Analysis of Software Update in Connected Vehicles

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ABSTRACT

The substantial increase of electronic systems and processors in vehicles is increasing the already remarkable amount of software code, generating thousands of software-related recalls according to the National Highway Traffic Safety Administration (NHTSA), leading to frequent customer updates. Current software updating methods are inconvenient for customers and dealers alike, requiring a significant amount of time and expensive hardware to implement. With Wi-Fi technology and embedded modems entering vehicles, several OEMs have already taken an innovative approach with Over-The-Air (OTA) technology. OTA updating has shown to be a proven method in the telecom industry with tens of millions of phones equipped with OTA capabilities and millions of successful OTA updates performed each year, contributing to a reliable and efficient method of updating. This paper analyzes the different ways OTA is currently being used to successfully achieve in-vehicle software updates. This paper also presents the results of a questionnaire conducted to assess the familiarity and acceptance of software update technologies. This paper concludes with an analysis of the questionnaire results and the authors' preferred implementation method of OTA based on the research.

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INTRODUCTION

Dozens of microprocessors and hundreds of vehicle functionalities are based on a substantial amount of code. With the emerging trend of connected vehicle and increased functionality, software is only going to become more complex. OEMs have to ensure the software is reliable and future proof by providing updates. To ensure these updates are successfully implemented, OEMs have to provide an efficient method of updating.

Some OEMs have already taken the initiative to tackle these issues by including Over-The-Air (OTA) updating capabilities in their current and future vehicle line-ups. OTA technology gives OEMs the ability to provide a convenient method of updating. This paper analyzes the different implementation methods OEMs have used to improve the process of in-vehicle software updates.

SOFTWARE UPDATE

Software in Connected Vehicles

The increase of software code in modern vehicles gives consumers increased functionality and safety. The average vehicle today contains millions of lines of code, offering customers the ability to stay connected with the world from the seat of their vehicle using telematics and smartphone integration technologies. Recent cars have offered the ability to not only sense collisions but also warn drivers, and in some instances act autonomously on the behalf of the driver. Moreover, several OEMs have already shown the connected capabilities of their electric vehicles, offering customers the ability to monitor the energy of their vehicle through a smartphone app, and the ability to schedule when to draw power from the electrical grid.

The addition of these technologies and functionalities in modern vehicles leads to an increase of software and complexity for OEMs. This software complexity can be difficult to master during the initial release of a vehicle, and some software bugs and defects can only be uncovered with real-time consumer usage. To keep vehicles safe and up to date, it is essential for OEMs to have the ability to update their code when desired.

The situations when an update is needed are:

- Recall
  OEM will recall vehicles that have safety concerns.
- Customer issue
  Customer will have a software related issue that requires updating.
- New software release
  Updating the vehicle with a new software release sent by the OEM.

Updates can consist of hardware or software:

- Hardware Updates

  Updated when recalls are issued or customer has specific problem.

- Applications

  New or existing applications that need updating, typically weekly.

- Stack

  Software updates to the stack of the infotainment unit, typically several times per year.

- OS Kernel

  Update of the kernel, several times per year.

Customer Implemented Update

For customer implemented updates, the customer either receives a CD with the latest software directly from the OEM or has to manually download the software on a USB drive. This update method gives customers the luxury of updating the radio/infotainment system at their own convenience. But the update procedure is inconvenient, requiring an extensive amount of labor and an excessive amount of vehicle on-time. To successfully update the radio/infotainment system, it requires the user from 30 minutes to several hours beginning with the download procedure and ending with the update confirmation. Not only is the procedure unintuitive, but there is also a security risk of having the software in the hands of many customers, which increases the possibility of reverse engineering and uploading a hacked version of the file to the internet.

The following is a detailed description of a self-implemented USB update:

1. Open a browser and log on to OEM site
2. Locate the updates section, click "get update"
3. Click update and connect your empty USB drive
4. Click Start Download Process to your USB drive
5. Remove USB after download complete
6. Take the USB drive to your vehicle. Turn on your vehicle, and then turn on the radio.
7. Make sure your car is in a well-ventilated area. Your vehicle will need to be turned on, with the engine running between 25 to 35 minutes. Make sure that your vehicle is not in Accessory mode.
8. Plug the USB drive in to your vehicle's USB port.
9. Press AUX to select Line In. Press OK.
   a. Press Menu. Media displays. Press OK.
10. Media Menu displays, and then Play Menu appears. Press Seek until Select Source is highlighted. Press OK.
11. USB displays. Press OK.
   a. USB Selected displays. Press OK.
12. Press Seek until System Settings is highlighted. Press OK.
   a. Press Seek until Advanced is highlighted. Press OK.

13. Prompts display. Press Seek until Install Applications is highlighted. Press OK.
14. Automatically detects the files on your USB drive, and then displays "Install Application?" Press OK to confirm.
15. Prompts "Installation Complete." Press MENU to exit installation mode. It is now safe to remove your USB drive.
16. Once you have installed the software updates, you will need to pair your phone again. To complete the process, take the USB drive to your computer to report the successful installation.

Dealer Implemented Update

For software related recalls, OEMs require customers to update their vehicles at the dealers. Primarily, these types of recalls affect the vehicle's ECUs. ECUs are located throughout the body of a vehicle and require special tools and procedures to communicate with and successfully achieve a reliable update. Moreover, if customers lack the ability to update their own radio/infotainment system, they have the option to voluntarily drive to the dealer for an update.

Dealer implemented updates are reliable and done in a controlled environment, giving the customer assurance that the update was implemented successfully. From the customer's point of view, driving to the dealer and the long waits associated with service centers can be a major inconvenience.

The following is the update procedure at the dealers:

1. OEM issues a recall notice (or new software release) to dealers and customers.
2. OEM sends the CD with the latest software to the dealer.
3. The customer drops off the vehicle at the dealer.
4. Technician updates the reprogramming tool with the content from the CD and connects it to the in-vehicle bus to target the ECU (or inserts CD in radio/infotainment system) and starts update process.
5. Technician ensures update successful.
6. Customer is contacted to pick up vehicle at their desired time.
7. Dealer charges OEM for labor costs.

OVER-THE-AIR UPDATES

Over-The-Air Technology

This paper will not detail Over-The-Air (OTA) technology, but rather the implementation of OTA updates in vehicles. Nonetheless, a brief description of OTA technology is provided below.

In general, the term OTA in the automotive industry implies the use of wireless mechanisms to send data or update packages for software updates to a vehicle. OTA mechanisms require the existing software and hardware of the vehicle to support the features for receiving, processing, and setting parameters.

Several software companies already provide expertise in helping OEMs and Tier 1s deploy end to end solutions for OTA updates. A typical update consist of: creating the software update package, deploying the software update package over the air, receiving the software update package in the automotive device, and finally installing the software update package.

OTA update use cases:

- **Embedded 3G/4G modem.**

  OEM contracts with a mobile network operator to provide network services through its embedded modem in its vehicles.
- **Embedded Wi-Fi**

  OEM adds Wi-Fi to access update via WLAN or mobile hotspot.
- **Smartphone OTA using Bluetooth® or wired tethering.**

  OEM sends updates through OEM's smartphone App. Customer tethers smartphone with radio/infotainment system either by wired USB connection or wireless Bluetooth® connection to install software updates.

Described below are several important characteristics required with each use case:

- **Security:** Security is essential for ensuring a safe transaction of the data between the OEM server and the vehicle.
- **Download speed:** A high-bandwidth network is preferred to ensure a fast and reliable download.
- **User expense:** Additional monthly payments can discourage customers from enrolling in an embedded vehicle data plan.
- **Multiple devices:** OTA updates have to be convenient and intuitive for the customer, if multiple devices and steps are required then the OTA use case is less attractive.
- **Access of wireless reception:** To ensure a reliable connection to the wireless network the customer must have reliable network reception.
- **Infotainment/Radio memory**: For a reliable update, there should be sufficient memory to store the new image before installation. Without an increase of storage the new image will directly download into the flash and overwrite the old code, which can disable the system if connection is lost at any point during the download.
- **Automatic "forced update" feasibility:** Some customers might delay their updates several times until they find the convenient time to update. If an OEM has an urgent update that needs immediate implementation, a use case allowing the OEM to always have an access to the system will allow OEMs to better implement forced updates.

Use Case	Embedded Modem	Embedded Wi-Fi	Smartphone OTA using Bluetooth® or wired tethering
Security	Strong	Dependent on hotspot	Dependent on smartphone
Download Speed	(3G) Range from (0.59 Mbps – 3.84 Mbps)	Wi-Fi (1-100 Mbps) Phone Hotspot Range from (0.59 – 3.84 Mbps)	Bluetooth® USB
User Expense	Monthly subscription charge	Wi-Fi free at local hotspots, phone data connection	Phone data connection
Multiple Devices	No	Yes	Yes
Access of Wireless reception	3G/4G network area	Wi-Fi or 3G/4G network area	Smartphone
Infotainment/Radio storage increase	Yes	Yes	Yes
Automatic "forced update" feasible?	Yes	Limited range	No

Embedded Modem (3G/4G)

- Advantages:
  1. Convenient and efficient for frequent updates.
  2. 3G/4G connection common in urban areas.
  3. Secure HTTP (SSL) connection with servers, which store the firmware updates.
- Disadvantages:
  1. Not in controlled environment.
  2. User has to pay for data subscription.
  3. Slower download speeds.
  4. Carriers generally limit the number of "devices" that updates can be pushed to at a time for bandwidth limitations.
  5. Hardware upgrades

Embedded Wi-Fi

- Advantages:
  1. Faster download speeds.
  2. Secure connection.
  3. Wi-Fi connections are very common in urban areas.
  4. OEM is not concerned with network limitation bandwidth.
- Disadvantages:
  1. Vehicle has to be within Wi-Fi range.
  2. Frequent updates can be inconvenient for customer.

Smartphone OTA with Bluetooth® or wired tethering

- Advantages:
  1. Reliable updates.
  2. Update can be made outside data connection and WLAN network range after downloading to smartphone
- Disadvantages:
  1. Complicated procedure.
  2. Multiple devices are involved.
  3. Frequent updates can be inconvenient for customer.
  4. Less secure since software can be reverse engineered when placed on customer's smartphone, or USB drive.

Current OTA Updates

Several OEMs have already deployed some OTA update capabilities in North America:

- **Tesla:** OTA through an embedded AT&T 3G data connection or a Wi-Fi router, also offering customers a complimentary hardware change to 4G modem.
- **Chevy Volt:** The OnStar Verizon 3G data connection. For customers without an OnStar subscription, they simply press the OnStar button to inform an operator that they have received an update letter from GM. A 30 day, temporary access window will be opened and GM will push the update into their system.
- **Mercedes mbrace2:** OTA through an embedded Verizon 3G data connection. The updates are pushed into the system and are updated during the next vehicle start.
- **Chrysler Uconnect:** OTA through an embedded Sprint 3G data connection or Wi-Fi router. The updates are pushed into the system and are updated during the next vehicle start.
- **Audi Connect:** OTA through an embedded T-Mobile 3G data connection.
- **Toyota Entune:** Limited OTA update using Bluetooth® or USB smartphone data connection. Customer is notified when update is available through an App. The Smartphone is tethered to the system to provide the update. Some updates may require using a USB drive.

QUESTIONNAIRE

Survey and Results

An online survey was generated to reach a wide variety of vehicle consumers to research opinions and preferences regarding software updates in vehicles. 14 questions were asked. The survey concluded with 51 total participants, from a wide variety of occupations.

The following are the questions and results:

What is your age?

Answer Options	Response Percent
18 to 24	39.2%
25 to 34	9.8%
35 to 44	19.6%
45 to 54	23.5%
55 to 64	5.9%
65 to 74	2.0%
75 or older	0.0%

Figure 1. Age Results

What is the year, make, and model of your automobile?

Answer Options	Response Percent
Year	
Make (e.g., Ford)	
Model (e.g., Mustang)	

Figure 2. Vehicle Year, Make, and Model

2. What is your current occupation?

Answer Options	Multiple (Details in Analysis)

Figure 3. Occupation

In what region do you live?

Answer Options	Response Percent
North America	96.1%
South America	0.0%
Europe	3.9%
Asia	0.0%

Figure 4. Region Results

Have you had issues with your vehicle's radio/infotainment system?

Answer Options	Response Percent
Yes	43.1%
No	56.9%

Figure 5. Issues Results

Are you interested in updating your radio/infotainment system?

Answer Options	Response Percent
Yes, I like to stay updated	74.5%
No, I don't care about updating	25.5%

Figure 6. Interest Results

How would you prefer to update your vehicle's radio/infotainment system?

Answer Options	Response Percent
Update at home	94.1%
Drive to dealer for an update	5.9%

Figure 7. Preferability Results

Have you taken your vehicle to the dealer for a software issue?

Answer Options	Response Percent
Yes, it was a hassle	13.7%
Yes, it went great	5.9%
No	80.4%

Figure 8. Dealer Experience Results

When parked at home, is your vehicle in Wi-Fi range (100 Ft., 30m)?

Answer Options	Response Percent
Yes	88.2%
No	11.8%

Figure 9. Wi-Fi Results

Would you have access to a Wi-Fi network if an update is needed for your radio/infotainment system?

Answer Options	Response Percent
Yes	96.1%
No	3.9%

Figure 10. Access to Wi-Fi Results

Does your mobile phone have Wi-Fi capabilities?

Answer Options	Response Percent
Yes	88.2%
No	11.8%

Figure 11. Mobile Phone Capability Results

Would you be willing to use your mobile phone as a part of the updating procedure?

Answer Options	Response Percent
Yes, through wireless methods only	37.3%
Yes, through wired methods only	0.0%
Yes, either wireless or wired methods are fine	47.1%
No	15.7%

Figure 12. Updating Procedure Results

How would you like to be involved in the update procedure?

Answer Options	Response Percent
I want to be notified when an update is available and initiate the update.	80.4%
I want to be notified when an update has occurred.	9.8%
I want the update to occur without my knowledge.	5.9%
Other (please specify)	3.9%

Figure 13. Involvement Results

What is the idlest time you will be willing to wait for your radio/infotainment system to update?

Answer Options	Response Percent
1 - 10 minutes	43.1%
10 - 20 minutes	35.3%
20 - 30 minutes	7.8%
Greater than 30 minutes	13.7%

Figure 14. Idle Time Results

Analysis of the Results

The survey participants consisted of engineers, non-engineers, and students, North America was the main region in which the participants lived.

The participants were asked if they had issues with their radio/infotainment system. 43% of the survey participants reported they had issues with their radio/infotainment system. Also 74.5% of the survey participants answered they are interested in software updates. When participants were asked about their preference of where to update their vehicle either at home or at the dealer, 94% stated they were willing to update their radio/infotainment system at home instead of driving to a dealer, undeniably showing the inconvenience of visiting a dealership. To further support the process of updating at home, 88% of the participants stated their vehicle is in Wi-Fi range when parked at home, and 96% stated they have access to a Wi-Fi reception if an update is needed.

With the latest technological evolution of mobile phones, the capabilities and features of smartphones has revolutionized the way people communicate and use phones. To further evaluate the acceptance of smartphone use within vehicles, participants were asked several questions. First, 88% of the participants stated their mobile phone has Wi-Fi capabilities. Moreover, when participants were asked if they are willing to use their mobile phones as part of their updating procedure, 84% of the participants stated they are willing to use their mobile phone in the update procedure with 37% stating through wireless methods, 47% open to both wireless and wired methods, and a mere 15% not willing to use their mobile phone as part of their update procedure. Although some current mobile hotspots have slow download speeds, the evolution to 4G networks will give users the ability to download and upload at faster speeds from their mobile phones. These statistics conclude that the majority of the participants are willing to use their mobile phones in the updating procedures, with the majority requesting to have flexibility in having both wireless or wired methods for updating.

To further assess the participants' willingness to interact with the update procedure, the survey asked participants "How would you like to be involved in the update procedure?" 80% stated they want to be notified and initiate the update, 9.8% stated they only want to be notified when an update has occurred and 3.9% specified a different procedure, giving a total of 94.1% of the participants want to have some sort of interaction with the update procedure. The remaining 5.9% wanted the update to occur without their knowledge.

Software Issues Analysis

To further evaluate and distinguish the popularity of software updates, the results of Figure 6 were analyzed in greater detail. Of the participants that reported issues with their radio infotainment system, 95% stated they are interested in software updates, and of the participants that stated they did not have software issues only 62% are interested in software updates. A conclusion can be made that the people that had

experience with software issues are signaling an unmet need for software updates. It can be extrapolated that once a participant does have issues they will likely want software updates. Moreover, from the participants that stated they had software issues, 36% stated they had made a trip to the dealership. This result shows the inconvenience of driving a vehicle to the dealership, because only 36% actually took action to solve their problem. If someone is sick the probability of them driving to the doctor or taking medicine at home is relatively high, but what if the medicine takes more than 40 minutes to swallow? Finally, all of the people that reported software issues had access to Wi-Fi reception.

Vehicle Model Year Analysis

A closer look was taken at the disparity of the model years, between newer and older vehicles. Of the participants that own a vehicle model year of 2008 or later, 82.5% concluded they are interested in software updates in contrast to participants that own a model year of 2007 and older, only 47% of which concluded they would be interested in software updates. Moreover, participants that own a vehicle model year of 2008 or later visited the dealership twice as much as owners of vehicle model year 2007 or older, they also stated audio, connectivity, navigation, and HMI being the issues they faced with their systems. Many conclusions can be drawn up from these statistics, but one thing is certain that newer vehicles are having more software related issues than older vehicles and more new model year drivers are driving to the dealerships. The inconvenience is a burden on the drivers and a more appropriate updating method is needed.

Age Analysis

With younger generations being the ones dictating the acceptance rate of innovations and technologies within newer vehicles, a closer look was taken at the results of participants 34 years old and younger compared to participants 35 years old and older. Of the participants that are 34 years old and younger 92% of them concluded they will be willing to use their mobile phone as part of the update procedure, compared to 76% of the participants that are 35 and older stated they will be willing to use their mobile phone. With younger generations becoming more experienced with smartphones, the percentage of people willing to use their smartphone as part of the update procedure is likely to increase. Moreover, 52% of participants under the age of 35 stated "1 to 10" minutes is the longest time they will wait for an update, compared to participants over the Age of 35 only 34% expect their system to update in 1 to 10 minutes, while 24% are willing to wait more than 30 minutes. Not only are the younger participants willing to use their mobile phone as part of their update procedure but the majority also want the total update time to be from 1 to 10 minutes.

CONCLUSION

OTA Conclusion

All three use cases "Embedded 3G/4G modem", "Embedded Wi-Fi", and "Smartphone OTA using Bluetooth® or wired tethering" have their advantages and disadvantages. The best use case would be for the OEM and the customer to have a safe transaction of the update, at a very minimal labor and no added costs. Embedded 3G/4G modem use case comes with the best flexibility of being able to update through secure wireless reception that is located in many urban areas depending on the carrier, but what if all vehicles are already equipped with 3G modems and the next generation of telecommunications networks is released with faster network bandwidth? If drivers are keen on always being up to date with the latest technology then OEMs have to take into account the cost of hardware change in their vehicles. Wi-Fi technology should be considered for software updates because it is widely available, ensures fast download speeds and a secure connection depending on the location.

Robustness of the update process is a key attribute. Both embedded Wi-Fi and 3G/4G OTA updates are subject to failure depending on the network availability and reliability. It can be inconvenient if the download is interrupted and a vehicle is stalled during a vacation. But OEMs, with added costs, can provide a more reliable update by providing extra storage for the old files to be stored while the new update is being downloaded. Also, most 3G/4G networks are too slow to achieve the participants' preferred download/install time of 1 to 10 minutes. Wi-Fi download speeds are much faster and can make 1 to 10 minute download/install time a reality. Finally, even though 84.4% of the participants stated they would be willing to use their mobile phone as part of their update procedure, Smartphone OTA updates with Bluetooth® or wired tethering can be a complicated procedure with multiple devices being involved. Smartphone updates can have an advantage by allowing drivers to update the system outside a network data connection or WLAN network range by downloading the update to the smartphone. But hackers can reverse engineer the update file when placed on a smartphone. Also frequent smartphone updates can be inconvenient for the drivers.

Best Use Case

The best use case would be for a driver to arrive home, park his/her vehicle, and get notified of an update after the vehicle is in park mode and within Wi-Fi reception range. The driver will be able to initiate the update while the vehicle is turned off. The system will automatically download the update, install, and restart the system within 1 to 10 minutes total time. Moreover,

safety related ECU updates and recalls should be done at the dealership since it gives the dealer control over sensitive updates.

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DEFINITIONS/ABBREVIATIONS

OTA - Over-The-Air

ECU - Electronic Control Unit

OEM - Original Equipment Manufacturer

OS - Operating System