DRIVER ALCOHOL DETECTION SYSTEM FOR SAFETY (DADSS) – DEVELOPMENT OF THE SUBSYSTEM PERFORMANCE SPECIFICATIONS

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Paper Number 17-0301

ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) and the Automotive Coalition for Traffic Safety (ACTS) began research in February 2008 to try to find potential in-vehicle approaches to the problem of alcohol-impaired driving. Members of ACTS comprise motor vehicle manufacturers representing approximately 99 percent of light vehicle sales in the U.S. This cooperative research partnership, known as the Driver Alcohol Detection System for Safety (DADSS) Program, seeks to develop technologies that are less intrusive than the current in-vehicle breath alcohol measurement devices. Detection technology must be seamless (passive) with the driving task. It also must be able to quickly and accurately measure a driver's blood alcohol concentration (BAC) in a non-invasive manner. These technologies will be a component of a system that may deter the vehicle from being driven when the device registers that the driver's BAC exceeds the legal limit. Such devices ultimately must be compatible with mass-production at a moderate price, be durable, meet high levels of reliability, and require no maintenance. Therefore, the performance standards for the adoption of these devices among the general public, many of whom do not drink, let alone drink and drive, must be much more rigorous if they are to cause minimal inconvenience, and must deter the vehicle from being driven when the device registers that the driver's BAC exceeds the legal limit (currently 0.08 g/dL throughout the United States).

To assess these technologies, detailed performance specifications were developed. The specifications were designed to focus the current and future development of relevant emerging and existing advanced alcohol detection technologies. In addition to requirements for a high level of accuracy and very fast time for measurement, the influences of environment, issues related to user acceptance, long-term reliability, and system maintenance are also addressed. The resulting list of specifications with definitions, measurement requirements, and acceptable performance levels are documented in the DADSS Subsystem Performance Specification Document[1]. The accuracy and speed of measurement requirements adopted by the DADSS Program are much more stringent than currently available commercial alcohol measurement technologies are capable of achieving. Translating that to appropriate performance specifications was approached by calculating the potential for inconvenience if reliability, accuracy, and time for measurement were set at various levels.

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[1] Driver Alcohol Detection System for Safety (DADSS). Draft Subsystem Specifications Performance Specifications. DADSS001-DRAFT08. April 21, 2010.

INTRODUCTION

Alcohol-impaired driving (defined as driving at or above the legal limit in all states of 0.08 g/dL or 0.08 percent in all states) is one of the primary causes of motor vehicle fatalities on U.S. roads every year and in 2015 alone resulted in almost 13,966 deaths. There are a variety of countermeasures that have been effective in reducing this excessive toll, many of which center around strong laws and visible enforcement. Separate from these successful countermeasures, the NHTSA and the ACTS began research in February 2008 aimed at identifying potential in-vehicle approaches to the problem of alcohol-impaired driving. Members of ACTS comprise of motor vehicle manufacturers representing approximately 99 percent of light vehicle sales in the U.S. This cooperative research partnership, known as the Driver Alcohol Detection System for Safety (DADSS) Program, is exploring the feasibility, the potential benefits of, and the public policy challenges associated with a more widespread use of non-invasive technology to reduce alcohol-impaired driving. The 2008 cooperative agreement between NHTSA and ACTS (the "Initial Cooperative Agreement") for Phases I and II outlined a program of research to assess the state of detection technologies that are capable of measuring blood alcohol concentration (BAC) or Breath Alcohol Concentration (BrAC) and to support the creation and testing of prototypes and subsequent hardware that could be installed in vehicles.

Since the program's inception it has been clearly understood that for in-vehicle alcohol detection technologies to be acceptable for use among drivers, many of whom do not drink and drive, they must be seamless (passive) with the driving task, they must be non-intrusive, that is, accurate, fast, reliable, durable, and require no maintenance. To that end, the DADSS program is developing non-intrusive technologies that could prevent the vehicle from being driven when the device registers that the driver's BAC exceeds the legal limit (currently 0.08 percent throughout the United States).

To achieve these challenging technology goals, very stringent performance specifications were developed. The specifications are designed to focus the current and future development of relevant emerging and existing advanced alcohol detection technologies (Ferguson et. al., 2010). In addition to requirements for a high level of accuracy and very fast time to measurement, the influences of environment, issues related to user acceptance, long-term reliability, and system maintenance also will be assessed. The resulting list of specifications with definitions,

measurement requirements, and acceptable performance levels are documented in the DADSS Subsystem Performance Specification Document. The accuracy and speed of measurement requirements adopted by the DADSS Program are much more stringent than currently available commercial alcohol measurement technologies are capable of achieving. Translating that to appropriate performance specifications was approached by estimating the potential for inconvenience if reliability, accuracy, and time to measurement were set at various levels. Presented below are the processes used to derive them.

Reliability Developing an alcohol detection device as original equipment for the vehicle environment brings with it special challenges. Reliability is defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time. Levels of reliability that are too low would result in an unacceptable number of failures to operate the vehicle. It has been estimated that at the 3σ reliability (sigma - Greek letter σ - is used to represent the standard deviation of a statistical population) there could be the potential for 66,800 defects per million opportunities, where an opportunity is defined as a chance for nonconformance. The accepted level of reliability within the industry is 6σ. The term "six sigma process" comes from the notion that with six standard deviations between the process mean and the nearest specification limit, there will be practically no items that fail to meet specifications. In practice, 6σ is equivalent to 99.9997% efficiency. Processes that operate with "six sigma quality" over the short term are assumed to produce long-term defect levels below 3.4 defects per million opportunities.

Accuracy and Precision Accuracy is defined as the degree of closeness of a measured or calculated quantity to its actual (true) value (also referred to as the Systematic Error – SE). Precision is the degree of mutual agreement among a series of individual measurements or values (also referred to as the Standard Deviation – SD). To limit the number of misclassification errors, accuracy and precision must be very high, otherwise drivers may be incorrectly classified as being over the threshold (false positives), or below the legal limit (false negatives).

Speed of measurement Another important performance requirement is that time to measurement be very short. Sober drivers should not be inconvenienced each and every time they drive their vehicle by having to wait for the system to function. Current breath-based alcohol measurement devices can take 30 seconds or more to provide an estimate of

BAC. However, it was determined that the DADSS device should take no longer to provide a measurement than the current industry standard time taken to activate the motive power of the vehicle, approximately 300-350 milliseconds.

BACKGROUND

When embarking on the development of a new technology or taking an existing one to a new unheard of level of performance one needs to consider the words of Dale Carnegie "Begin with the end in mind". One method to do that is to consider the voice of the customer at the beginning of the project and then develop specifications which meet those "voices" and finally a product which fulfills the specifications. A tool made popular in the 1980s and 1990s which is still used today is Quality Function Deployment (QFD). QFD begins with the voice of the customer or customer needs and then allows one to develop specifications which meet those needs and balance potential conflicts between those needs.

The DADSS Subsystems development has multiple customer needs to be considered but of the many, there are a few which may be considered the most critical and in fact challenging. These critical needs are accuracy, precision and response time. Table 1 shows the relationship strength between the customer needs and the Performance Specifications.

Table 1. Customer needs and performance specificaitons relationship strength

Customer Needs	Accuracy	Precision	Response Time
If I am not over the limit, it needs to know that and let me drive	Strong	Moderate	N/A
The device must consistently give a correct reading	Moderate	Strong	N/A
If I am over the legal limit it should not let me drive	Strong	Strong	N/A
I want the vehicle to start	N/A	N/A	Strong

quickly			

PERFORMANCE SPECIFICATIONS

The DADSS Subsystem, shown in Figure 1, is a non-invasive sensing mechanism to determine the BAC of an intended motor vehicle operator. The Subsystem is intended to be part of the normal driver interface. It provides BAC information to the Vehicle Decision Module (VDM) and informs it of its health status (i.e. system is functional, not tampered with, etc…)
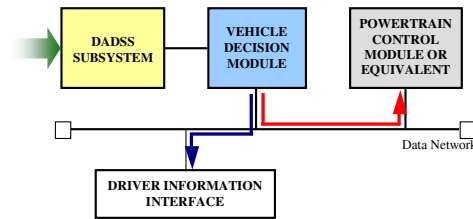

Figure 1. Example of a DADSS Subsystem Context Diagram

Subsystem Content

The DADSS Subsystem is comprised of:

- Sensor
- Signal Processing Unit

The Subsystem should be developed so that it is capable of sensing motor vehicle operator BAC values ranging from 0.01% to 0.12 % (1.5 times the legal limit in all 50 states), and activate the sensor no later than activation of motive power of the vehicle.

It should determine BAC value in no more than 325 milliseconds from sensor activation to completion of communications with the VDM and 400 milliseconds from sensor recycle/reset to completion of communications with the VDM. The time required for sensor activation and recycle is based on current immobilizer technology time requirements. Further, the Subsystem is anticipated to interface with the immobilizer and current immobilizer technology is judged to be transparent or non-intrusive to vehicle operators.

Environmental Performance Requirements

The DADSS Subsystem should be designed and developed so it conforms to ISO Standards 16750-2, 16750-3, 16750-4, 20653-2, and 12103-1 for environmental requirements where applicable.

Interfaces

Interfaces between the DADSS Subsystem and the vehicle driver shall be designed and implemented in a manner to measure BAC non-invasively. Interfaces between the DADSS sensor and the DADSS SPU

shall perform in a manner to minimize the risk of manipulation by the vehicle owner, its authorized drivers, or other parties. Such techniques may include shielding of interfaces, rolling counters, or encrypted communication. Interfaces between the DADSS Subsystem and the vehicle Subsystems shall be designed and implemented in a manner that supports encrypted communication requirements.

Performance

The DADSS Subsystem shall have all functions tested to reflect 187,500 miles / 15 years (Lu, 2006), and shall be tested at the following five points to the number of samples shown in Table 2 with no failures:

1. T_{max}, V_{min}
2. T_{min}, V_{min}
3. T_{max}, V_{max}
4. T_{min}, V_{max}
5. T_{nom}, V_{nom}

Where,

V = Electrical supply voltage
T = Temperature cycle

The functional tests shall be performed on each sample before and after Environmental Testing to demonstrate C_{PK} (Process Capability Index) > 1.72 [3], where C_{PK} is a statistical measure of process capability, or the ability of a process to produce output within specification limits.

Table 2. DADSS Subsystem reliability requirements validation

	Validation Number of Samples	Validation Test & Parameters
Mechanical		
Vibration	23	ISO 16750-3, section 4.1.2.4 or section 4.1.2.7
Mechanical Shock	23	ISO 16750-3, Section 4.2.2
Free Fall	23	ISO 16750-3, Section 4.3
Climatic		
Tests at Constant Temperature	23	16750-4, Section 5.1
Temperature Steps	23	16750-4, Section 5.2
Temperature Cycling	23	ISO 16750-4, Section 5.3.1 (with 1000 cycles) and Section 5.3.2 (with 100 cycles)
Salt Spray	23	ISO 16750-4, Section 5.5.1 (severity 5) and Section 5.5.2
Humid Heat Cyclic	23	ISO 16750-4, Section 5.6 (Test 2)
Damp Heat Steady State	23	ISO 16750-4, Section 5.7
Electrical		
Electromagnetic Compatibility (EMC)	3	IEC standards CISPR 25 and 61000-4-21 in addition to ISO standards 7637-2, 7637-3, 10605, 11452-2, and 11452-4 Radiated Emissions, Component Tests Bulk Current Injection, Component Tests Radiated Immunity, Component Tests Conducted Transient Emissions and Immunity, Component Tests Electrostatic Discharge (ESD), Component Tests
Electrical Loads	3	ISO 16750-2
Enclosure		
Protection Against Dust	23	ISO standard 20653 (code IP5KX) using ISO 12103-1, A2 fine test dust
Protection Against Water	23	ISO standard 20653 (code IPX2)

Interfering Compounds

In demonstrating the validity of an alcohol measurement system (breath or touch) the possibility of interference by other substances in both breath and touch exists. Therefore it is critical that the DADSS Subsystems are able to provide accurate values in the presence of interferening substances.

Breath-Based Subsystems - The breath-based DADSS sensor shall comply with IEC 60529, 61010, EN 50436-2, and ISO 7637-2. The sensor shall provide accurate BAC values in the presence of the following air borne substances introduced by the driver:

- Perfume
- After shave
- Tobacco smoke
- Mouthwash
- Disease-state halitosis containing sulfur or ketones

A breath-based sensor system shall not detect over the threshold value in the presence of the following substances and concentrations in the ambient air;

- Acetaldehyde (0.08 mg/L)
- Acetone (0.25 mg/L)
- Carbon monoxide (0.10 mg/L)
- Diethyl ether (0.15 mg/L)

- Ethyl acetate (0.08 mg/L)
- N-Heptane (0.10 mg/L)
- N-Hexane (0.10 mg/L)
- Methane (0.15 mg/L)
- Methanol (0.05 mg/L)
- N-octane (0.10 mg/L)
- N-pentane (0.10 mg/L)
- 2-propanol (0.05 mg/L)
- Toluene (0.10 mg/L)

Touch-Based Subsystems - The touch-based DADSS sensor shall comply with IEC 60529, 61010, and ISO 7637-2. The sensor shall provide accurate BAC values in the presence of the following substances on the arm and hand of the driver:

- Perfume
- After shave
- Tobacco
- Antibacterial soap
- Lotion
- Hand cleaner
- Suntan lotion
- Vehicle Fuel
- Paint
- Grease
- Dirt/Soil
- Food

The touch-based sensor system shall not detect over the threshold value in the presence of any contaminant in ambient air.

- Acetaldehyde (0.08 mg/L)
- Acetone (0.25 mg/L)
- Carbon monoxide (0.10 mg/L)
- Diethyl ether (0.15 mg/L)
- Ethyl acetate (0.08 mg/L)
- N-Heptane (0.10 mg/L)
- N-Hexane (0.10 mg/L)
- Methane (0.15 mg/L)
- Methanol (0.05 mg/L)
- N-octane (0.10 mg/L)
- N-pentane (0.10 mg/L)
- 2-propanol (0.05 mg/L)
- Toluene (0.10 mg/L)

Accuracy and Precision

In order to better understand the DADSS Subsystem accuracy and precision, the DADSS Program Team started with the requirements for Evidential Breath Testing devices currently being used to measure the BrACs of drivers arrested for DWI. They are:

- Accuracy (SE) = 0.005 %BrAC
- Precision (SD) = 0.0042 %BrAC

According to U.S. Bureau of Transportation Statistics, there are 327 billion trips taken annually by personal vehicle in the US (Santos, 2011). According to NHTSA, drivers who have consumed alcoholic beverages within two hours of starting their driving (drinking-driving) trip made an estimated 906 million trips. Of these trips, 11% (100 million) were estimated to be made by a driver with a BAC level of .08 or. An additional estimated 12% (109 million) of trips were made when the driver's BAC was between .05 and .079 (Dawn, 2001) as shown in Figure 2.
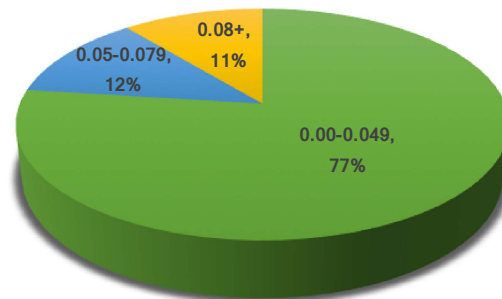

Figure 2. Percent of all drinking-driving trips, by calculated estimate of BAC (Dawn, 2001)

To better understand the effect of precision on the development of the DADSS Subsystem the total driving population have been grouped into the following groups:

1. Population with BAC < 0.05, a population that cannot be inconvenienced
2. Population with 0.05 <BAC< 0.079, a population that can potentially be asked to re-test
3. Population with BAC>0.08, a population that will not be allowed to drive

Assume that there are a total of 109 million drinking-driving trips per year at BAC between .05 and .079. The total number of people within this group that will be inconvenienced or asked for a re-test is dependent on the number of standard deviations as shown in Table 3.

Table 3. Potential number of people asked to re-test

Standard Deviation	Population
3σ	294,300
4σ	10,464

5σ	37
6σ	0.2

Since the project aims to develop unobtrusive in-vehicle alcohol detection technologies, the sensors should be developed with a 6σ requirement. The following text outlines the rationale for selecting a threshold at which a retest is required, based on current device performance, to prevent nearly all 0.08 BAC drivers from operating their vehicles. Subsequently, we discuss how this threshold changes as device performance improves.

Assume we have a population with a mean BAC of 0.08. Some customers will read above the mean and some will read below the mean. Applying the 6σ requirement using the accuracy and precision requirements outlined above (an SD 0f 0.0042 and SE of 0.005) will prevent drivers with BACs as low as 0.0498 from driving, and permit drivers with BAC of up to 0.1102 of to drive (Figure 3).
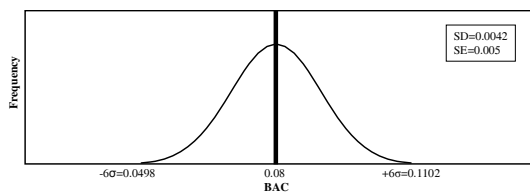

Figure 3. Six Sigma distribution using evidential breath testing SE and SD.

This performance is not acceptable since no one who registers a BAC of 0.08 or above should be allowed to drive. Therefore a mean shift to 0.0498 will be required to ensure that no one at or above 0.08 is allowed to drive. This will mean that drivers with BAC as low as 0.02 may prevented from driving (Figure 4). This performance is not acceptable since there is the potential to inconvenience people with very low BACs.
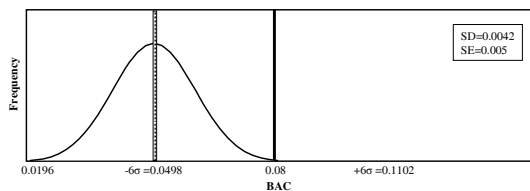

Figure 4. Six Sigma distribution using evidential breath testing SE and SD with a mean shift to 0.0498

The above examples highlight the issues associated with the mean and precision. In this case pecision is too large; hence the range is too large. To improve the performance of the Subsystem a tighter precision will be required.

Assuming the same population distribution as the previous two examples with a mean of 0.08 and instead we will use precision of 0.0003 and accuracy of 0.0003. Applying the 6σ requirements will potentially prevent drivers with BAC as low as 0.0779 from driving and permit drivers with BACs of up to 0.0821 to drive (Figure 5). Although this represents a great improvement in performance, it is still not acceptable to allow anyone with a BAC at or above 0.08 to drive. As in the previous example, a mean shift to 0.077 will be required to prevent anyone at or above a BAC of 0.08 to drive. With this mean shift, no one at or above 0.08 BAC will be allowed to drive and people as low as 0.0749 BAC potentially will be required to re-test (Figure 6).
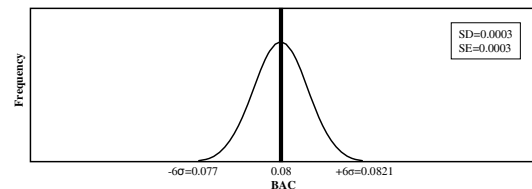

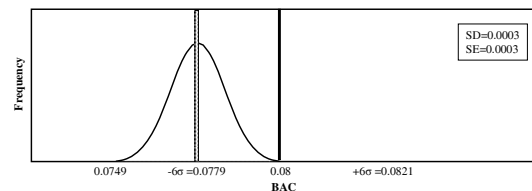*Figure 5. Six Sigma distribution using a specified SD and SE of 0.0003*

Figure 6. Six Sigma distribution using a specified SD and SE of 0.0003 with a mean shift to 0.0779

Therefore, by tightening SD and SE to 0.0003 and requiring six sigma performance, a mean shift of threshold to 0.0779 BAC will minimize the risk of having a driver with a BAC at or above 0.08 allowed to drive and prevent a driver with BACs as low as 0.0749 from driving; an acceptable Subsystem performance specification.

Based on the above data, the DADSS Subsystem shall be designed and tested to meet the SE and SD shown in Table 4 measured to a standard calibrated device that will be determined at a later stage of this project.

Table 4. DADSS Performance Specifications (% BAC or % BrAC)

Ethanol concentration	SE	SD
0.020	0.0010	0.0010
0.040	0.0010	0.0010
0.060	0.0007	0.0007
0.080	0.0003	0.0003
0.120	0.0010	0.0010

CONCLUSION

The performance standards for the adoption of passive/non-invasive in-vehicle alcohol detection devices must be much more rigorous, with high accuracy, precision, and speed of measurement if they are to cause minimal inconvenience to the sober driver, and deter the vehicle from being driven when the driver's BAC exceeds the legal limit.

To limit the number of misclassification errors, it was determined that accuracy and precision must be very high, otherwise drivers may be incorrectly classified as being over the threshold, or below the legal limit. Furthermore, the DADSS devices should take no longer to provide a measurement than the current industry standard time taken to activate the motive power of the vehicle so that the sober drivers are not inconvenienced each and every time they drive their vehicle by having to wait for the system to function.

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