert panel of industry thought leaders | Share findings Strengthen cases for candidate eligibility Prioritize candidates | Refined list of prioritized Award candidates |
| 6 | Conduct global industry review | Build consensus on Award candidates' eligibility | Hold global team meeting to review all candidates Pressure-test fit with criteria Confirm inclusion of all eligible candidates | Final list of eligible Award candidates, representing success stories worldwide |
| 7 | Perform quality check | Develop official Award consideration materials | Perform final performance benchmarking activities Write nominations Perform quality review | High-quality, accurate, and creative presentation of nominees' successes |
| 8 | Reconnect with panel of industry experts | Finalize the selection of the best-practice Award recipient | Review analysis with panel Build consensus Select recipient | Decision on which company performs best against all best-practice criteria |
| 9 | Communicate recognition | Inform Award recipient of Award recognition | Announce Award to the CEO Inspire the organization for continued success Celebrate the recipient's performance | Announcement of Award and plan for how recipient can use the Award to enhance the brand |
| 10 | Take strategic action | Upon licensing, company is able to share Award news with stakeholders and customers | Coordinate media outreach Design a marketing plan Assess Award's role in future strategic planning | Widespread awareness of recipient's Award status among investors, media personnel, and employees |

The Intersection between 360-Degree Research and Best Practices Awards

Research Methodology

Frost & Sullivan's 360-degree research methodology represents the analytical rigor of our research process. It offers a 360-degree-view of industry challenges, trends, and issues by integrating all 7 of Frost & Sullivan's research methodologies. Too often companies make important growth decisions based on a narrow understanding of their environment, leading to errors of both omission and commission. Successful growth strategies are founded on a thorough understanding of market, technical, economic, financial, customer, best practices, and demographic analyses. The integration of these research disciplines into the 360degree research methodology provides an evaluation platform for benchmarking



industry participants and for identifying those performing at best-in-class levels.

About Frost & Sullivan

Frost & Sullivan, the Growth Partnership Company, enables clients to accelerate growth and achieve best-in-class positions in growth, innovation and leadership. The company's Growth Partnership Service provides the CEO and the CEO's Growth Team with disciplined research and best practice models to drive the generation, evaluation and implementation of powerful growth strategies. Frost & Sullivan leverages more than 50 years of experience in partnering with Global 1000 companies, emerging businesses, and the investment community from 45 offices on six continents. To join our Growth Partnership, please visit <u>http://www.frost.com</u>.