

**Application of Autonomous Driving Technology to Transit - Functional Capabilities for Safety and Capacity**

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## **Application of Autonomous Driving Technology to Transit - Functional Capabilities for Safety and Capacity**

### **ABSTRACT**

Because of rapid advancements in autonomous driving technology, the National Highway Traffic Safety Administration (NHTSA) has issued a Preliminary Statement of Policy Concerning Automated Vehicles. Automobile manufacturers are beginning to market NHTSA defined "Level 2" packages which involve "automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions." Combining adaptive cruise control and automatic lane keeping is an example.

A package of advanced collision avoidance and mitigation technologies is being offered by Mercedes Benz in its Intelligent Drive option for 2014 "S Class" vehicles. This paper discusses incorporating a similar package into the design of transit buses. A case study illustrates the business case that could be made for using automated technology to reduce bus crashes and claims for NJ TRANSIT, one of the largest transit agencies in North America. It also shows how some features could improve capacity in a heavily used transit facility, the Exclusive Bus Lane (XBL) into New York City.

### **INTRODUCTION**

Driving a transit bus in an urban environment is a highly skilled and demanding profession. In addition to maneuvering a 40 to 60 foot (12 to 18 meter) long, 25 ton (23 tonne) vehicle in heavy traffic, which demands constant vigilance, drivers must administer a sometimes arcane fare system, navigate dozens of complex routes and schedules, monitor passengers, respond to stop requests, and serve customers as knowledgeable and pleasant representatives of the company.

Handling that kind of driving for hours on end induces fatigue and stress, and mistakes are inevitable. When a bus driver makes a mistake, the results can be highly visible. Even worse, bus driver mistakes can be deadly. Industry-wide for 2011, there were 57,000 reported bus crashes, resulting in 13,000 injuries and 244 fatalities. (1)

This paper builds on a previous study proposed in 1996 by Kornhauser and Pignataro that examined the potential benefits of an Operational Test of Automated Highway System (AHS) technology for buses between New Jersey and New York.(2)

### **BUS COLLISION WARNING TECHNOLOGY EVALUATION**

In 2004, the Federal Transit Administration (FTA) released a report by the Volpe Center that looked at the potential for employing Intelligent Vehicle Initiative (IVI) technology to reduce transit bus accidents. (3) The report used data from the 2002 National Transit Database (NTD) to analyze bus crash damage patterns and determine the severity of the crash depending on the direction of the collision and other factors. The report concluded that front, side and rear collision warning systems would reduce collisions and estimated the length of time needed to recover the cost of installing the systems through reduced property damage claims for a number of scenarios. The report did not consider crash costs of time lost, personal injury claims and fatalities.

In 2007, FTA released a report by Booz Allen Hamilton, Inc. that evaluated the business case for installing advanced collision avoidance systems on transit buses. (4) The report used data from the NTD Safety & Security reporting system and crash data provided by six US transit

systems to analyze bus collisions and to determine the frequency and severity of several types of collisions. A panel of experts was used to estimate the effectiveness of collision avoidance detection and warning technologies to reduce the probability of specific types of crashes, such as front, rear, side, and pedestrian. Benefit cost analysis was used to estimate the cost-effectiveness of each technology. The report concluded that while only side object detection met the benefit cost threshold, that technology and some of the other technologies that came close to the threshold should be advanced into operational testing.

### **NHTSA PRELIMINARY POLICY ON AUTOMATED VEHICLES**

On May 30, 2013, NHTSA released a preliminary policy statement on automated vehicles. The policy defined five levels of automation and offered guidance for regulating the testing of automated vehicles. (5)

**“No-Automation (Level 0):** The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.

**Function-specific Automation (Level 1):** Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.

**Combined Function Automation (Level 2):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.

**Limited Self-Driving Automation (Level 3):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation. (6)

**Full Self-Driving Automation (Level 4):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.”

### **ADVANCES IN COLLISION AVOIDANCE TECHNOLOGY**

The collision warning systems described in the 2004 Volpe Center report and the 2007 Booz Allen Hamilton, Inc. report would fall into Level 0, since the driver would be required to react to a visual or audible warning. Since 2004, however, automotive technology has advanced beyond just warning the driver that a collision is imminent. Automobiles are entering the market with Level 2 automated systems that not only sense that a collision is imminent, but actually take control of throttle, steering and braking functions to avoid or mitigate collisions. In particular,

Level 2 systems for autos are available that will initiate autonomous braking to bring a vehicle to a stop prior to a crash, even if the vehicle operator does not apply the brakes manually.

In November 2012, Mercedes-Benz announced the availability of its “Intelligent Drive” assist system for the 2014 model year “S Class” vehicles. (7) The system uses several cameras and radar sensors to detect highway lane markings, other vehicles, and pedestrians. Sensor inputs are processed and the car can react automatically to impending collisions. Among the system capabilities are the following:

**Adaptive Cruise Control (ACC)** senses speed and speed changes in the vehicle preceding the equipped vehicle and automatically adjusts speed to maintain proper spacing. Sensors also can detect speed changes in two vehicles ahead to react more quickly. The system is capable of maintaining spacing in stop and go traffic.

**Lane Keeping Assist** detects lane markings, the presence of cars in parallel moving lanes, and oncoming traffic. It can prevent the car from changing lanes if there is a risk of collision with an adjacent vehicle in a blind spot. The system applies braking on one side to keep the car centered in the lane.

**Autonomous Braking** detects cross traffic and pedestrians using stereoscopic cameras and radar, and autonomously can increase braking force or, if the driver does not react, initiate braking to stop the vehicle before impact. If there is insufficient distance to stop, the vehicle will slow and activate passenger protection devices to mitigate the impact.

The Mercedes system includes a number of other functions including night vision assist, active occupant protection measures to mitigate collision impacts, and warnings that a driver is becoming inattentive or drowsy. The entire package will be available as an option priced at \$2,800.00. (8) The various capabilities can be seen in a Press Information video. (9) The 2014 assist package has more capabilities than the assist package offered for 2013 models and is \$150.00 lower in price. (10)

## **APPLYING LEVEL 2 AUTONOMOUS VEHICLE TECHNOLOGY TO TRANSIT – A CASE STUDY**

NJ TRANSIT is the state-owned transit operator in New Jersey. The agency serves almost 900,000 daily trips on 12 commuter rail lines, three light rail lines and 261 bus routes. The bus fleet includes 3,027 vehicles as shown in Table 1. (11)

Shown in Table 1, Cruiser buses are 41 or 45 feet (12.5 or 13.7 m) long with a single passenger door, respectively have 49 or 57 high-backed individual seats and are generally used for longer intercity trips. (12) Transit buses typically are 30 or 41 feet (9.1 or 12.5 m) long with two doors, respectively seating 27 or 43 passengers in low-back double, single, or bench style seats. (13) Suburban buses are 41 foot (12.5m) transit-style buses with a single door and are used on some longer routes. (14) Articulated buses are 59 feet (18 m) long and seat 59 passengers.(15) “Purchased Transportation” buses are operated by contractors and wear NJ TRANSIT paint schemes, while “Private Carrier” buses are leased to, and operated by, privately owned bus companies and wear private carrier paint schemes.

<b>TABLE 1 NJ TRANSIT Bus Fleet Fiscal Year 2012 (12)</b>				
NJ TRANSIT Bus/Private Carrier	Owned and Operated by NJ TRANSIT	Purchased Transportation	Private Carrier	Total
Cruiser*	1,076	0	518	1,594
Suburban**	249	0	0	249
Articulated	85	0	0	85
Transit***	776	204	106	1,086
Minibuses/WHEELS	0	13	0	13
Subtotal	2,186	217	624	3,027
*includes 76 CNG & 4 Hybrid buses				
**Includes 2 Hybrid buses				
***Includes 3 Hybrid buses				

Table 2 shows annual reported incidents, collisions, fatalities, injuries and passenger miles for the past eleven years from the NTD. (16) NJ TRANSIT annual financial reports show aggregated claims paid for the agency as a whole by fiscal year. (17) The agency typically has been self-insured for most types of claims up to \$10 million per occurrence, with commercial excess liability insurance coverage for claims from \$10 million to \$250 million.

NJ TRANSIT financial reports do not show the claims cost disaggregated by mode. An estimate of claims attributed to Bus Operations was created by multiplying the total claims paid by the ratio of passenger miles on directly operated bus service to total reported passenger miles for the agency. A measure of claims paid per bus was then created by dividing the estimated bus portion of annual claims paid by the number of buses operated in that year.

Overall, NJ TRANSIT Bus Operations enjoys an excellent safety record, and has shown reductions in collisions and injuries over the past eleven years while increasing passenger miles of service. It may be possible to improve safety and reduce collisions even more by applying collision avoidance technology. It is appropriate to examine the potential at this time, because the 1,594 Cruiser buses, for which delivery was completed in 2003, are nearing the expected end of their service lives, and will soon need replacement.

To perform a benefit analysis, a variation of the methodology employed by the Volpe Center in its 2004 report for FTA was used. Using the publicly available data shown in Table 2, the average annual cost of claims paid per bus was estimated at \$4,846.00. Using this cost and estimating the cost of adding a collision avoidance package based on the Mercedes Intelligent Drive package, a preliminary determination was developed of the potential benefits that could be achieved by adding collision avoidance technology to buses.

To estimate the cost of installing a collision avoidance system, the advertised cost of the Mercedes Intelligent Drive system was used as a base. Because this package is specifically designed for installation in a limited line of cars, the technology may need considerable modification and testing for use on buses. For example, additional sensors may be needed to detect pedestrians in close proximity to the bus. To account for the uncertainty and likely increase in cost, four additional price levels were created as multiples of the base price, from doubling the base price to quintupling the base price. Because collision avoidance technology

may not eliminate all risk of claims, claims reduction was estimated in ten per cent intervals from ten per cent reduction to 90 per cent reduction. The results are shown in Table 3.

FTA has set twelve years as the minimum service life for buses and vans.(18) Therefore, the estimated years to recoup the installation cost of the system were compared with the twelve year minimum vehicle life to determine if the investment will be recouped within the expected lifespan of the bus.

As can be seen in Table 3, except for three scenarios in which the system is estimated to reduce claims by only 10 percent and cost \$8,400 to \$14,000 per bus, and one scenario in which the system is estimated to reduce claims by 20 per cent and cost \$14,000 per bus, all of the other scenarios estimate that the installation costs will be recouped well within the vehicle life. For the mid-range scenario, with 50 percent claims reduction and a cost three times the base price, installation cost would be recouped in 3.5 years.

The preliminary analysis documented above represents only one area for potential savings to the transit agency. Passengers and service can be delayed by collisions. Accident investigation, vehicle recovery, repairs, and legal services, take time and expense. The need to anticipate vehicles being out of service for collision repair must be included in calculating spare vehicle needs. For most transit agencies claims experience will be factored into insurance premiums. Incidents attract media attention and can tarnish the agency's reputation and adversely impact ridership. And the human cost of injuries and fatalities goes beyond what can be measured in monetary terms.

Because of the many costs that may be attributed to bus collisions and the limited data publicly available, it is suggested that a detailed analysis be undertaken to establish a more accurate estimate of the total potential cost savings that could be achieved by reducing bus collisions.

### **TRANS-HUDSON CAPACITY IMPROVEMENT – A POTENTIAL ADDED BONUS FOR NJ TRANSIT**

A large portion of NJ TRANSIT ridership is headed for New York City. The Hudson River, which separates Manhattan from New Jersey, is a significant geographical barrier. Vehicle crossings are limited to the Holland Tunnel, Lincoln Tunnel and George Washington Bridge. Consequently, most daily trans-Hudson commuters use transit. Because the demand for trans-Hudson travel is projected to significantly increase, for a number of years NJ TRANSIT has worked to advance a project called Access to the Region's Core (ARC) that was intended to double rail capacity between New Jersey and New York. ARC's six track station was expected to accommodate 24 trains in the peak hour, carrying approximately 24,000 passengers. In 2009, the project's estimated cost was \$8.7 billion. (19) Because of uncertainty about increased cost (estimates ranged from \$10 billion to \$13 billion) and funding, in 2010 New Jersey shut down the project. (20) Efforts to add additional rail capacity into and through New York are still needed and are under way under the auspices of the Federal Railroad Administration (FRA) and Amtrak, but these efforts are not fully funded and will take many years to complete. (21,22)

Consequently, the need still exists for additional Trans-Hudson transit capacity in the nearer term. To that end, the potential was examined to increase bus transit capacity into mid-town Manhattan through the Lincoln Tunnel using some of the capabilities provided by Level 2 autonomous driving technology.

**TABLE 2 - 2002-2012 Safety and Claims Data for Service Directly Operated by NJ TRANSIT Bus Operations  
(does not include purchased transportation or private carriers)**

Year	Incidents*	Collisions*	Injuries*	Fatalities*	Total Claims Paid**  (\$millions-fiscal year)	Bus Passenger Miles* (Passenger Km)  (millions)	Total NJT Passenger Miles* (Passenger Km)  (millions)	Estimated Bus Claims***  (\$millions-fiscal year)	Peak Buses*	Total Buses Operated****	Bus Claims/ Total Buses Operated (\$ per bus)
2012	163	34	217	4	43.2	1,040 (1,673)	3,200 (5,149)	14.0	1,810	2,186	6,404
2011	167	42	247	1	26.8	1,040 (1,673)	3,213 (5,170)	8.67	1,810	2,186	3,966
2010	133	66	178	2	44.1	1,031 (1,659)	3,254 (5,236)	14.0	1,833	2,179	6,425
2009	149	90	252	3	33.6	991 (1,595)	3,558 (5,725)	9.36	1,819	2,162	4,329
2008	267	135	364	1	26.6	987 (1,588)	3,526 (5,673)	7.45	1,801	2,141	3,480
2007	284	176	452	1	45.2	920 (1,480)	3,379 (5,437)	12.3	1,785	2,122	5,796
2006	273	156	244	0	28.4	915 (1,472)	3,201 (5,150)	8.12	1,765	2,109	3,850
2005	408	266	536	3	20.1	937 (1,508)	3,065 (4,932)	6.14	1,731	2,029	3,026
2004	430	298	597	3	24.8	884 (1,422)	2,885 (4,642)	7.60	1,686	2,009	3,783
2003	458	278	600	2	37.0	885 (1,424)	2,357 (3,792)	13.9	1,708	2,034	6,834
2002	345	212	730	5	30.5	843 (1,356)	2,368 (3,810)	10.9	1,714	2,014	5,412
Total	3,077	1,753	4,417	25	360.3	10,473 (16,851)	34,006 (54,716)	112.4	n/a	n/a	53,305
Annual Average	280	159	402	2.3	32.8	952 (1,532)	3,091 (4,973)	10.22	1,769	2,106	4,846

\* Source: National Transit Database (NTD) Safety and Security Data <http://www.ntdprogram.gov/ntdprogram/data.htm>

\*\*Source: NJ TRANSIT Annual Financial Reports 2002-2012 <https://dSPACE.njstatelib.org/xmlui/handle/10929/19747/browse?type=dateissued>

\*\*\*Estimated Bus Claims = Total Claims x Bus Passenger Miles / Total NJT Passenger Miles

\*\*\*\*Source: 2002-2006, 2011-2012 NJ TRANSIT Facts at a Glance, 2007-2010 data interpolated using total buses = 1.189 x Peak Buses

<b>TABLE 3 Potential For Cost Savings in Annual Claims Paid by Installing a Collision Avoidance System on NJ TRANSIT Buses</b>						
Estimated Average Annual Claims Reduction per Bus		Collision Avoidance System Installation Costs Based on Mercedes Intelligent Drive System				
		\$2,800 per Bus – 2014 Base Price	\$5,600 per Bus – 2x Base Price	\$8,400 per Bus – 3x Base Price	\$11,200 per Bus – 4x Base Price	\$14,000 per Bus – 5x Base Price
(%)	(\$)	Estimated Years to Recoup Installation Cost				
10	484.60	5.8	11.6	17.3	23.1	28.8
20	969.20	2.9	5.8	8.7	11.6	14.4
30	1,453.80	1.9	3.9	5.8	7.7	9.6
40	1,938.40	1.4	2.9	4.3	5.8	7.2
50	2,423.00	1.1	2.3	3.5	4.6	5.8
60	2,907.60	1.0	1.9	2.9	3.9	4.8
70	3,392.20	0.8	1.7	2.5	3.3	4.1
80	3,876.80	0.7	1.4	2.2	2.9	3.6
90	4,361.40	0.6	1.3	1.9	2.6	3.2

### **Mid-Town Bus Access to Manhattan**

The Lincoln Tunnel consists of three two-lane tubes approximately 1.5 miles (2.4 km) long connecting Weehawken, New Jersey with New York City. (23) The Tunnel hosts what may be the most cost-effective transit facility in the world, the Exclusive Bus Lane (XBL).

Operating since 1970, the XBL is a 2.5 mile (4.0 km) long contra-flow lane on Route 495 connecting the New Jersey Turnpike at Exit 16E with the Lincoln Tunnel toll plaza. Each weekday morning from 6:00 A.M. to 10:00 A.M. the left lane of the three westbound lanes on 495 is converted into an eastbound lane exclusively for buses as shown in Figure 1. (24)

During its four-hour weekday operating period, the XBL carried an average of 1,791 buses per day in 2009. Maximum observed peak hour capacity of the lane is 725 buses and 34,685 AM peak hour passengers. Peak period buses on the XBL carry 62,000 passengers on an average weekday. (25)

At the New York end of the Lincoln Tunnel, exclusive ramps allow buses to directly enter the Port Authority Bus Terminal (PABT) which occupies one and a half city blocks between 40<sup>th</sup> and 42<sup>nd</sup> Streets and Eighth and Ninth Avenues as shown in Figure 2. Opened in 1950, the PABT has been expanded several times. The terminal has 223 bus gates, parking for 1,250 vehicles and accommodates 7,000 buses and over 200,000 passengers per day. (26)

The PABT is currently operating at volumes that exceed its capacity in the afternoon and evening peak period. NJ TRANSIT has acknowledged problems with overcrowding and late

departures. (27) Transportation advocates have called for expansion of the PABT to increase trans-Hudson capacity as a nearer-term alternative to another rail tunnel. (28) The Port Authority had announced plans in 2008 to renovate and expand the PABT in conjunction with development of a 1.3 million square foot (120,835 sq. m) office tower. Due to poor market conditions, however, the project has not moved forward.

**Increasing bus capacity to mid-town Manhattan would involve three elements:**

1. Increasing the AM peak hour flow of buses through the XBL
2. Increasing the capacity of the PABT, particularly to accommodate outbound passengers in the PM peak
3. Increasing the capacity to feed buses into the terminal for PM outbound service, either by making bus storage space available in Manhattan or by expediting the PM eastbound flow of buses through the Lincoln Tunnel.



**FIGURE 1 Exclusive Bus Lane (XBL) Contra-Flow Bus Lane in Operation**  
**Source: Port Authority of New York and New Jersey**

On June 27, 2013, the Port Authority announced it had awarded a contract to conduct a comprehensive study to “accommodate future growth in bus commuting heading to and from midtown Manhattan.” (29) The study will produce a master plan that will consider a number of options, including new bus staging and storage facilities, air rights development over the terminal, and possible replacement of the terminal itself. It is expected that solutions to items 2 and 3 above will be addressed by the new study. Item 1, increasing the capacity of the XBL is examined in the following section.



**FIGURE 2 Port Authority Bus Terminal New York City, NY**  
**Source: Google Earth 2013**

### **Potential to Increase XBL Capacity through Autonomous Driving Technology**

Research has shown that ACC has the potential to increase highway capacity, but that augmenting ACC with V2V technology, called Cooperative Adaptive Cruise Control (CACC) can produce dramatic increases in highway capacity from 103 per cent to 273 percent. (30,31) Level 2 autonomous driving technology has the potential to increase throughput by utilizing CACC to create “platoons” of buses. Drivers normally maintain sufficient separation from the preceding vehicle to allow them to come to a safe stop if the vehicle ahead suddenly decelerates. CACC will sense speed changes and react far more quickly than can a human driver. Consequently, platooning can decrease the distance and time interval between vehicles following one another in a lane.

At maximum throughput of 725 buses per hour, buses on the XBL follow one another at an average five second interval, and are separated by a distance of approximately 200 feet (61 m). CACC could significantly decrease the average interval as shown in Table 4. Decreasing intervals between buses to three seconds or less has the potential to increase peak hour capacity above that projected for the ARC project which was projected to cost between \$10 billion and \$13 billion.

While this paper shows that the technology to increase bus capacity into New York in the XBL has the potential to pay for itself in reduced claims costs, it does not explore the physical changes and additional costs involved in adding capacity to the PABT and increasing storage of buses in Manhattan. Those aspects will need further examination in the study commissioned by the Port Authority in June 2013. Clearly, however, with the price of added rail capacity estimated in the tens of \$billions, the cost of adding transit capacity by bus could be far lower than rail and deserves further study.

**TABLE 4 Potential Increased Capacity of Exclusive Bus Lane (XBL) Through Decreased Separation Using Adaptive Cruise Control and Vehicle to Vehicle Communications (Assumes 45 foot (13.7 m) buses @ with 57 seats)**

Average Interval Between Buses (seconds)	Average Distance Between Buses (ft.)	Average Distance Between Buses (m)	Buses Per Hour	Seated Passengers Per Hour	Increase in Seated Passengers per Hour from Base
1	6	2	3,600	205,200	164,160
2	47	14	1,800	102,600	61,560
3	109	33	1,200	68,400	27,360
4	150	46	900	51,300	10,260
5 (Base)	212	64	720	41,040	-

## CONCLUSION

This paper described the levels of automation defined by NHTSA and provided an example of Level 2 automation being offered by Mercedes Benz as an option for 2014 models. It then showed that the cost of installing collision avoidance technology on transit buses had the potential to be recouped well within the minimum useful life of the bus. The paper also showed how CACC features of Level 2 automation had the potential to increase bus throughput on the XBL into Manhattan.

Although Level 2 collision avoidance technology does exist for autos, there is, as yet, no commercially available system for buses. Consequently, a research and prototyping effort would need to be undertaken. However, it may be possible to prepare for the eventual deployment of a collision avoidance system by configuring buses to accept future installation of the various components and sensors. Based on these findings, it is suggested that specifications for the procurement of new buses to replace NJ TRANSIT's 1,594 Cruiser buses be developed to allow "plug and play" installation of Level 2 automation with the following capabilities:

- Route driving instructions
- Blind spot monitoring (for vehicles and pedestrians)
- Driver fatigue and attentiveness monitoring
- Adaptive Cruise Control
- Vehicle to vehicle communications for bus spacing control
- Autonomous emergency braking
- Lane departure detection and warning
- Lane keeping assistance
- Collision warning and mitigation
- Obstacle detection
- Parking assist

Specifications should adopt a modular, open architecture and standardize interfaces for data exchange among various systems. Given the rapid pace at which autonomous driving

technology is being developed, the procurement should encourage multiple sourcing and innovation from vendors.

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