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Using Consumer Accessible Mobile Devices To Collect Vehicle Emissions Compliance Data

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USING CONSUMER ACCESSIBLE MOBILE DEVICES TO COLLECT VEHICLE EMISSIONS COMPLIANCE DATA

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Abstract

The emissions inspection procedure has been largely stagnate for the last 20 years. Vehicle owners in the United States spend approximately 1.7 billion dollars annually for a technician to perform the simple task of plugging an emissions inspection computer into their car's computer. Smart Emissions was developed as an Android application to provide a new procedure for emissions inspection utilizing consumer-accessible mobile devices and an ELM327 Bluetooth adapter. With Smart Emissions, vehicle owners utilize the Android devices they already own to connect to a Bluetooth adapter inserted into the diagnostic link connector port of their vehicle. The adapter communicates with the onboard diagnostic computer to gather the status of the vehicle's emission compliance componentry. The data is collected and correlated according to industry standards and EPA rule EPA420-R-01-015. Results of the study showed that an Android device was capable of collecting emissions data with the same accuracy as existing OBD compliant methods. This study also examined the perception of study participants towards current emissions procedures and the proposed method of emissions collection via consumer accessible mobile devices. Of 115 survey respondents, 90% are in favor of a solution they can use from home in lieu of taking their vehicle to an inspection station. Inversely, 46% of survey respondents found it reassuring to have a certified technician conduct the inspection. Further research is needed to understand why having a technician perform the inspection is reassuring. Additionally changing emissions procedures to use to consumer accessible hardware presents new challenges in vetting the accuracy of the equipment used for the emissions inspection, and requires further research.

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Chapter 1 – Introduction

According to a 2008 estimation by the United States Environmental Protection Agency (EPA), vehicle owners who are required to have an Emissions Inspection conducted on their vehicle spend an estimated 1.2 billion dollars annually to conduct these tests (Tierney & Kotsakis, 2008). More recent estimates by the U.S. EPA place expenditures nearer to 1.7 billion dollars annually on an estimated 60,391,000 tests. For the vast majority of vehicles today (model year 1996 and newer), an emissions test consists primarily of a technician plugging their emissions compliance computer into the Data Link Connector (DLC) port of the vehicle along with a visual examination of the Maintenance Indicator Light (MIL). The technician's computer then requests the vehicle's emissions control status directly from the On Board Diagnostics (OBD) computer of the vehicle, and determines emissions compliance based on local and federal regulations. This means that the majority of vehicle owners are paying aggregate fees of between 1.2 and 1.7 billion dollars annually for a technician to plug a computer into their car's computer.

With most public policy, the costs of implementing any program must be justified against the benefit derived from the program. There is little argument that vehicle emissions programs have been effective in reducing harmful gasses from being released into the atmosphere. Prior to the introduction of the Clean Air Act of 1970, vehicles were producing "13 grams per mile hydrocarbons (HC), 3.6 grams per mile nitrogen oxides (NO_x), and 87 grams per mile carbon monoxide (CO)" (EPA, 2017 January, para. 1). This is in strong contrast to current regulations which limit light duty vehicles to between 20 and 160 mg per mile of NO_x, and between 1 and 4.2 grams of CO per mile depending on the certification level of the vehicle (MECA, n.d.). The difference in emissions output demonstrates a clear connection to the effort that has been expended improving the technology which is reducing overall emissions, but little has been done to reduce the costs of enforcing continued compliance with vehicles after they have been manufactured. This seems an oversight, considering the expenditure of 1.2-1.7 billion dollars annually to plug one computer into another. Lehmann and Gross (2017) noted that given the proliferation of smartphones, a great potential exists to considerably reduce the costs of gathering relevant emissions data from vehicles. An emissions program is mostly data gathering with some rule enforcement, so prudence suggests finding a way to utilize this proliferation of smartphones noted by Lehmann and Gross. According to the Pew Research Center (2017), 95% of American's own a cellphone, 77% of which are classified as a smartphone. This study explored an approach which leverages current smartphone technology to substantially reduce the costs of emissions compliance enforcement, while still maintaining the integrity of current emissions regulations. This study attempted to measure the impact on public perception towards emission testing under this proposed model.

Research Questions

Given the ubiquitous nature of mobile technologies it is reasonable to question how mobile technologies can be used to provide a more efficient way to conduct emissions tests. Specifically, this study sought to answer the question of how Android-based mobile devices can be used to access vehicle emissions data from the OBD computer. Logically, this raises the question that when mobile technologies are able to access emissions data, how does using existing consumer-hardware simplify emissions programs and effect the costs of running them? Lastly, this study endeavored to understand how using mobile devices to conduct in-home OBD-II based emissions tests impacts public-perception of emissions testing programs.

Problem and Rationale

To understand how a smartphone has the capability to perform an emissions test, we must first define what current emissions procedures are and identify any areas which are incompatible with using consumer accessible mobile devices for emissions collection. Central to any emissions inspection program is EPA rule EPA420-R-01-015 which provides the guidelines for an acceptable emissions inspection (Sosnowski & Gardetto, 2001). The emissions inspection in general consists of two major categories. First is a visual check of the MIL. This is commonly known in the industry as a “bulb check” because the test entails simply ensuring the MIL bulb illuminates on the vehicle dashboard when commanded on. This visual inspection cannot be completed electronically, and any future program which is conducted by vehicle owners must be granted an exception to this procedure. The second category is an examination of the OBD computer on the vehicle, which monitors vehicle emissions performance while the vehicle is being driven on a regular basis.

The EPA provides a seven-step generic process to conducting an emissions test. However, in practice the electronic interrogation of the OBD computer can be simplified to fewer steps. The interrogation begins after an ELM327 compatible adapter has been inserted into the DLC, and the vehicle is in the “key on, engine running” state. First, the connected software must determine the protocol being used by the vehicle. Second, the system then requests the Vehicle Identification Number (VIN) from the vehicle. This number uniquely identifies the vehicle being examined from all other vehicles in production. Third, the system then requests three key types of information: Vehicle readiness monitors, the MIL Status which may be commanded on or off, and any Diagnostic Trouble Codes (DTCs) stored when the MIL is commanded on. While all of these steps are required, an emissions test in its simplest form consists of ensuring that the MIL is commanded off, and that a sufficient number of vehicle readiness monitors are in the “complete” state.

Under SAE J1979 / ISO 15031-5 and CARB Title 13, CCR §1968.2(g)(4.1), gasoline vehicles are equipped with up to eleven standardized vehicle emissions readiness monitors. Each monitors a specific portion of a vehicle’s overall emission control system and may be set to one of three possible states: Complete, Not Ready, and Unavailable. “Complete” indicates the monitor has met minimum testing limits and has not exceeded maximum acceptable limits. “Not Ready” indicates the monitor has not been run. “Unavailable” indicates the vehicle is not equipped with the monitor, and that the monitor should not be factored into the overall pass/fail of an emissions test.

Considering these EPA guidelines, any proposed alternative to the testing process must conform as closely as possible to EPA420-R-01-015 until such time as the EPA issues new rules or guidelines. Smartphone based emissions data collection, by its very nature is unable to verify that the MIL bulb is functioning. The remaining elements of the emissions test are easily completed on vehicles model year 2005 and newer. The limitation in the model year is due to California’s Air Resource Board (CARB) requirements that the VIN be electronically readable from the OBD computer beginning in 2005. While some manufacturers chose to implement this sooner, it was not a formal requirement prior to 2005 and cannot be relied upon in vehicles model year 1996-2005. Because of these factors, this study will be limited to gasoline vehicles model year 2005 and newer, and only on the electronic interrogation of the OBD computer parts of the emissions inspection process.

Purpose

This study quantitatively examined the ability of an Android application, Smart Emissions, to meet the guidelines issued in current EPA regulations while meeting the same levels of accuracy as currently certified equipment. This was demonstrated by running a sample set of vehicles through a currently certified testing procedure, and through Smart Emissions to demonstrate the feasibility of the collection method.

Considering that public policy is driven by public opinion nearly as much as scientific, or legal requirements, participants in the study were issued a survey to gain their perception towards, and understanding of, current emissions testing procedures. Participants were also asked to consider a situation where they ran emissions tests remotely from a location of their choosing, utilizing their personal smartphone and an inexpensive OBD-II Bluetooth adapter. Participants were asked specifically to identify any concerns they had with conducting emissions inspections on their own, as well their personal preference between the two.

The remaining chapters in this study are organized as follows: in Chapter 2 a discussion on the history of emissions testing, and the current literature on the topic is provided. A discussion of the methodology of the application and its development is presented in Chapter 3. Also in Chapter 3 a discussion on the structure of the study in both the quantitative, and qualitative forms. The results of the study, along with a discussion of the potential impact they have is provided in Chapter 4. Lastly, in Chapter 5 a summary, final discussion, and thoughts on potential future research.

Chapter 2 – Review of Literature and Research

Central to the research governing vehicle emissions testing is understanding the history driving emissions development, enforcement, and research. At the conclusion of World War II, the United States began to see a sharp increase in the use of personal vehicles for transportation. The result of this increase in personal automobile use was a sharp increase in pollution, especially in cities with large populations. The correlation between vehicle emissions and air pollution was first noted by two researchers at the University of California, Riverside in 1950. Dr. Clifton Taylor, and Dr. Ray Thompson demonstrated that the chemicals being emitted from vehicles were not then known industrial pollutants and were the cause of significant crop losses, and a major contributor to air pollution (South Coast Air Quality Management District, n.d.). At the time of their discovery, the typical car emitted "nearly 13 grams per mile hydrocarbons (HC), 3.6 grams per mile nitrogen oxides (NO_x), and 87 grams per mile carbon monoxide (CO)" according to the EPA (EPA, 2017 January, para 1). This created a difficult problem. Vehicles themselves were the result of a booming economy and contributed to the continued success of the economy, but they also created significant air-quality problems. No federal standards existed for emissions control and likewise no motivation for the private sector existed to drive the technology development needed.

California Air Resources Board's Role in Emissions

California's Air Resource Board (CARB) has led the charge on emissions control since the 1960's with federal standards often mirroring or accepting the more rigorous California standards (Miller & Solomon, 2009; EPA, 2017). Miller and Solomon (2009) explained that in the early 1960's CARB initiated a process requiring auto makers to meet a specific emissions standard by 1966. However, because the technology did not yet exist, CARB allowed that the rules would not be enforced until at least two separate demonstrated, commercially viable technologies were certified. Essentially CARB was creating a set of regulations, but not enforcing them until the technology was created to meet the regulation. A large flaw existed in this plan. By 1964 automobile manufacturers were claiming they could not meet the new requirements until at least 1967. Three months later, four independently developed emissions control devices were certified by CARB, which resulted in the standards being required for any vehicle sold or operating in California by model year 1966. Astonishingly, two months later vehicle manufacturers announced their own technology which they described as “superior”, whereas five months previously they had claimed this technology would require at least three years to develop (Miller & Solomon, 2009, p. 5).

Unfortunately for the automotive industry, it was obvious that the various manufacturers had colluded together to prevent the introduction of clean vehicle technologies as previously discussed (Miller & Solomon, 2009). This was demonstrated by a lawsuit brought by the U.S. Department of Justice against major automobile manufacturers in January of 1969 alleging collusion to prevent the commercialization of air pollution control devices. The suit was later settled in October of 1969. However, the most important piece of this history was not the lawsuit itself, but rather a significant change that it prompted in the way that regulation was developed for emissions control.

The Clean Air Act of 1970

Up until the Clean Air Act of 1970, national regulation waited for technology to be available before requiring its use. It was obvious after CARB’s experience with automakers and pollution control devices that letting regulation wait for technological advancement would not lead to the “rapid development of the state of the art” (Hearings on Air Pollution, 1967, p. 766).

Rather, the regulation needed to demand that technology catch up. Senator Edward Muskie presented this controversial concept:

> The first responsibility of Congress is not the making of technological or economic judgments—or even to be limited by what is or appears to be technologically feasible. Our responsibility is to establish what the public interest requires to protect the health of persons. This may mean that people and industries will be asked to do what seems to be impossible at the present time. But if health is to be protected, these challenges must be met. (116 Cong. Rec. 32901-32902, 1970)

Senator Muskie's statements described well the approach first adopted by CARB, and later on a national level via the Clean Air Act of 1970.

This approach was described by Miller and Solomon (2009) as a "technology-forcing approach" (p. 4). Which is precisely what the Clean Air Act did. The original requirements mandated a 90% reduction in emissions by 1975 (EPA, 2017 January).

Early Emissions Testing

Once emissions technology was mandated an enforcement procedure had to be developed. This required the development of a new industry, which performed checks on the emissions control components of a vehicle. These were colloquially known as "Smog Checks". To perform the test, vehicles were placed on a dynamometer and an analyzer was attached to the tailpipe. The vehicle had to be driven at two speeds for a regulated period while the analyzer gathered and tested emissions coming out of the tailpipe. This process was expensive in terms of time and equipment required to complete the test. For example, a BAR97 Smog Check analyzer and dynamometer cost between $28,000 and $33,000 accompanied with annual maintenance of close to $2,000 (Lyons & McCarthy, 2009).

Historically, several issues existed with a tailpipe emissions test. The largest issue was the time and expense it took to perform the test. Vehicle owners were required to bring the vehicle to an approved station and tests could take 30 minutes to complete once the vehicle was placed on the dynamometer. Due to the costly equipment and the time required for a technician to conduct tests, the fee associated to the test ranged between $30 and $60 (Lyons & McCarthy, 2009). Beyond the issues with time and costs, tailpipe tests could be circumvented through what was known as “clean piping”. Clean piping was “the tailpipe probe is connected to a vehicle other than the one that is represented by the technician as being tested for tailpipe emission levels” (Lyons & McCarthy, 2009, p.7).

Current Emissions Procedures

Beginning in vehicle model years 1996, manufacturers were required to implement the Onboard Diagnostics Version 2 (OBD-II) protocol. This enabled a complete paradigm shift in relation to vehicle emissions testing. Prior to the introduction of the OBD system, the only monitoring of emissions control conducted was when the test was performed by the owner on an annual basis. Owners were completely unware if an emissions control device failed between tests. Vehicles with failing components were then driven for substantial periods of time while emitting significantly more harmful substances than the legal limit.

In contrast, OBD was developed to enable the vehicle to be self-regulating. Checks of emissions related equipment are performed on a regular basis, often multiple times in a single trip. When an emissions component fails, this causes the maintenance indicator light to illuminate on the dashboard alerting the driver to the failure. With the use of this indicator light, owners are notified of a problem so that they may proactively correct the error prior to their next inspection, preventing unnecessary emissions.

Once the vehicle became self-testing, the costs of required testing equipment was reduced substantially, from $33,000 with an additional $2,000 per year to a one-time cost of $2,000 and periodic software updates (Lyons & McCarthy, 2009). The result of this introduction was a reduction in the costs of the fees charged to the vehicle owner to conduct an emissions compliance inspection. CARB estimated that the introduction of OBD-II based tests reduced in fee reduction between an estimated $60-$350 million dollars annually for the State of California alone (Lyons & McCarthy, 2009). Additionally, an OBD-II test can be conducted in 5 minutes or less with currently certified OBD-II emissions systems compared to the 30 minutes or more of a tail-pipe test. OBD-II tests are currently required in 251 counties within 32 states across the United States.

Future Emissions Procedures

When considering current testing procedures, the process is relatively straightforward for light and medium duty vehicles. The weakness in the current system however, is the requirement that tests be conducted by a certified technician at a known location. The technician is simply plugging a computer into the car, which then conducts the test by interrogating the ECU of the vehicle. Several alternatives to this procedure have been proposed and explored. The EPA (2008) proposed three future methods which could be considered as replacements to current policy. First, a 24-hour self-serve kiosk where vehicle owners could plug the kiosk into their vehicle. Second, a remote “data-logger” which could be used to capture data, and then owners could drop-off / mail the logger to the relevant agency. Lastly, the idea of “Remote OBD” via a privatized limited-use network specifically implemented to capture transmitted emissions data from vehicles equipped with a dedicated transmitter (Tierney & Kotsakis, 2008). The deployment of these private ‘remote OBD networks’ has proven costly, and cumbersome to the several cities and other large entities which have deployed this type of procedure (Hull et. al., 2006). It is impractical to deploy a dedicated network for emissions compliance to the public at large. To this point the EPA has formed a Remote OBD Working Group to evaluate potential options beyond a dedicated network (Tierney & Kotsakis, 2008).

These three proposals presented in 2008 did not fully predict the path that technology would take. Specifically, the growth and capabilities of modern cellular networks and devices. Wei, Wang, and Liu (2015) suggest that by using existing smartphones and ELM-327 Bluetooth adapters, that emissions data could be collected in real time. While this data could be gathered in real-time, many consumers are concerned with allowing government access to vehicular data in real-time for fear of being monitored and the possible creation of a police state.

Alternatively, Lehmann and Gross (2017) proposed a model to estimate emissions based on driving conditions. This concept is novel because rather than simply reporting what the OBD computer is already monitoring, they proposed to use sensors on a smartphone to estimate emission production based on driving conditions. While novel, this concept required accurate measurement of fuel consumption by the user of the application. This also does not account for various manufacturers, engine and fuel types, possible component failures, nor different tiers of emission regulation.

Hilpert, Thoroe, and Schumann (2011) propose a contrasting proposal. They proposed a solution that rather than being based off estimation as Lehmann and Gross proposed, or being based off of external analyzers as Merkisz, Pielecha, and Gis (2008) proposed that a combination of OBD-II to Bluetooth adapters, a smartphone, and an enterprise information system would provide the ability to again track emissions data in real-time. Their solution is particularly designed to support companies maintaining fleets of vehicles running some form of a transportation network. Considering the corporate nature of that proposed application it is less-likely to run into concerns of government monitoring that other real-time proposals carry.

The literature shows a consistent gap between current emissions procedures, and the use of consumer accessible devices for emissions data collection, which presents an opportunity. While much of the research-field is focused on real-time emissions collection, the current procedures remain in place. However, research shows the combination of a smartphone connected via Bluetooth to the OBD computer to be inevitable. Attempting to overcome public fears about being tracked and monitored are real hurdles to a successful large-scale implementation of real-time emissions data collection. Rather, this study proposes a middle ground. Allow consumers to run the tests themselves, at home or wherever they choose, using their own hardware. Costs could be substantially decreased as the overhead to manage such a program would be a fraction of current programs. Users do not have to fear being tracked as the test is only run when required, much like the current programs. However, the technician collecting emissions data is being replaced by a smartphone and an ELM327 Bluetooth adapter used by a consumer to collect emissions data.

Chapter 3 – Methodology

As suggested by Tierney and Kotsakis (2008) an alternative to the current methodology for emissions compliance needs to be developed. As the literature also has shown, several different approaches have been taken, but the current focus of the industry at large is improving the emissions componentry rather than the technology used to enforce the program. Smart Emissions is a functional artifact that has been designed to meet the requirements of EPA rule No. EPA-420-R-01-015 with the limitations previously discussed in chapter 1, and to meet those needs at greater user convenience and reduced operating costs. Smart Emissions was developed as an Android application designed for commercial use under a separate grant at Weber State University in conjunction with the Marron Institute at New York University. Due to the commercial nature of Smart Emissions, the actual structure of the code written during the creation of the application will not be discussed. Rather the focus of this study is on what any mobile application should be written to do.

Designing Smart Emissions to meet the research questions discussed in Chapter 1 required several distinct areas of research. These areas can be grouped into EPA regulations, OBD communication, and application design. The first step involved researching current EPA guidelines, CARB regulation, and reaching out to the National Center for Automotive Science and Technology at Weber State University which manages the OBD Clearinghouse and designed much of the current testing procedures in conjunction with the EPA working group. Once an understanding of what constituted a valid emissions test was established the second major step was handling OBD communication. Consideration had to be given to the ELM327 Bluetooth adapter being used, the various protocols which are used by vehicles, and the ELM commands utilized to access data from the OBD Computer. Third, effort was expended on the interface of the application itself. Considering this effort is designed to be public-facing rather than simply serve a smaller subset of trained individuals, the application had to be simple, intuitive, secure, and robust. The final step was to design a survey which would accurately measure current public sentiment towards emission testing procedures, and model how the model proposed in the study would be accepted by the public.

Step 1: Understanding Current EPA Guidelines

As the regulations were explored, one of the most important aspects was to determine which elements of an emissions inspection could or could not be conducted remotely via a smartphone and Bluetooth adapter. The current guidelines require the manual inspection of the bulb used to illuminate the MIL. However, this cannot be done via software. Overall when considering the relatively minor nature of this step, the lack of direct correlation to excess emissions production, and the fact that the computer will document whether the light is commanded on or not does not outweigh the potential benefits from the proposed method under study. The proposed solution of this study would mandate an exception to that rule. Additionally, the EPA must provide guidelines for all vehicles which are required to be tested. As previously discussed, an electronically readable version of the vehicle identification number (eVIN) is not guaranteed to be present before model year 2005. This precludes these vehicles from being tested remotely via a smartphone. This restriction does not outweigh the benefits because there is a continually dwindling percentage of the overall fleet of vehicles in use that were produced prior to model year 2005. Also, this phenomenon is not fundamentally different than when the transition from a tailpipe inspection to OBD-II based inspections required both testing procedures to be concurrently available for a time. This process and the shrinking nature of the fleet are both well documented from the previous transition to OBD based emissions inspections (Lyons & McCarthy, 2009).

Overall, the process of an emissions inspection is quite simple, and is discussed at length in Chapter 1 of this study. However, for the sake of completeness Figure 3.1 provides a

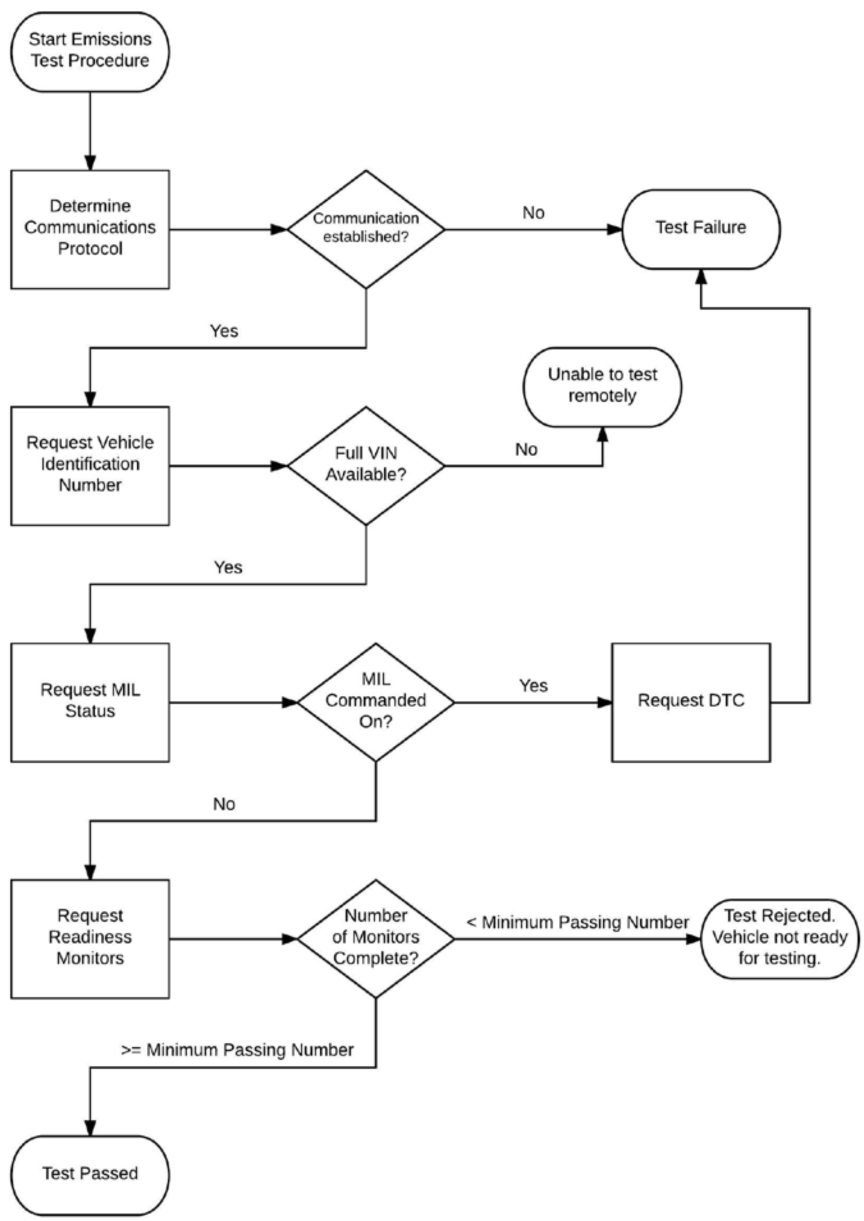


Figure 3.1. Flowchart depicting the process a valid emissions collection procedure must follow after a connector is inserted into the DLC (Sosnowski & Gardetto, 2001).

demonstration for the logic necessary for the application to perform when conducting an emissions test.

Step 2: Establishing OBD Communication

Smart Emissions opted to utilize the Bluetooth standard to interact with an ELM327 compliant Adapter inserted into the DLC of a vehicle. Other possible solutions could be considered such as Wi-Fi or a wired connection. However, due to the significant cost reductions for the adapter when compared to Wi-Fi and the lack of portability and convenience presented with a wired connection, Bluetooth was selected.

In the early years of OBD-II, manufacturers could utilize any protocol they wished from the list in Table 3.1 below. In general manufacturers tended to select one protocol to use across all their offerings. Table 3.1 shows each of the protocols allowed by CARB Title 13, CCR §1968.2(g)(3) along with a listing of the manufacturers that used it most frequently. Essentially, this describes the necessary protocols required to support the range of manufacturers vehicle's operating in the U.S.A. Several of these protocols support various speeds, and in some cases different data widths which adds to the complexity of the proposed solution. Beginning in Model Year (MY) 2008 as part of the EPA's Tier 2 emissions standards, manufacturers were required to use ISO 15765-4 Controller Area Network (CAN) Protocol by CARB Title 13, CCR §1968.2(g)(3.4). Manufacturers had the option to begin implementing this protocol earlier, as soon as MY 2003, but not all did. Having a standardized protocol greatly simplifies testing, debugging, and the toolset required to manage OBD communication, especially as older vehicles begin to age out of the fleet.

Table 1.

Protocol	Manufacturer Usage

ISO 15765-4 Controller Area Network (CAN)	All Manufacturers
SAE J1850-41.6 Pulse Width Modulation (PWM)	Ford
SAE J1850-10.4 Variable Pulse Width (VPW)	GM
ISO 9141	Daimler-Chrysler, Honda, Toyota
Key Word Protocol 2000 / ISO-14230 (KWP)	Most U.S. Imports: Bentley, BMW, Daewoo, GEO, Hyundai, Kia, Subaru, Suzuki

Note. OBD Protocols and Manufacturer Usage

Most of the effort in handling the communications protocol differences is in the firmware of the ELM327 Bluetooth adapter itself. This is due to the need to vary the voltages uniquely for each protocol, use different numbers of pins for different purposes, etc. to meet the demands of the standard. Figure 3.2 shows a prototype adapter. In addition to moderating the signaling itself, there are several variances to how the protocol structures returned data.

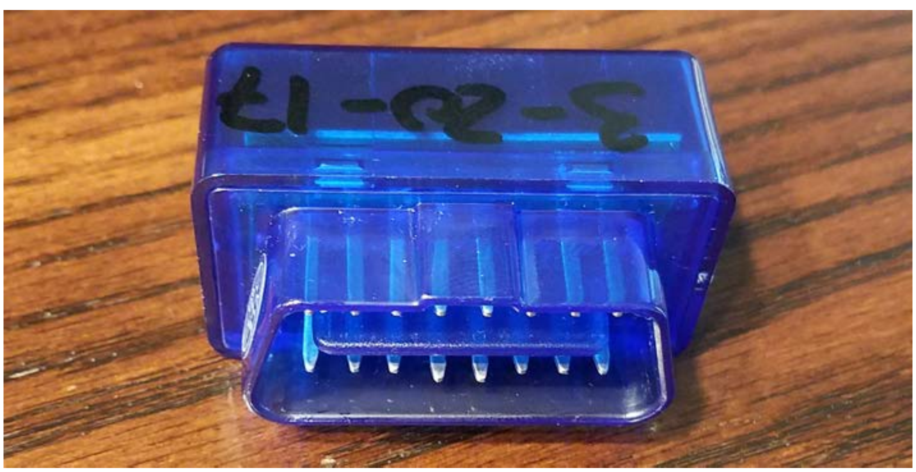


Figure 3.2. a prototype ELM327 Bluetooth compatible adapter.

These adaptations require special-use code for each within the smartphone application itself. The largest difference is apparent with the Content Area Network (CAN) protocol. Other protocols such as Key Word Protocol (KWP), ISO 9141, Variable Pulse Width (VPW), and Pulse Width Modulation (PWM) utilize the pattern of repeating the requesting mode and Paramater ID (PID) by adding 0x40 to the mode and embedding them sequentially at the first bytes of each response, followed by the response number before finally including the data in each response. The CAN protocol does not return the requesting mode and PID encoded in each response as do the other protocols, but rather only in the first response. A typical CAN response will include the length of the response (in hex, counting bytes) and utilizes a "**:**" char to indicate the separation of response number and the beginning of data for that response. A typical CAN response can be seen in Figure 3.3.

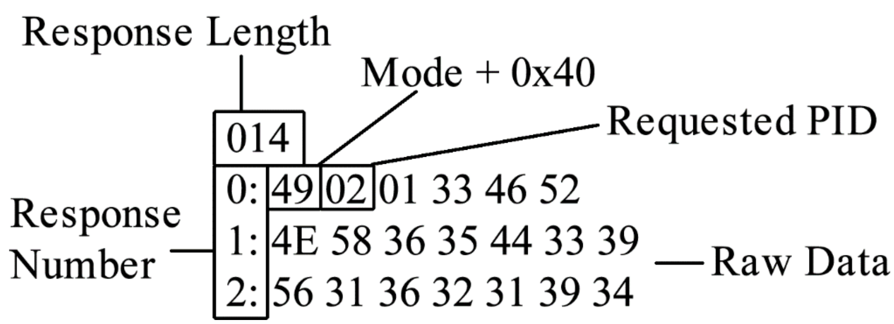


Figure 3.3 Typical response to a request using the CAN protocol, with multiple lines of response.

The ELM command protocol defines the necessary OBD-II communications protocol. This protocol runs on top of the communications protocol, and allows a connected device to communicate with the OBD-II computer. This protocol sends commands as two hex pairs, and is generally broken into two major pieces: mode and PID. Some modes do not require a PID. The ELM OBD-II specification described in SAE J1979 allows for 9 modes, numbered 01 through 0A. Not all modes are required, and manufacturers may define additional modes beyond these standard 9. All micro-controllers also support issuing "00" as a mode which requests the supported modes of the controller. Some commands will also expect additional arguments beyond the mode and PID. As an emissions test steps through the necessary phases, each step represents a command sent to the ELM micro-controller on the adapter. The following sections will discuss each of the necessary commands, and the necessary data interpretations following the diagram represented previously in figure 3.1 as they are fundamental to the validity of the study.

ELM Step 0: Simplify output to be read by software

Prior to the selection of the protocol it is best practice to issue several commands to the ELM controller itself before communicating with the OBD computer. When a command uses “AT” for the mode, this indicates the command is intended for the ELM controller, not the OBD-II computer. First issue the command:

```
AT Z
```

which notifies the ELM controller to reset communications settings to default. Second, issuing

```
AT E0
```

will notify the ELM controller to not ‘echo’ commands back to the requesting device thus placing unexpected data in the output stream. During debugging it is useful to see that the ELM is receiving commands correctly, during production this is unnecessary. Last, notify the ELM controller not to inject line feeds after carriage returns into the output by issuing:

```
AT L0
```

ELM Step 1: Determine communications protocol

The communications protocol is set by issuing the following command:

```
AT SP #
```

Where # is replaced with the selection number of the desired communications protocol. The possible values, and their implications are listed in Table 3.2.

Table 3.2.

Argument (#)	Protocol Selection
0	Automatic Protocol Selection
1	SAE J1859 PWM (41.6k baud)
2	SAE J1859 VPW (10.4k baud)
3	ISO 9141-2 (5 baud initialization, 10.4k baud)
4	ISO 14230-4 / KWP 2000 (5 baud initialization, 10.4k baud)
5	ISO 14230-4 / KWP 2000 (fast initialization, 10.4k baud)
6	ISO 15765-4 CAN (11 bit ID, 500k baud)
7	ISO 15765-4 CAN (29 bit ID, 500k baud)
8	ISO 15765-4 CAN (11 bit ID, 250k baud)
9	ISO 15765-4 CAN (29 bit ID, 250k baud)

Note. ELM327 OBD Protocols Selection

Setting the communications protocol to AUTO allows the ELM micro-controller to communicate with whichever protocol is best suited to the vehicle under examination, rather than being restricted to a specific version. Overall, this provides greater flexibility and larger vehicle coverage, though the result is more work in the smartphone application because it now needs to support all of these protocols.

ELM Step 2: Request VIN

Every vehicle is uniquely identified by a 17 character identification number known as the VIN. This value is used to track vehicles performance with emissions tests, as it remains with the vehicle over time, unlike a license plate in the US which is limited to a single owner. The ELM command to request VIN data is under mode 09, PID 01. This request looks like this:

```
09 02
```

The OBD computer responds with the VIN number encoded in ASCII. Each response will also include the original mode and command to which it is responding. It will also note which response it is as many requests will require more data than can be encoded in a single transmission. The encoded requesting mode (mode + 0x40) and PID are the first two bytes of an ELM response, and are at first two bytes of each response when using a protocol other than CAN. This way the issuing command can be differentiated from other data. The response is then interpreted according to the ASCII standard. Figure 3.4 shows sample output when requested over the VPW communications

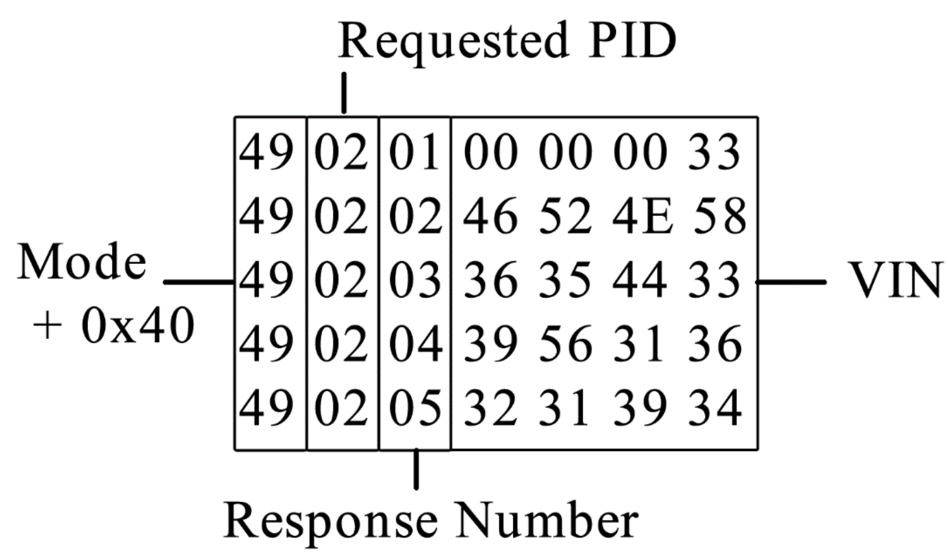


Figure 3.3 Mode 09 PID 02 “09 02” results in a 35 byte result-set when the overhead from VPW is included. First is the requesting mode, then the requesting PID, followed by the response number and finally the requested VIN data. This diagram demonstrates the positioning of each piece of data.

protocol and the positioning of the data in the response. The VIN data itself is encoded ASCII, so a simple ASCII interpretation of the raw hex values is all that is needed to convert the value to the expected format. Figure 3.3’s data would result in the VIN 3FRNX65D39V162194.

ELM Step 3: Request MIL, Monitor Status, and DTC Count

Arguably this step could be considered the "heart of an emissions test." The status of the MIL, current statuses of all the required emissions monitors, as well as the count of currently set DTCs are all returned with a single request. This data is requested under mode 01, PID 01. Mode 01 allows access to real-time vehicle data. It is issued by sending the bytes:

```
01 01
```

the expected response is 4 bytes, labeled as A, B, C, and D. Byte A contains the status of the MIL light in the most significant Bit (A7). The remaining 7 bits of "Byte A" contain a count for the number of currently set DTCs. These DTCs are only required to be requested if the MIL is commanded on via a 1 being present in that MIL bit. Byte B contains the ignition type, as well as the first 3 monitors, and their status. Figure 3.5 shows the meaning of each bit in Bytes A & B.

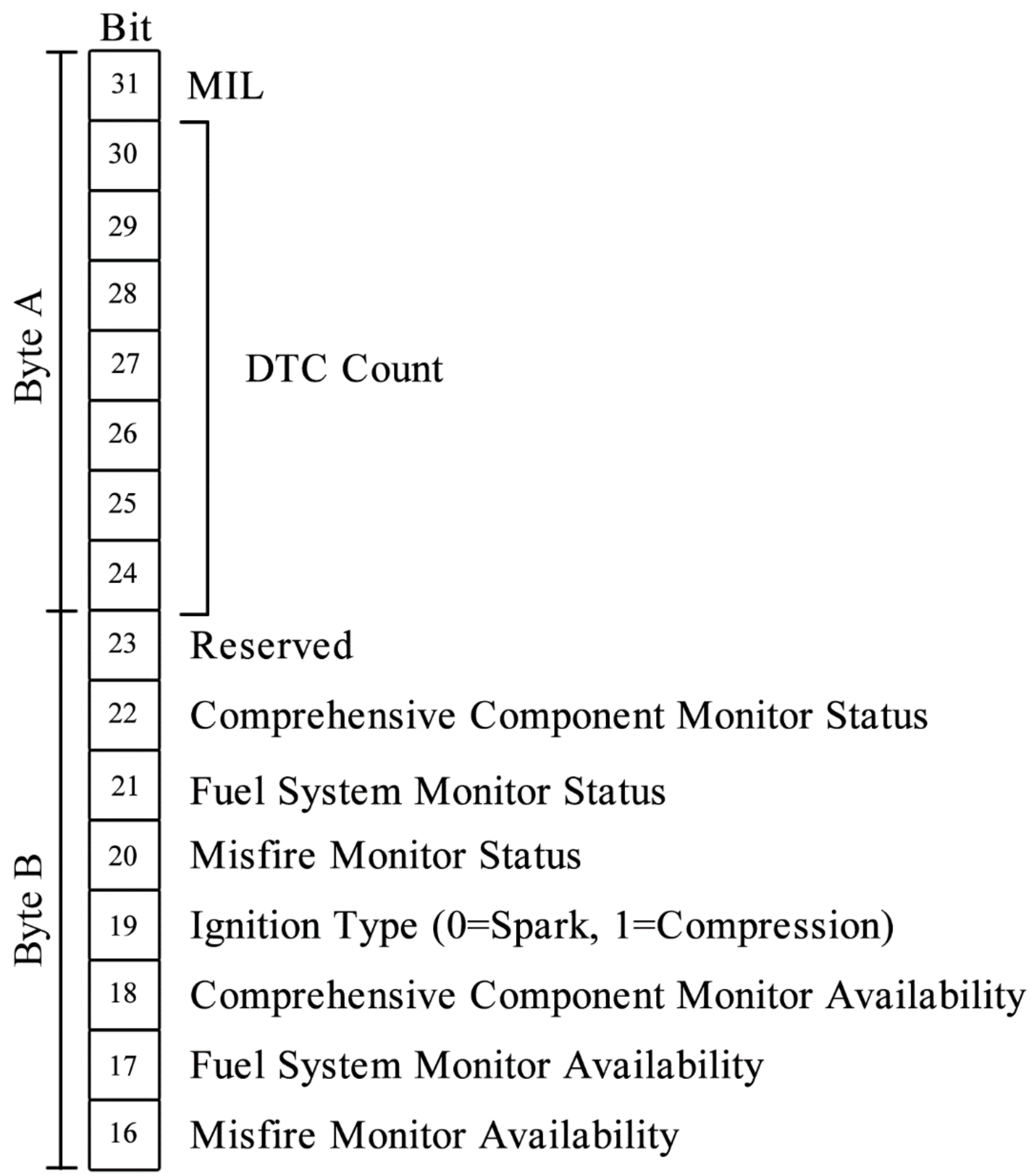


Figure 3.5 Mode 01 PID 01 “01 01” results in a 4 byte result-set with each byte labeled A, B, C, & D. The above diagram shows how to interpret those results in spark ignition engines for Bytes A & B.

Bytes C and D contain the remaining monitors, and use a different key depending on ignition source. Figure 3.6 shows the decoding key for the remaining monitors on a spark ignition engine.

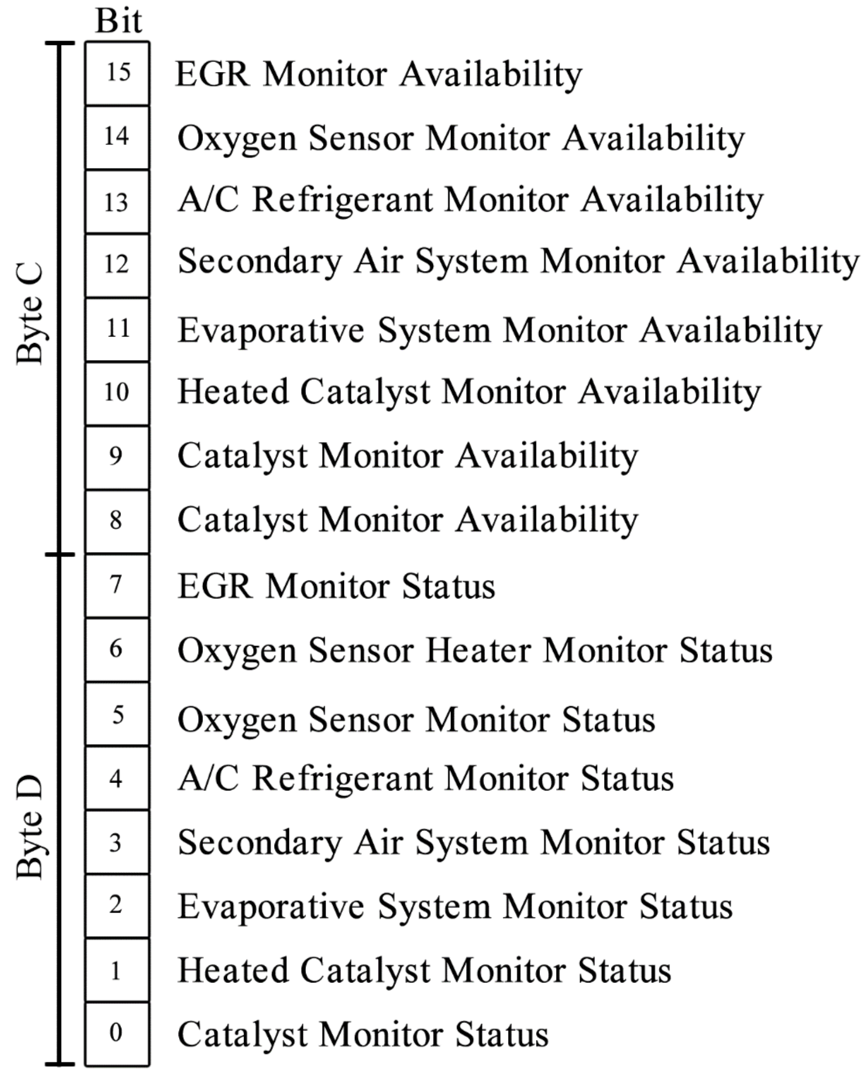


Figure 3.6 Mode 01 PID 01 "01 01" results in a 4 byte result-set with each byte labeled A, B, C, & D. The above diagram shows how to interpret those results in spark ignition engines for Bytes C & D.

Vehicles which are utilizing ISO 15765-4 (CAN) as their protocol require one additional step before requesting this data. These vehicles may have multiple ECU's on board (i.e. engine control, transmission, etc.). In a content-area-network, all capable devices respond as the request is received. The order of responding devices also is not guaranteed, but identifying headers accompany the response so that the correct ECU may be determined. On an ELM conforming chip a simple AT CRA command can be issued to tell the device to filter responses to a specific ECU. Otherwise the application must check the responding ECU to ensure it is the Engine Control Module which contains emissions data. In 11-bit CAN, the correct identifier for the ECM is 7E8. In 29-bit CAN, the correct identifier to use is 18 DA F1 10. The complete command to be issued is:

```
AT CRA 7E8 or AT CRA 18 DA F1 10
```

Once the data has been returned it is interpreted as described. Each monitor is checked, and the number of monitors in the “Not Ready” state are counted. If an insufficient number of monitors are set, and the MIL is commanded *OFF* the vehicle is rejected for testing because the vehicle doesn’t yet know the state of all required componentry. The user should be informed at this point that they need to drive the vehicle through varying conditions so that each monitor is exercised. Most owner’s manuals contain a suggested driving procedure to meet this need.

ELM Step 4: Request DTCs

If the MIL is commanded *ON*, the vehicle will fail the emissions inspection. Before failing the vehicle, EPA guidelines require that the DTCs which represent the failing component must be requested and reported. If the MIL is commanded *OFF* this step should be skipped, as any codes that are set are considered ‘transient’ and may correct themselves. DTC’s are accessed as mode 03 data, by issuing the command:

```
03
```

Note the lack of a PID in this request. The OBD response length will vary based on the number of DTCs currently set, though SAE J1979 requires a minimum of 6 bytes for the response. The interpretation of these codes is straight forward. Each code is one byte in length. By looking at the first hex digit, the category of response is determined. Table 3.3 contains the chart used in this process. Once the first digit is replaced by the necessary prefix, the remaining 3 hex digits are appended to the prefix. For example, if the response was something like 43 01 33 00 00 00 00, it would be interpreted by looking at the first digit which is a “0”. This “0” is then replaced by “P0” and the remainder of the byte is appended to the interpreted code. This would result in “P0133”.

Table 3.3.

Digit	Replacement	Trouble category and definition source
0	P0	Powertrain Codes: SAE Defined
1	P1	Powertrain Codes: Manufacturer Defined
2	P2	Powertrain Codes: SAE Defined
3	P3	Powertrain Codes: Jointly Defined
4	C0	Chassis Codes: SAE Defined
5	C1	Chassis Codes: Manufacturer Defined
6	C2	Chassis Codes: Manufacturer Defined
7	C3	Chassis Codes: Reserved For Future Use
8	B0	Body Codes: SAE Defined
9	B1	Body Codes: Manufacture Defined
A	B2	Body Codes: Manufacture Defined
B	B3	Body Codes: Reserved For Future Use
C	U0	Network Codes: SAE Defined
D	U1	Network Codes: Manufacturer Defined
E	U2	Network Codes: Manufacturer Defined
F	U3	Network Codes: Reserved For Future Use

Note. Diagnostic trouble code interpretation

ELM Step 5: Interpreting Results

As previously discussed an emissions inspection has three possible outcomes: Failure, Rejection, and Success. Failure comes anytime the MIL is commanded on. Rejection happens if an insufficient number of monitors have run, and success is anything that did not result in failure or rejection. Some states, such as Oregon, do not allow results to be given to the user. Rather, they require the user to find out success, failure, or rejection directly through a state agency's website after tests have been completed. Because of this restriction, Smart Emissions required the ability to calculate the results, but only show them to some end users based on their zip-code which is self-reported.

Step 3: Designing the application

Designing something for public consumption is much more difficult than designing something just as a proof of concept. One of the cornerstones of Smart Emissions was that it needed to be intuitive and simple enough that anyone could use the app without issue. It also needed to be secure and robust. Part of meeting these goals was automating as much of the existing process as possible and eliminating extra steps for the user. The goal being no more than two steps to begin the test. This is a pretty stark contrast to current testing programs, some of which ask a dozen or more questions before beginning the inspection.

Beginning a test

The initial screen a user encounters is a demonstration of the consolidation of the emissions process. Figure 3.7 shows this screen. To conduct the inspection, the application only needs two things: a Bluetooth connection to an OBD-II adapter, and the user's zip code. The zip code allows the application to target the correct set of requirements and informs the application where to send the completed data once the test is finished. When the user enters a zip code, it is checked against a remote database of participating counties and states. This also returns the testing requirements belonging to the county which the user desires to register their vehicle with.

The second user-facing requirement was that connecting a Bluetooth device should be simple, painless, and as automatic as possible. To complete this goal, Smart Emissions automatically goes into a discovery mode searching for nearby Bluetooth devices. Each of the devices in range is noted, and the application looks for the device with the strongest signal strength and appropriately named ‘OBDII’. Nearly all OBDII Bluetooth adapters share this name to simplify connection with any of the apps on the app store. This process continues until a connection is made or the device attempts too many unsuccessful searches. If the app is not able to find an eligible adapter, the application will prompt the user to plug in the adapter to the vehicle. It will also provide a link to a website which will help the user find the DLC of their vehicle.

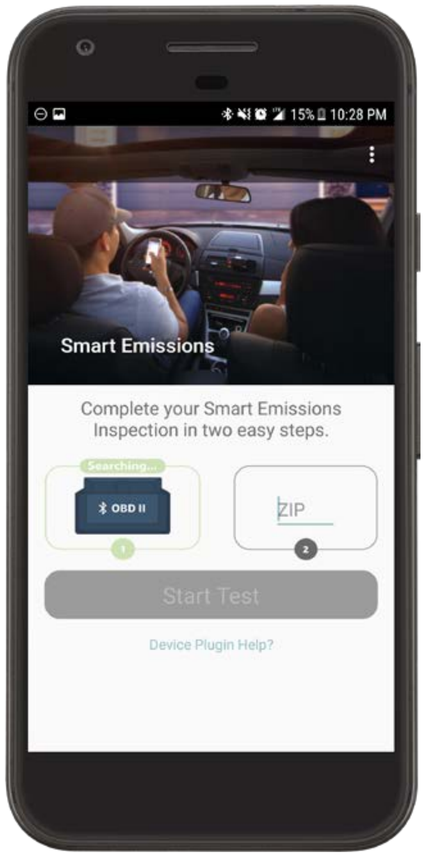


Figure 3.7 The Initial screen of Smart Emissions. Users must self-report their Zip Code. The device will automatically scan for and connect to an active OBDII Bluetooth adapter.

Running a test

Once the user presses on the "Start Test" button they are immediately taken to the "Testing" screen as shown in Figure 3.8. This test invokes the OBD-II test by following the ELM procedure as shown in Figure 3.1, and discussed at length in Step 2: Establishing OBD Communication.

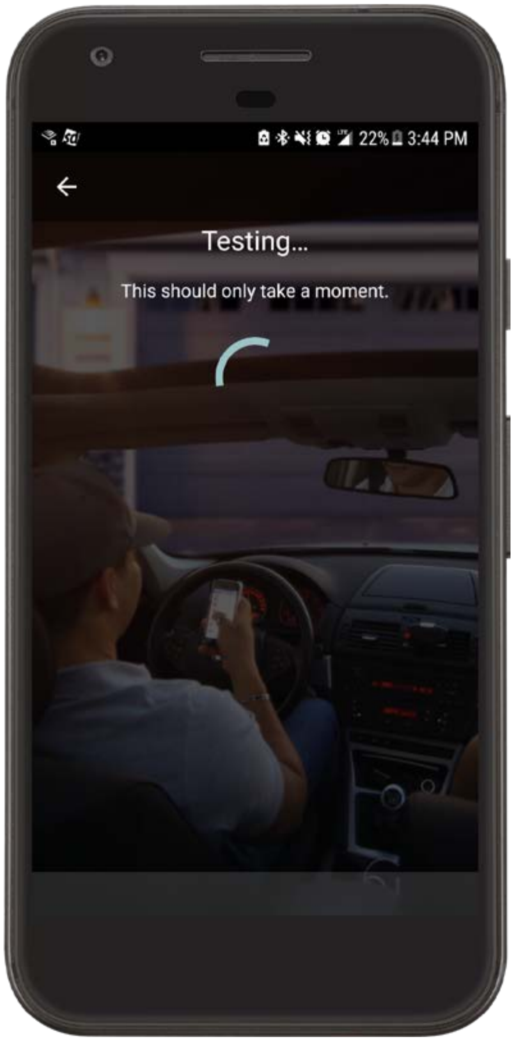


Figure 3.8 The testing screen shows the user the test is ongoing. The bottom of the screen will also load the model year, vin, and make of the vehicle being tested.

Testing results

After a successful emissions inspection, the results are correlated. In states where it is legal to show the inspection results in the application, the user will see one of the three screens shown in Figure 3.9. In a successful inspection, the user will be given a link that they can use which will take them directly to their registration authority, where they can complete their registration online if they choose. If the vehicle fails inspection, the user is notified of this and given a button which will help them find the nearest mechanic who can tell them what is wrong and help them correct the deficiency. Lastly, if their vehicle is not ready to test they will be linked to a website which will explain what that means and how to find the necessary drive cycle and exercise the monitors. Most consumers are unaware of the details of an emissions inspection or how to drive the vehicle to exercise all monitors. In the case of a state where the results cannot be shown, the user is given a generic message that the test is complete, and a button which will link them to the official site where they can view their results and complete their registration.

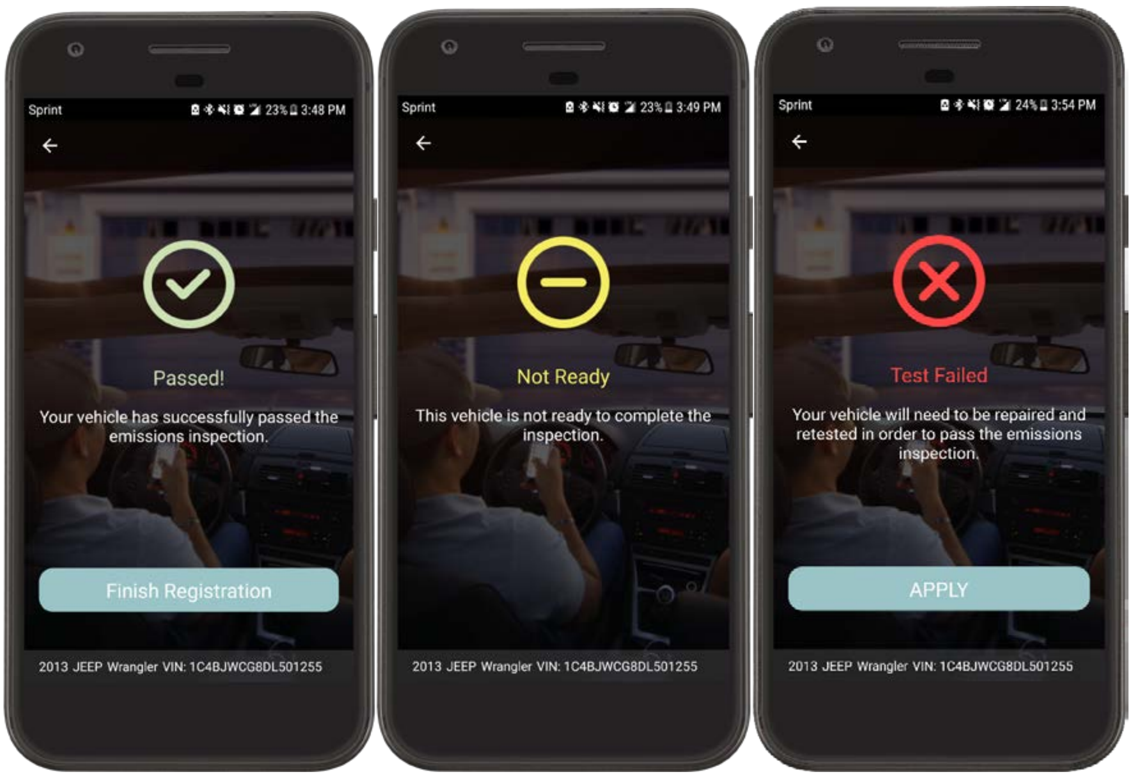


Figure 3.9 There are three possible outcomes to an inspection. Passing, Failure, or Rejection.

Step 4: Validating Application Performance

Developing the application was only the first step though towards exploring using consumer-accessible devices in an emissions test. This study explored the efficacy of the application in conducting emissions tests. To accomplish this goal, study participants were asked to volunteer their vehicles model year 2005 and newer to have an emissions inspection run twice. Once using a currently certified device, a Systech NYUVIP2 Emissions Station, on loan from the State of New York Division of Motor Vehicles (NY DMV) to the National Center for Automotive Excellence at Weber State University. This is the same type of machine used to run official safety and emissions within the State of New York. The second test was then run on the same vehicles using Smart Emissions. For the purposes of this study, the tests on the Systech device were run in the 'training mode' setting so as to not create erroneous test records in New York's official databases. In 'Training Mode' the testing procedures are the same, the only difference is certificates are water marked as 'Training' and the results are not distributed as official to the New York Division of Motor Vehicles. A sample certificate is shown as Appendix A. Also, the Systech machine is designed to run an integrated safety inspection as required by the laws of the State of New York which is outside the scope of this study. The researcher provided the same answers to the safety portion of the inspection process, essentially officially passing each vehicle's safety components to isolate the test to only emission procedures and data.

Validation of the proposed solution is dependent upon both systems reporting the same results consistently in each: the VIN, readiness monitors, MIL status, and DTC codes (if any). As each test was conducted via Smart Emissions, the results were then stored in a remote database accessible by the researcher. As tests were run using the Systech machine were recorded as printed compliance forms, in the traditionally manner. The data was then recorded digitally.

Step 5: Understanding Current and Future Emissions Perceptions

The purpose of this study is to discover a simple, secure, more convenient, and cost-effective way to run emissions programs. The need to control vehicle emissions is not going away, so finding ways to enhance public participation in the program is paramount to continued long-term environmental success. At the root of this is understanding public sentiment towards the current procedures, and towards any potential replacement procedures. To meet this end, study participants were given a 15 question survey. The survey was structured into three major sections: current testing procedures, future testing procedures, and demographics. This study was approved by the Human Subjects Institutional Review Board at Regis University, and Weber State University where the study was conducted.

Current testing procedures

Before participants were asked questions about their perception of emissions procedures, a brief summary of the emissions procedure in Utah as experienced by a consumer was given. Because the survey was administered in Utah, it was customized with relevant data to that state. Participants were given the following paragraph:

> As a reminder, the general process you follow now is when you receive a reminder card in the mail to take your car to an emissions inspection location. The technician at the location will plug their computer into your car, which runs the emissions check. You pay the technician a fee (the average fee is $25 in Utah) and they send your results to the state.

Afterwards, the survey asked participants the following questions: First, they were given a Likert scale of 1 to 5 ranging from inconvenient to convenient to select from while considering the question: “Do you find the current emissions process:”. Next they were asked “Do you find it reassuring to have a certified technician perform your emissions inspection?” Participants were then asked if they would rather pay $25 and have a mechanic conduct the inspection, or pay $5 and do the work themselves. Next participants were asked if they feel current emissions procedures help solve the real air problems that affect Utah currently. Lastly, a box for additional thoughts, comments, or concerns on current testing procedures was provided. A full copy of the survey can be found in Appendix B.

Future Emissions Procedures

After considering current emissions standards, participants were asked to consider a potential change to emissions testing procedures. They were given the following summary of the study:

> Rather than taking your car to a mechanic, you would use a Bluetooth adapter which you purchased yourself (for a small fee) and a smart device (phone or tablet) which you already own. You would plug the adapter into the DLC (OBD-II) port on your car, and use a free app to conduct the inspection. The app would ask you for your zip code, and then would do everything else needed to run the test autonomously. This inspection can be conducted from any location.

The first question participants encountered was an image the Bluetooth ELM327 adapter shown in Figure 3.2 accompanied by the question “Would you feel comfortable plugging an adapter like the above into your car?” Participants were also asked what they would be willing to pay for a Bluetooth adapter needed to conduct tests in the proposed solution. Next participants were asked to rate their comfort in using a smartphone. Participants were also asked if they owned a smartphone or tablet, and which OS the device uses. Participants were also asked which procedure they would be more likely to use, the proposed solution or the current procedure. Participants were also asked directly if they had any specific concerns about conducting an emissions exam on their own before being given a spot for final comments.

Demographics

The last section of the survey asked participants basic demographic information. Participants were asked to indicate their age from a list of 5-year bands. Participants were also asked to provide their gender. Both question gave the option to decline to answer.

Chapter 4 – Results

Smart Emissions was developed as an Android application to provide emissions tests conforming to EPA rule EPA420-R-01-015. The purpose of the quantitative portion of this mixed-methods study was to compare Smart Emissions as a sample of using consumer accessible mobile devices to conduct emissions inspections against the currently certified methodology. This was accomplished by running a random sampling of vehicles through both the Smart Emissions Android application and a Systech NYUVIP2 emissions station. The first step was determining the needed number of vehicles. Chow, Shao, and Wang, (2008) provided the formula used to calculate the sample size when comparing a new proportion p against a reference value p_0. The new proportion p is the calculated result of the emissions test by the Smart Emissions application. The reference value, p_0 is the calculated result of the NYUVIP2 Emissions Station. The formula provides the sample size n as

$$n = p_0(1 - p_0)\left(\frac{z_{1-\alpha} + z_{1-\beta}\sqrt{\frac{p(1-p)}{\left(p_0(1-p_0)\right)}}}{p - p_0}\right)$$

where n is the sample size, p_0 is the comparison value α is Type I error, β is Type II error (meaning 1- β is the power; Chow, Shao, & Wang, 2008, p. 85). When calculating the sample size to be used in the study, the power was set at 0.92, the true proportion was set to 0.95, the null hypothesis was set to 0.99999 and the Type I error rate was 1%. This resulted in a sample size of 40 vehicles that needed to be tested.

Quantitative Data

For the study, 40 vehicles were tested using first the Smart Emissions application, and then the NYUVIP2 Emissions Station. The vehicles were pulled from a convenience sample of vehicles owned and volunteered by students, employees, and departments of Weber State University. Under New York state emissions policy, a vehicle is considered “failing” even if the vehicle is in a not-ready state, resulting in a test result of failing or pass only. Smart Emissions follows EPA guidelines directly, and supports all three allowable results. EPA regulations were applied to the New York result set, and putting vehicles in the “fail” category when the MIL was commanded *ON*. If vehicles had more than the allowed number of monitors for their model year, and the MIL was commanded *OFF* they were considered as “not ready” for purposes of the study. Table 4.1 provides a breakdown of the test results, by final result, on these vehicles in aggregate.

Table 4.1.

Result	Smart Emissions (p)	NYUVIP2 (p_0)
Pass	23	23
Not Ready	13	13
Fail	4	4
Total	40	40

Note. Emissions Test Study Results

Qualitative Data

Along with the quantitative portion of this research, a qualitative inquiry was used to assess the perception of survey participants regarding current emissions procedures along with the proposed solution presented by Smart Emissions. The data was collected by polling the owners of vehicles used in the test, and an additional random sample of adults at least 18 years of age and older recruited through social media. Every question was allowed to be optional per Institutional Review Board guidelines. In total there were 115 survey participants. Of these participants, 44.3 % were male, and 52.2% were female with 3.5% opting to not disclose their gender. Table 4.3 presents the gender data of the survey participants. These participants varied in age from 18 to 55+. Exact ages were not gathered, but a wide variety of ages can be seen among the participants. Table 4.3 shows a summary of the demographics of survey participants. These demographics were self-reported by the survey participants.

Table 4.2.

Gender	Responses (percentage)
Male	51 (44.3%)
Female	60 (52.2%)
Not disclosed	4 (3.5%)

Note. Survey participant gender demographics

Table 4.3.

Age	Responses (percentage)
18-20	2 (1.8%)
20-25	15 (13.2%)
25-30	10 (8.8%)
30-35	28 (24.6%)
35-40	18 (15.8%)
45-50	10 (8.8%)
50+	30 (26.3%)
Age not disclosed	1 (0.9%)

Note. Survey participant age demographics

The survey itself was broken down into three major sections: Current Emissions Procedures, Future Emissions Procedures, and Demographics. As described in chapter 3, each section began with a description of the procedure that belonged to it. Because the study was conducted at Weber State University, the survey was written to reflect current emissions procedures, and adherence to the laws and ordinances of the State of Utah. After reading the current emissions procedures for the State of Utah, participants were first asked to rate their perception of convenience when using the current emissions procedures. They were given a Likert scale from 1 to 5 with 1 being Inconvenient and 5 being Convenient. Participant responses can be seen in Figure 4.1.

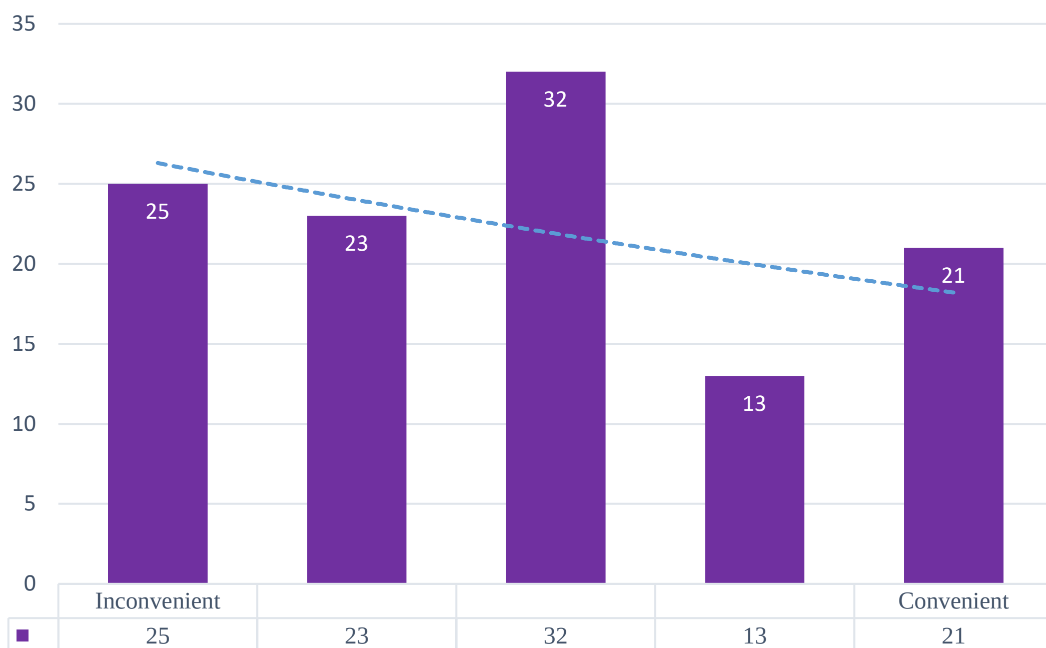
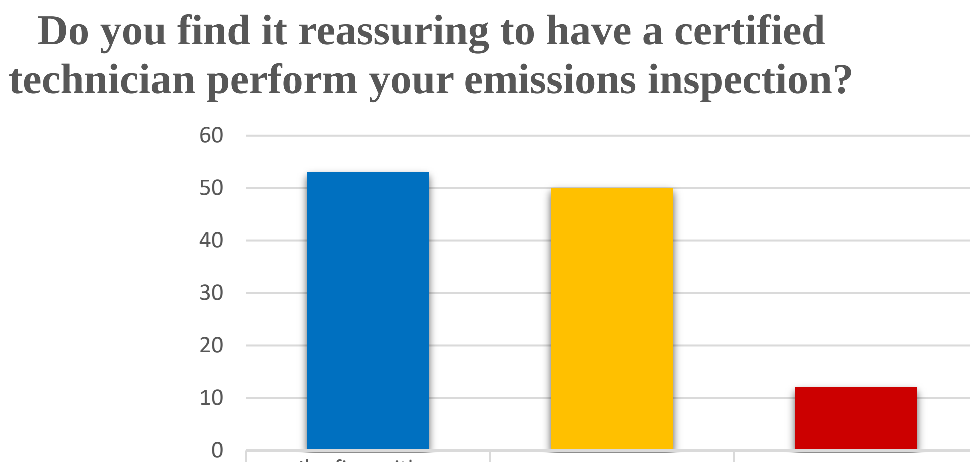


Figure 4.1 Participants rated their feeling towards the current emissions process on a Likert scale from Inconvenient through Convenient. 114 Responses were recorded.

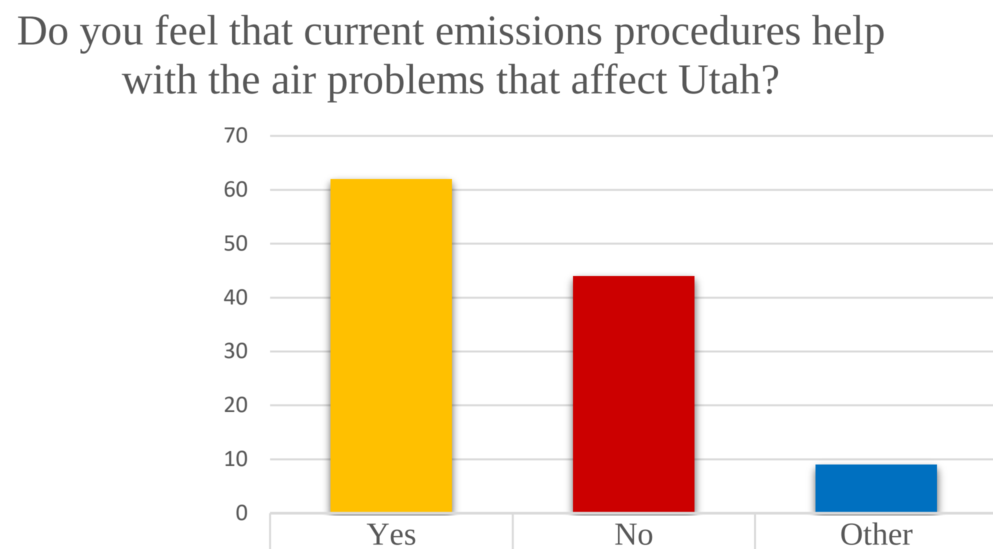
The second question attempted to understand whether the public finds it reassuring to use a certified technician to perform the inspection. Under current regulations in the state of Utah, a technician must be certified by the county where the test is performed, and possess a current I/M Permit from that county. Figure 4.2 presents the data gathered from this question.



	I'm fine with a mechanic, or doing it myself	Yes	No
Do you find it reassuring to have a certified technician perform your emissions inspection?	53	50	12

Figure 4.2 Participants answered the question "Do you find it reassuring to have a certified technician perform your emissions inspection?" There were 115 responses.

Emissions are a common topic of discussion in Utah due to a problem effecting the Wasatch Front known as an inversion (Malek, Davis, Martin, & Silva, 2006). Essentially, an inversion is where cold air and pollutants are trapped in the valleys due to the geography of the area and produce a visible haze because of the poor air quality. Inversions happen often in the winter, where the effects are both visually un-appealing, and dangerous to everyone, but especially to individuals with certain medical conditions (Malek et al., 2006). Because of this participants were asked whether they felt current emissions procedures were helping solve the air problems that affect Utah. Participants could select, Yes, No, or type in their own comments in a free-form ‘Other’ field. Sixty-two participants responded yes, 44 responded no, and nine respondents chose to enter their own comments under ‘Other.’ Six of the nine ‘Other’ comments conveyed a general “Don’t Know” or similar-type statement.



	Yes	No	Other
Do you feel that current emissions procedures help with the air problems that affect Utah?	62	44	9

Figure 4.3 Participants answered the question “Do you feel that current emissions procedures help with the air problems that affect Utah?” There were 115 responses.

For the last question in ‘Current Emissions Procedure’ section, participants were given an opportunity to offer any other comments or concern on the current program. Fourty-two responses were collected, after discarding 16 comments of ‘no’. Fifty percent of the free-form comments noted in some form or another that current procedures are not convenient. Other general themes emerged that the emissions program as it is, is not nearly effective enough, or that they were leery of mechanics in general, or that they didn’t understand what the fees charged were for. For example, along the theme of a program that is not effective enough, one respondent noted “Seems like despite emissions tests terrible offenders are out there still”. Another respondent noted, “Some cars get problems that just after the tests for the year are run then the car is driven for nearly a year producing crap that we don't want in the air”. Still another respondent, noting a distrust of mechanics stated “I have a general distrust for auto mechanics. In the case of an emissions test it is a computer doing the work anyways, so I don’t know that a certified mechanic lends to a better result.”

The last remaining section to be reported was the perception of the public on the “Future Emissions Proposal”. As described in Chapter 3, participants were given a description of the procedure that would be used if Smart Emissions was approved for use in their area. The first area of interest was assessing how comfortable the public would be in plugging an adapter such as the one shown in Figure 3.2 into the DLC port on their vehicle. Participants were shown a photograph of a DLC port, along with the Bluetooth adapter so that they could see the full scope of what would be required. Figure 4.4 shows that 91% (105) of respondents felt they would be comfortable plugging the dongle into their car.

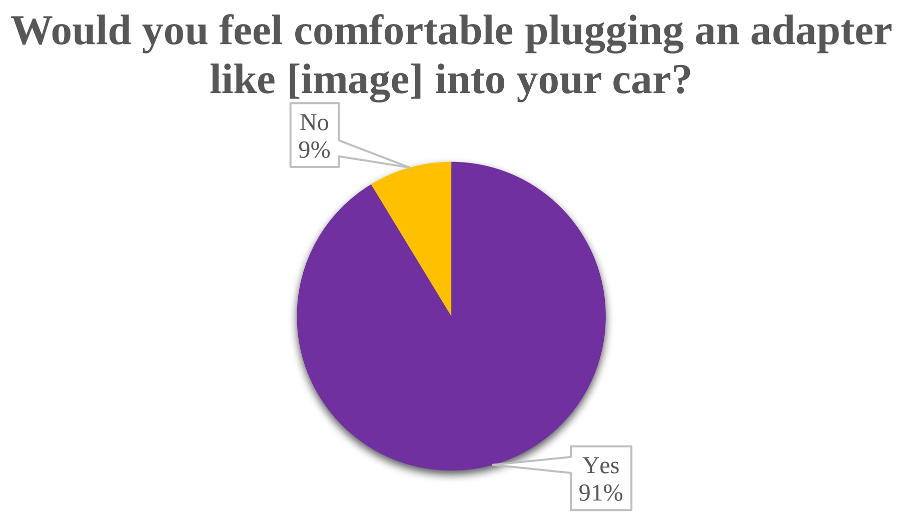
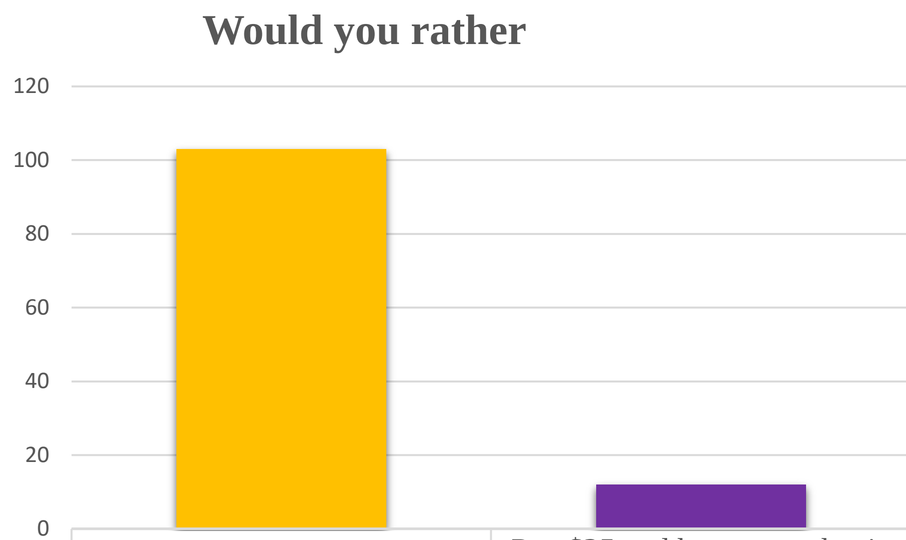


Figure 4.4 115 Respondents answered the question "Would you feel comfortable plugging an adapter like [image] into your car?" The [image] can be seen in Figure 3.2.

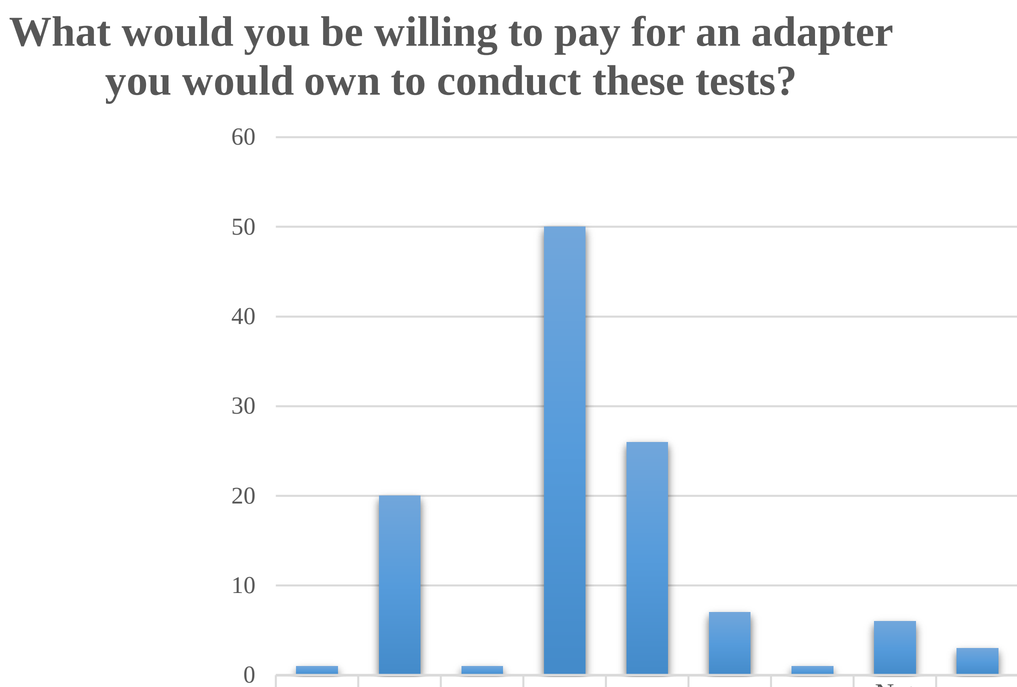
After gauging the comfort level of participants in attaching the Bluetooth adapter to their vehicle, they were asked if they would prefer to do this test on their own or continue to have a mechanic conduct the inspection at an approved location. One hundred and three respondents preferred to do this test on their own, with the remaining opting to use a mechanic. The full results can be seen in Figure 4.5.



	Pay $5 and do the inspection myself at a time and location convenient to you.	Pay $25 and have a mechanic conduct the inspection at an approved location during business hours
Would you rather	103	12

Figure 4.5 Participants answered whether they preferred to pay $25 and have a mechanic conduct an inspection at an approved location during business hours, or if they preferred to pay $5 and do the inspection on their own at a time and location convenient to them. There were 115 responses.

Of primary concern in this new procedure was whether or not the public would be willing to purchase a Bluetooth adapter for use with this system. Under the current procedures, no consumer-accessible equipment is required as the inspection station maintains their own equipment. Participants were asked what, if anything, they would be willing to pay for one of these Bluetooth adapters. Participants were given several price points to choose from, or they could also enter their own price point. Taking all of the responses together, participants were willing to purchase an adapter for an average price of $16.00. Six participants were unwilling to purchase an adapter, and three others entered a non-numeric answer. One respondent noted “If it’s a one-time use then less < $10. Multiple use then more.”



	$50	$30	$20	$15	$10	$8	$5	Not willing	Other
What would you be willing to pay for an adapter you would own to conduct these tests?	1	20	1	50	26	7	1	6	3

Figure 4.6 Participants were asked what they would be willing to spend on an adapter they would own to conduct emissions tests. 115 responses were recorded.

Beyond the primary concerns of if consumers are willing to use an adapter on their own and purchase one, consideration must be given to the consumer-equipment which would be communicating with the adapter to retrieve test results. All 115 participants indicated that they owned their own smartphone or tablet. This consideration extends beyond just the equipment. When evaluating the potential for proposed solution, the user’s ability to use applications on their smart device becomes paramount. This is because using the Smart Emissions application will be similar to using other applications. Some assumptions can be made then based on the user's comfort in using a smartphone in general. If the user is not already comfortable using a smartphone application, there is a strong likelihood Smart Emissions would not be a great fit for that individual. One hundred and fifteen participants were asked whether they felt comfortable using a smartphone. A substantial 111 respondents said "yes", 3 responded "somewhat", and 1 responded "no." Figure 4.7 demonstrates the relationship among these responses.

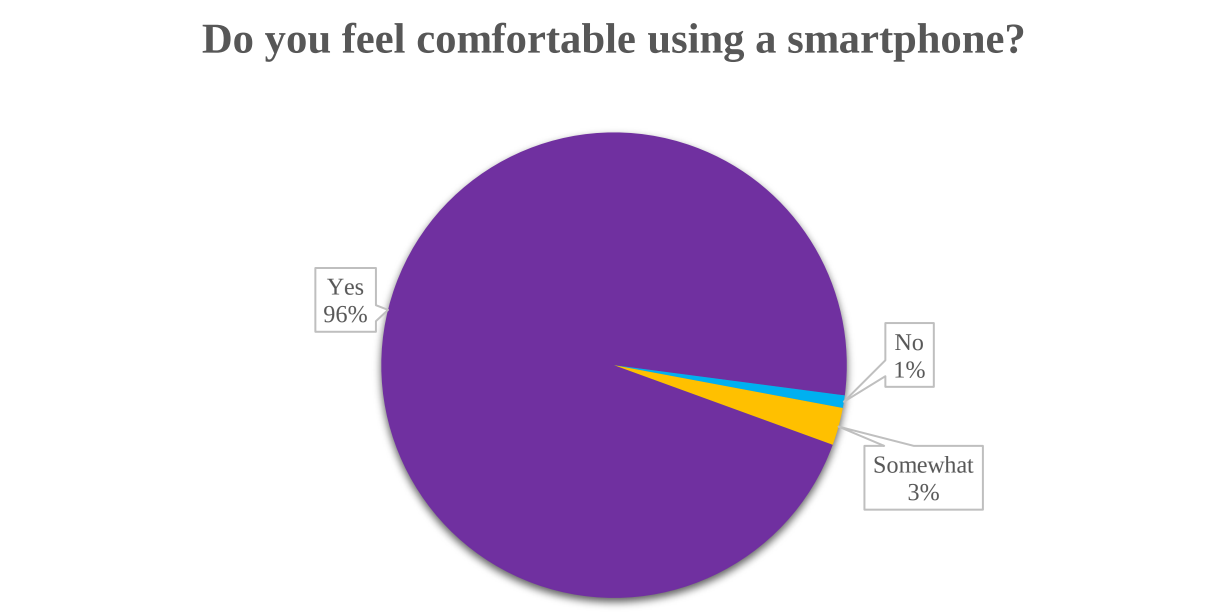


Figure 4.7 115 Respondents were asked if they feel comfortable using a smartphone.

Consideration must also be given to what operating systems are in use among the general population, and which should then be supported to maximize the reach of the application. Among the 115 respondents, there was a slight preference for the Android operating system, followed closely by iOS. A small percentage used devices running a Windows-based operating system. Two respondents noted they owned multiple devices, with multiple operating systems. Figure 4.8 demonstrates the distribution of these operating systems among these participants.

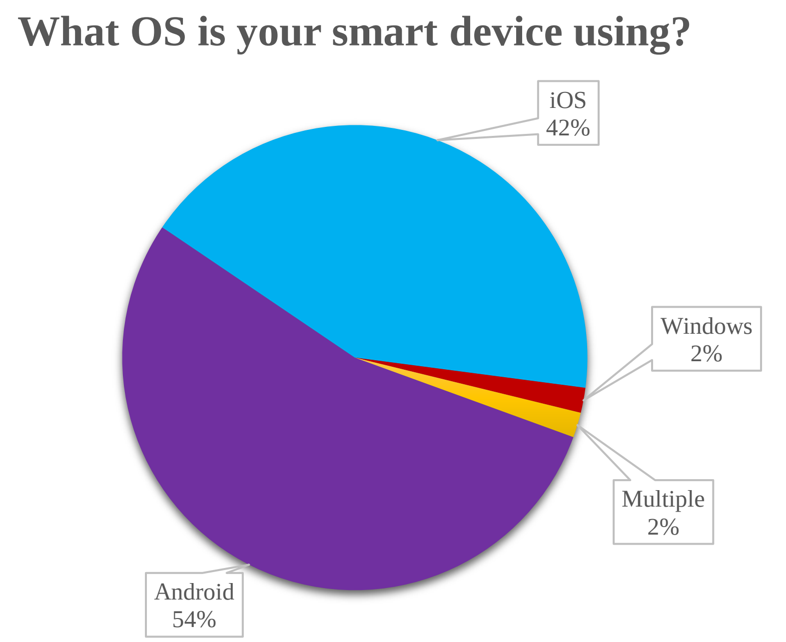


Figure 4.8 115 Respondents were asked what OS their smart devices are running.

For the final question, respondents were asked to consider both the current procedure involving visiting a certified inspection station, and to consider the proposed solution and to then make a decision about which method they felt they would be more likely to use. Of the 115 responses to this question, 82% (94 participants) felt they would be more likely to conduct the tests on their own using a smart phone if they were allowed. Nine percent of participants would likely continue to visit an inspection station, while the remaining 9% felt no strong affinity to either option. Figure 4.9 shows the aggregated data.

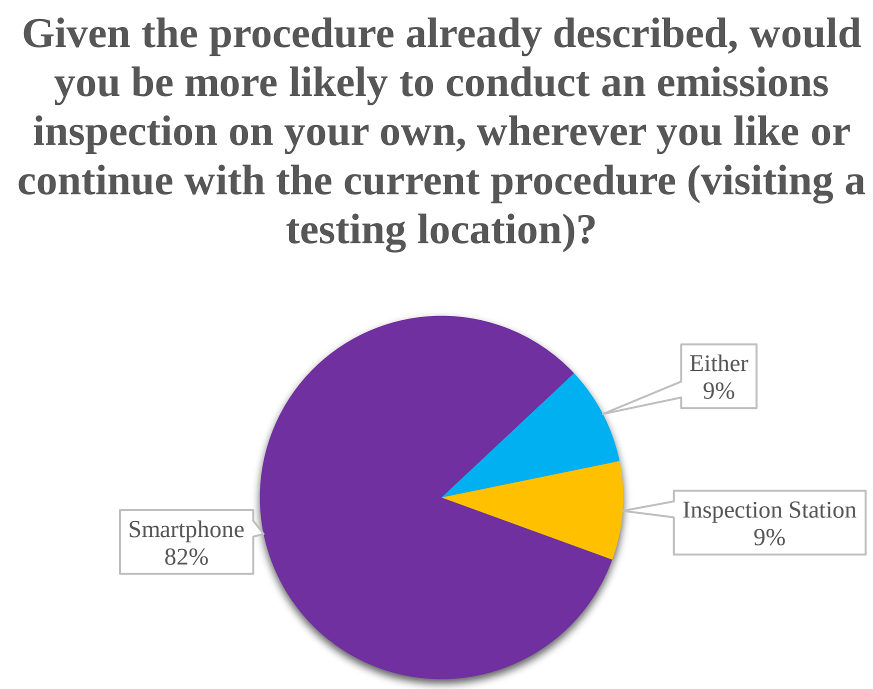


Figure 4.9 115 Respondents were asked to consider the current emissions procedure, and the new procedure described to them. Considering both of those options, respondents chose which they would likely use.

Chapter 5 – Analysis and Conclusions

Analyzing the data from this research study allows several key conclusions to be drawn in response to the original research questions proposed by the study. Specifically, this study sought to answer three questions. First, how Android-based mobile devices can be used to access vehicle emissions data from the OBD computer. Second, how does using existing consumer-hardware simplify emissions programs and effect the costs of running them? Third, how using mobile devices to conduct in-home OBD-II does based emissions tests impacts public-perception of emissions testing programs. Additionally, a careful analysis of the data presented in Chapter 4 brings two major themes to light. First, a mobile phone in cooperation with a Bluetooth adapter is able to access emissions data from the OBD computer just as accurately as existing technologies. In previous evolutions of emissions procedures the biggest hurdles to adoption were technological in nature. Rather, hurdles to adopting the proposed solution are primarily political and educational in nature. Political due to the changes needed to implement the program both from a structural perspective and a policy perspective. The educational nature of the hurdles is seen readily in the second theme discovered: the public generally does not understand how current emissions inspections are completed or what the current fees are used for. This chapter discuses those themes along with conclusions based on each of the three original research question. Additionally, opportunities for future research are identified.

Accuracy and Adoption

When Smart Emissions performance is compared to that of a Systech NYUVIP2 emissions station as shown in Table 4.1 the accuracy of the two systems is identical. Technologically speaking, it is possible to implement the same protocols on a consumer-accessible device in a secure manner. The procedure for this was explained in chapter 3, and addresses the first research question of how Android devices can be used to access emissions data from the OBD computer. This results in a consumer-accessible solution that is substantially less expensive, and as accurate as existing solutions. Additionally, current solutions such as the NYUVIP2 system support the use of a Bluetooth ELM adapter that is essentially the same as what would be used in conjunction with a smart-phone.

The largest technical danger to using consumer accessible mobile devices for emissions collection is not in the application which has been the center of this study. This also means is not easily seen in the result set. The danger rests in the Bluetooth adapter being of poor quality. The communication between the phone and the adapter is relatively simple in nature, while the most complex portions of the communications protocols are implemented in the Bluetooth adapter at a firmware level between the adapter and the vehicle's computers. However, due to a rise in hobbyist's interest in accessing vehicle data, the marketplace has seen a proliferation of inexpensive OBD-II ELM adapters available for purchase created from cloned chips that may contain bugs in the firmware of the adapter itself resulting in poor data. Some efforts can be made with the smartphone application to ensure data received is within acceptable norms. However, due to the bit-coded binary nature of most data returned, coupled with the lack of error detection data sent by the OBD standards, issues of this nature could prove difficult to detect.

Under current emissions procedures the hardware and software used by inspection stations is often contractually restricted to a limited set of vendors which must first be approved by the appropriate governing body. This often presents inspection stations with a single vendor to choose from. This reduces competition in the marketplace, removes urgency for vendors to produce feature-rich products, and reduces price-competition resulting in expensive equipment. Also, due to the limited number of companies producing inspection equipment, it is simpler to enforce tight production standards on the limited set of emission inspection equipment. This model of accuracy through scarcity is not feasible over the long-term, especially as the transition to consumer-accessible hardware is made and the need for a wide variety of offerings is justified. Instead, as policy is developed to allow consumer-accessible hardware to be accepted, procedures should be put in place to ensure that hardware meets acceptable quality standards.

More serious issues in adopting a consumer-driven emissions procedure are political and educational in nature. Considering the State of Utah, where the study was conducted, just over 1 million emissions tests are conducted annually for an average fee of approximately $26 each. Each county collects between $1 and $3 per test to administer the program. The balance of the fee goes to the inspection station, with a portion also going to the emissions vendor in use. This fee sent to the vendor is on-top of the current amounts charged to obtain and maintain the hardware/software needed to conduct an inspection. Assuming the highest level of fee collected in Utah at $3, this leaves an average of $23 per inspection to be split between the current vendor and the inspection station. Mechanics and vendors have not, and will likely continue to be, unwilling to lose this revenue stream.

Despite this natural reluctance on the part of vendors and mechanics, the costs in administering an emission program should be considered when evaluating the efficacy of the program. The costs of the program should not exceed the value derived from the program itself. Smart Emissions has the potential to substantially reduce these costs. For consumers who opt to participate, there would no longer be a need for certified emissions inspection technicians or expensive hardware driving the fees they pay. Considering that each user of the emissions collection system described by this study would use their own devices, they would also be responsible for the purchase and maintenance of the devices of their choosing. This would remove the costs required of inspection stations in the acquisition of highly expensive hardware. Examining the responses of the participants in this study and national trends previously discussed, most consumers already own a smart device (Pew Research Center, 2017). They would only need to obtain a Bluetooth adapter. Common costs that would need to be covered through emissions fees would be reduced to the computing hardware necessary to maintain the back-end application programming interfaces and databases used to transmit and store results.

In addition to the costs of administering emissions inspection procedures, the public must either choose to participate or be required to participate. If the proposed solution were to be considered as an official option for emissions procedures, there must be enough consumers willing to do it. Of the 115 survey respondents, 90% indicated they would rather conduct the inspection on their own. This is consistent with the combined 90% that stated they would conduct the inspection at home. Together this presents a response to the research question of "how does using existing consumer-hardware simplify emissions programs and effect the costs of running them."

Educating the Public

The third and final research question to be discussed is how using mobile devices to conduct emissions inspections impacts public perception. The survey instrument utilized in this study was designed to provide perspective for this particular research question in specific. The respondents of the survey provide a sample with a distribution of participants from both genders and a wide range of ages. Survey respondents expressed frustration with the current emissions procedures as being inconvenient, and they also expressed misconceptions and misunderstandings of the inspections' purpose and procedures. For example, one survey respondent stated, "I feel that the check engine light and emissions do not coincide that often and therefore should not make you automatically fail emissions if the check engine light is on." This statement alone demonstrates a clear lack of understanding on what purpose the check-engine light serves in the context of the vehicle. Based on informal conversations with participants while testing their vehicles, the researcher noted that nearly all participants did not know that only an emissions-related issue could activate the MIL. Most assumed anything wrong with the car would cause the light to illuminate. Under EPA guidelines as previously discussed the MIL is restricted to emissions systems only. Manufacturers must provide their own means of notification to drivers if vehicular issues occur which require attention but are unrelated to emissions. Another participant noted "certain checks can't be done by yourself that would fail an emissions. For example I had a family member fail an emissions because when you revved the car a certain way the engine mounts were breaking." A mechanic may note an issue such as this, but checking engine mounts is not actually part of an emissions inspection. Rather, the participant must have utilized an aware mechanic as current emissions procedures do not require the opening of the vehicle hood. It is also possible that the participant in question does not understand the difference between a safety inspection which does require visual inspections and an emissions inspection which does not.

Survey participants frequently mentioned one common concern in the free-form comments of the survey. Notably, the idea of security. Participants were concerned that results could be "faked", "hacked" or that people would "cheat". Interestingly in a 2009 report by CARB titled *Transitioning Away from Smog Check Tailpipe Emission Testing in California for OBD II Equipped Vehicles* similar concerns were noted regarding the transition from tailpipe-based inspections to OBD-based inspections (Lyons & McCarthy, 2009). Regardless of the technology being used to enforce emissions compliance, there will always be a subset of individuals who seek to circumvent the enforcement for one reason or another. This concern should not be held as a standard to prevent innovation, but rather as a guideline to govern implementation.

Future Research

Within the survey results, and apparent contradiction was noted. Ninety percent of participants would rather conduct tests on their own, yet 46% of that same group found it re-assuring to have a certified technician perform the emissions inspection. If so many participants find it reassuring to have a technician, why would so many prefer to do the inspection on their own? These two data points seem somewhat at odds with one-another and present an opportunity for future research. It would also be interesting to explore what specifically is reassuring about having a certified technician perform the inspection. Under current procedures, an emissions inspection is essentially plugging two computers into each other which arguably anyone could do.

As the move to consumer-based hardware for emissions inspection inches closer to acceptance, future research should be conducted related to the accuracy of the wide-variety of adapters currently available. Many are based on cloned chips, some are not. Understanding the potential of this key element of the procedure to return accurate or inaccurate data is paramount to success.

Conclusion

This study has shown that a consumer-accessible device is capable of conducting an emissions inspection with the same accuracy as existing methods. However, under the regulations of many counties and states using consumer accessible mobile devices to conduct emissions inspections is not currently possible. As the public continues to push to use their own devices wherever possible, governing entities must evaluate which aspects of their enforcement policies are producing the desired effect and which are simply there because of historical procedures. One notable change that must be effected is the removal of the requirement to check MIL bulb-illumination visually. Governing entities must also put careful thought into ensuring that devices are of sufficient capability to accurately communicate with the vehicle to prevent false readings as they develop new policy. As a singular example, this could be done by simply vetting, or white-listing, the dongles allowed to be used as part of the inspection procedures. Along with any policy changes, a comprehensive communication plan should also be designed to communicate to the public regarding emissions procedures.

A simplification of emissions procedures coupled with education of the public at large on emissions procedures, purposes, and value will reduce enforcement costs and increase public awareness. Education should lead to less fear regarding emissions related issues due to increased understanding, reducing overall output from failing vehicles. Additionally, this education may increase public understanding of their vehicle's data, and how they can have access to it. This awareness may lead to a more agreeable public regarding emissions enforcement, or at least to increased feelings of responsibility for the environment we all live in.

References

116 Cong. Rec. 32901-32902 (1970) (statement of Sen. Edward Muskie).

Chow, S. C., Wang, H., & Shao, J. (200). *Sample size calculations in clinical research* (2nd ed.). New York, NY: CRC press.

EPA. (2017, January 10). *Timeline of Major Accomplishments in Transportation, Air Pollution, and Climate Change*. Environmental Protection Agency, www.epa.gov/air-pollution-transportation/timeline-major-accomplishments-transportation-air-pollution-and-climate. Accessed 31 Aug. 2017.

EPA. (2017, February 28). History of Reducing Air Pollution from Transportation in the United States (U.S.). Retrieved August 16, 2017, from https://www.epa.gov/air-pollution-transportation/accomplishments-and-success-air-pollution-transportation#road

Hearings on Air Pollution: Committee on Public Works, Subcommittee on Air and Water Pollution. 90th Congress, 1st Session, Pt. 2, P. 766-797 (1967). *Washington, DC: Government Printing Office*. (Testimony of John Gardner).

Hevner, A., March, S., Park, J., & Ram, S. (2004). Design science in information systems research. MIS Quarterly, 28(1), 75-105.

Hilpert, H., Thoroe, L., & Schumann, M. (2011, January). Real-time data collection for product carbon footprints in transportation processes based on OBD2 and smartphones. In *System Sciences (HICSS), 2011 44th Hawaii International Conference on* (pp. 1-10). IEEE. Kauai, Hawaii.

Hull, B., Bychkovsky, V., Zhang, Y., Chen, K., Goraczko, M., Miu, A., ... & Madden, S. (2006). CarTel: a distributed mobile sensor computing system. In *Proceedings of the 4th* *international conference on Embedded networked sensor systems* (pp. 125-138). ACM. Doi: 10.1145/1182807.1182821

Lehmann, A., & Gross, A. (2017, May). Towards vehicle emission estimation from smartphone sensors. In *Mobile Data Management (MDM), 2017 18th IEEE International Conference on* (pp. 154-163). IEEE. Daejeon, South Korea.

Lyons, A., & McCarthy, M. (2009). Transitioning Away from Smog Check Tailpipe Emission Testing in California for OBD II Equipped Vehicles. *California Air Resources Board*.

Malek, E., Davis, T., Martin, R. S., & Silva, P. J. (2006). Meteorological and environmental aspects of one of the worst national air pollution episodes (January, 2004) in Logan, Cache Valley, Utah, USA. *Atmospheric research*, *79*(2), 108-122.

MECA. (n.d.). *U.S. EPA Tier 3 and California LEV III Rulemakings*. Retrieved from http://www.meca.org/regulation/epa-tier-3-and-california-lev-iii-rulemakings

Merkisz, J., Pielecha, J., & Gis, W., (2008). Possibilities of evaluation of vehicle emissivity with the use of OBD2 system in road tests. *Better Air Quality*.

Miller, P., & Solomon, M. (2009). A brief history of technology-forcing motor vehicle regulations. *EM: Magazine for Environmental Managers*, 4-8.

Pew Research Center. (2017, January 12). Mobile Fact Sheet. Retrieved September 09, 2017, from http://www.pewinternet.org/fact-sheet/mobile/

S.A.E. (2017). E/E Diagnostic Test Modes. *SAE J1979.* Retrieved from: http://standards.sae.org/j1979_201702/

Sosnowski, D., & Gardetto, E. (2001). *Performing onboard diagnostic system checks as part of a vehicle inspection and maintenance program* (No. EPA-420-R-01-015).

South Coast Air Quality Management District. (n.d.). History of Air Pollution Control in Southern California. Retrieved August 31, 2017, from http://www.aqmd.gov/home/library/public-information/publications/history-of-air-pollution-control

Wei, Z. Q., Wang, X. W., Jia, D. N., & Liu, H. (2015). An Information Collection and Transmission Strategy of Vehicle State-Aware System Based on OBD Technology and Android Mobile Terminals. *Applied Mechanics and Materials, (719).* 573-579.

Appendix A

Sample Systech NYUVIP2 Emissions Certificate in 'Training Mode'

Page 1 of 1

NYVIP2 State of New York Vehicle Inspection Program

STATE OF NEW YORK

VEHICLE INSPECTION REPORT

Systech

Print Date: 10/26/2017 2:08:34 PM Inspection Date: 10/26/2017 2:04:56 PM Expiration Date: 10/31/2018 Inspection Type: T Version: 17.01.08

VEHICLE DETAILS	**VIN**	3GCPCPECXFG305480	**MODEL**	Silverado 1500	**FUEL**	G
	YEAR	2015	**PLATE**	NOPLATE	**WEIGHT**	0 - 8500 lbs
	MAKE	Chevrolet	**MILEAGE**	1	**EIR #**	

INSPECTION SUMMARY	**Inspection Result**	**Safety**	**Emission**	**Sticker Number**	**Fee**
	PASS	PASS	PASS	:	$21.00

INFO

Congratulations, your vehicle has passed its annual New York State inspection. Please retain this receipt for your records. You may be required to present this receipt in order to renew your vehicle registration.

Wheel Removed
1: L/F
2: L/R

The Result of the inspection will be transmitted electronically to DMV, usually within 24 hours.
Recall Advisory - Your vehicle may be subject to a manufacturer's safety recall. To check, go to safercar.gov and enter your vehicle's VIN (Vehicle Identification Number). Safercar.gov will quickly tell you if your vehicle has not been repaired as part of a safety recall in the last 15 years. In case of an open recall on your vehicle, you may visit a local new car dealer who sells and repairs your brand of vehicle to have it repaired at no expense.

VEHICLE INSPECTION QUESTIONS:
For additional information please contact the Department of Motor Vehicles at website address: http://www.dmv.ny.gov.
Or by telephone number: 518-486-9786.

FACILITY INFO	**Inspector Number**	**NYVIP2 Record Number**	**Online/Offline**	**DMV Record Match**
	14TA		Offline	
	Facility Number	**Facility Name**	**Facility Phone Number**	**Analyzer Number**
	SYSTECH	SYSTECH INTERNATIONAL	8012650099	WSU0000001
	Address	6 S. Cottonwood, Albany		**Name/RO#:**

Appendix B

A full copy of the survey given to participants in the study.

Auto Emissions Perception

Thank you for taking a few moments out to help me with this research project. This survey should take around 10 minutes.

* Required

Informed Consent Statement

Josh Jensen, a graduate student at Regis University, and faculty member at Weber State University is conducting a research study to evaluate the public's perception on current vehicle emissions procedures. This study will also explore a potential replacement allowing consumers to conduct an emissions inspections on their vehicles using a smartphone.

Participation is voluntary. The survey will take approximately 10 minutes or less to complete. You must be at least 18 years old to take this survey.

This study involves no foreseeable serious risks. We ask that you try to answer all questions; however, if there are any items that make you uncomfortable or that you would prefer to skip, please leave the answer blank. Your responses are anonymous.

If you have any questions or concerns feel free to contact Josh or his faculty advisor:

RESEARCHER
Josh Jensen
Computer Science
(801) 626-7753
joshuajensen1@weber.edu

ADVISER
Dr. Kevin Pyatt
Computer Science
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If you have questions about your rights as a research participant, you may contact the Regis University Institutional Review Board (IRB), which is concerned with the protection of volunteers in research projects. You may reach the board office irb@regis.edu.

If you would prefer not to participate, please do not fill out a survey.

If you consent to participate, please complete the survey.

1. **Informed Consent Agreement to Participate** *
   Check all that apply.

   ☐ I have read the informed consent statement above, and give my consent to participate in this study.

Current Emissions Procedures

The following questions will take a moment to ask your thoughts on the current emissions procedures in use today. As a reminder, the general process you follow now:
- You may receive a reminder card in the mail to take your car to an emissions inspection location.
- The technician at the location will plug their computer into your car, which runs the emissions check.
- You pay the technician a fee (the average fee is $25 in Utah)
- The technician's computer sends your results to the state.

2. **Do you find the current emissions process:**
Mark only one oval.

	1	2	3	4	5	
Inconvenient	◯	◯	◯	◯	◯	Convenient

3. **Do you find it reassuring to have a certified technician perform your emissions inspection?**
Mark only one oval.

◯ Yes
◯ No
◯ I'm fine with either a mechanic, or doing it myself

4. **Do you feel that current emissions procedures help with the air problems that affect Utah?**
Mark only one oval.

◯ Yes
◯ No
◯ Other: ____________________

5. **Do you have any comments or concerns on the current program?**

____
____
____
____
____

Future Emissions Proposal

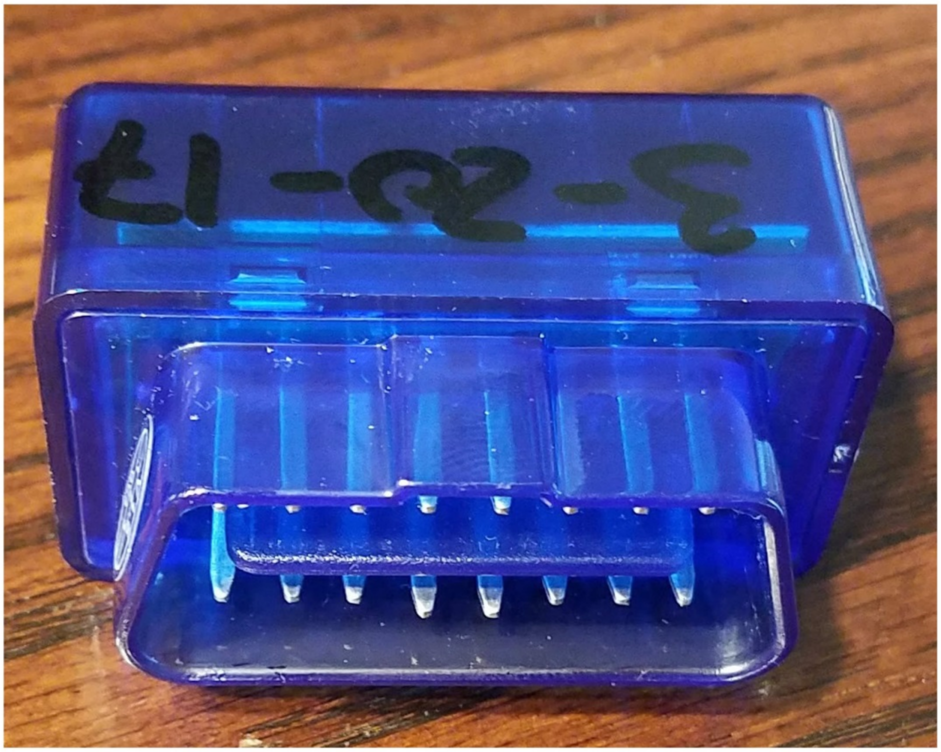
The next set of questions will ask your impressions on a proposed change to emissions procedure. Please use this procedure to answer the next set of questions.

Rather than taking your car to a mechanic, you would use a Bluetooth Dongle which you purchased yourself (for a small fee) and a smart device (phone or tablet) which you already own. You would plug the dongle into the DLC (OBD-II) port on your car, and use a free app to conduct the inspection. The app would ask you for your zip code, and then would do everything else needed to run the test autonomously. This inspection could be conducted from any location where you have wireless connectivity.

Future Emissions with a Smartphone / Tablet

This is a sample view of what the DLC port may look like in your vehicle. You would need to plug an adapter such as the one shown below, into a connector such as this.

This is a Bluetooth Dongle which could be used to conduct an emissions inspection with your smartphone or tablet. It would be inserted into your OBD-II port (often under the dashboard on the driver's side as shown above).



6. **Would you feel comfortable plugging an adapter like that into your car?**
Mark only one oval.

- ◯ Yes
- ◯ No

7. **Would you rather:**
Mark only one oval.

- ◯ Pay $25 and have a mechanic conduct the inspection at an approved location during business hours
- ◯ Pay $5 and do the inspection myself at a time and location convenient to you.

8. **What would you be willing to pay for an adapter you would own to conduct these tests?**
Mark only one oval.

- ◯ $8
- ◯ $10
- ◯ $15
- ◯ $30
- ◯ Not willing to buy a dongle
- ◯ Other: ____________________

9. **Do you feel comfortable using a smartphone?**
Mark only one oval.
   - Yes
   - Somewhat
   - No

10. **Do you own a smartphone or tablet?**
Mark only one oval.
   - Yes
   - No

11. **What OS is your smart device using?**
Mark only one oval.
   - Android
   - iOS
   - Windows
   - I don't own a smart device
   - Other: ______________________

12. **Given the procedure already described, would you be more likely to conduct an emissions inspection on your own, wherever you like or continue with the current procedure (visiting a testing location)?**
Mark only one oval.
   - I'd like to test from home with my smartphone
   - Either option would be about the same to me.
   - I'd rather continue to visit an inspection station
   - Other: ______________________

13. **Do you have any specific concerns with conducting an emissions exam on your own?**

____
____
____
____
____

14. **Do you have any other thoughts or comments you would like to share with the researcher?**

____
____
____
____
____

About you

This last section asks a little about you as an individual.

15. **What is your Age?**
Mark only one oval.

- Under 20
- 20-25
- 25-30
- 30-35
- 35-40
- 45-50
- 50+
- Prefer Not to Say

16. **What is your Gender?**
Mark only one oval.

- Male
- Female
- Prefer not to say

Powered by Google Forms