Exhibit D

Cooperative High-Accuracy Location (C-HALO) service for Intelligent Transportation Systems: A Cost Benefit Study

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BIOGRAPHY

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ABSTRACT

This paper presents a cost benefit study of a Cooperative High-Accuracy LOcation (C-HALO) service as a nationwide service capable of providing decimeter level positioning accuracy to enable several new applications across various industries. We survey and summarize work by others quantifying the benefits reaped from enabling applications that require C-HALO. However, benefits to the economy from enabling C-HALO for Intelligent Transportation Systems (ITS) have not been quantified in the literature. This study estimates these benefits. We also provide an order of magnitude rough estimate of the cost of implementing part of a C-HALO infrastructure based on N-RTK technology.

Given the assumptions presented in the paper, our estimate of the benefits of a C-HALO service to ITS applications is on the order of $160 billion to $320 billion

over a time horizon of 22 years. This translates into 1.1 to 2.2 percent of the US GDP. After researching several local and state-based deployments of C-HALO services, we picked N-RTK as one nascent technology to partially deploy C-HALO nationwide. We assess the current cost to be $560,000 to $1.6 million per base station covering a 60x60 sq.km area. A rough calculation yields a total cost of implementation to be between $1.6 billion to $4.4 billion. We conclude that the benefits for implementing a nationwide C-HALO service far outweigh the costs of deployment.

INTRODUCTION

High accuracy positioning is mandated for many applications and there has been considerable efforts taken to develop infrastructure for enabling precise localization. The largest of these is the global positioning system (GPS) that has been developed and deployed by the US government. Other GNSS are being upgraded (GLONASS) and established (Galileo, etc.) Extending the coverage, accuracy and reliability of GPS (GPS herein meaning all available GNSS) has been, for years, the objective of much private sector research and deployment efforts. For example, technologies such as DGPS [1], GPS-WAAS, GPS+INS, GPS-RTK, and Network RTK [2] have been developed in recent years and are partially deployed. Limited-coverage pseudolite-based systems are also available and wide-area multi-lateration systems are being substantially deployed around airports for aircraft and ground vehicle tracking. However, to this day no system has been proven to be able to ubiquitously provide accurate and reliable wide-area positioning information approaching what is needed for C-HALO. In most cases, such as with GPS-RTK, the cost of the positioning system in their limited uses (such as high-end agriculture and surveying), has been a barrier to wider-scale deployment. Moreover, these technologies rely on GPS, and only work well in areas where GPS reception is not weak or compromised by substantial radio multipath. In areas such as urban canyons and forested streets, or even in traffic with many adjacent vehicles passing by, these systems may not function well. Certain new pseudolite-based solutions, which can cover these dark areas are limited in range and are "not yet ready for prime time." Inertial navigation systems (INS) in vehicles can extend GPS coverage beyond areas of accuracy but not for substantial distances before loss of required accuracy. Wide-area multi-lateration systems being increasingly deployed around airports (as noted above) are cost-effective and sufficiently accurate for their purposes, but without modifications and far more extensive use of base stations, will not meet C-HALO requirements.

Combinations of multiple technologies will be needed for C-HALO, and phases seem needed for affordable, practical implementation, starting with higher value applications in geographic areas that can be affordably covered with sufficient accuracy and reliability, to eventual nationwide coverage, higher performance, higher volumes and lower per-unit cost, and an increasing range of applications extending to the mass market. In addition to technological difficulties, deployment of C-HALO on the scale planned requires significant government support and funding. This has discouraged the private sector from aggressively attempting to resolve the technological issues. Overcoming the current technological hurdles and enabling C-HALO; therefore, warrants government and private foundation support of research and development initiatives. This study aims at providing a tool, which will enable government and private funding agencies to assess the benefits of investing in a new breed of positioning technologies and wide-scale deployments to meet the goals first noted above.

To assess the benefits for ITS, we first identify new information services sought by society and enabled by a C-HALO capability. We then quantify the benefits of these services. Examples of such services include smart systems to manage infrastructure elements such as traffic signal corridors and applications for collision warning etc. A large group of such services have been identified by the different administrations of the USDOT over the past twenty years, advanced by the academic community and the ITS industry, and comprehensively managed at the policy level by the ITS-JPO (Intelligent Transportation Systems Joint Program Office). A subset of these services work only when the location information is good enough to know the lanes of travel of vehicles, i.e. positioning to a decimeter precision. We assume most such services require C-HALO. Accordingly the benefits of such a service, as evaluated in this study of the literature, are assigned to C-HALO.

The ITS benefits accrued from a C-HALO service are projected in direct relation to the added safety and mobility on the roadway. ITS applications that require high accuracy in locating vehicles and infrastructure elements are identified and their efficiency in reducing accidents and congestion is estimated based on published literature. These numbers are then used to project the monetary benefits over the next 22 years by assuming a cost of human life and a discount rate among other factors. We also assume an adoption curve for the new technology that assumes some government ownership in the roll-out process of the technology. Given the assumptions presented in the report, our estimate of the benefits of a C-HALO service to ITS applications is on the order of $160 billion to $320 billion. The range depends on whether one uses the low-level or the mid-level efficacy rates in reducing accidents using ITS safety applications. This translates into 1.1 to 2.2 percent of the US GDP.

After researching several local and state-based deployments of C-HALO services, we picked N-RTK as one nascent technology to partially deploy C-HALO nationwide. We assess the current cost to be $560,000 to $1.6 million per base station covering a 60x60 sq.km area. A rough estimate for a nation wide deployment yields a cost of $1.6 billion to $4.4 billion.

In the sections to follow we present a literature review and the methodology used to estimate the benefits and costs.

LITERATURE SUMMARY

We have reviewed existing GNSS related market analyses and cost benefit studies done by others on various sectors of the economy and in various parts of the globe. This section summarizes our findings.

Market Analysis

Rob Lorimer of Position One Consulting performed a three year projection on the GNSS global market in his report titled: GNSS Market Research and Analysis September 2008 [3]. Based on this report and analysis, we created a table of global positioning companies, along with which industry(ies) each company is involved in. The complete table is included in the technical report [4].

The table identifies the three most ubiquitous providers of GNSS-based services as Leica Geosystems, Trimble, and TopCon/Sokkia. Omnistar is also relevant in many industries, but they are mainly focused on precision augmentation services, while the other three are more vertically integrated, and typically incorporate numerous levels of the value chain. Interviews conducted by Lorimer with the CEO's of the companies listed in the table provided insight into the industries that are major consumers of location services. The biggest consumers are the Aerospace, Agriculture, Autonomous Vehicles, Construction, Defense, Maritime, Mining, and Surveying industries. Clearly void from this list is the transportation sector, which we choose to analyze as part of this CBA. Benefit estimates have been completed in some of these industries and are discussed in more detail in the subsequent section.

Published Benefit Analysis Reports of Various GNSS

The Allen Group [5] estimated the economic benefits of C-HALO type technology in three specific Australian industries: Agriculture, Mining, and Construction. The Allen Group determined the benefits to be between $100 and $200 billion, approximately 10 to 20 percent of the Australian GDP. These three markets make up approximately 10 to 13 percent of the GDP. Assuming that the U.S. transportation market makes up 5 percent of the GDP, a simple linear scaling of the Allen Group's numbers suggests the HALO benefits derived from the transportation sector alone should be 4 to 9 percent of the GDP, which would be approximately $560 to $1200 billion in benefits. We find $160 to 300 billion. These benefit numbers appear conservative in relation to the Allen Group study. We have incorporated a key piece of the Allen Group report in our method. The adoption rate for the C-HALO technology is represented by this studies' industry-wide national rollout adoption scenario.

A socio-economic benefit study was commissioned by US Department of Commerce (DoC) [6] to determine where there is value added by the CORS and GRAV-D systems. The study focused on the benefits derived from the increased vertical accuracy of GPS. We do not consider this dimension at all. The study suggests that the surveying and mapping industry will be the most significantly impacted, but goes on to list other possible industries like construction, agriculture, environmental science, and transportation. Again this reiterates the fact that researchers are continuing to view transportation as a realm for potential benefits from C-HALO technology. The US DoC study assesses benefits utilizing the productivity methodology, which is typical and similar to the methodology used in our study and many others contained in the literature review. One slight difference to our methodology is that their time horizon is 15 years while ours is 22 years.

Alcantarilla, et al. analyze the benefits of a multi-constellation system, versus a stand-alone GNSS system, and ultimately a SBAS approach [7]. A piece that may be of importance to us when discussing the costs is the distribution of the number of satellites in view. They conduct a simulation of an urban environment and contend that with GPS & Galileo 65% of the area is covered by more than 3 satellites, while 20% is covered by 3, and 15% by less than 3. They then go on to qualitatively discuss the principal pieces of a future GPS system along with the envisioned benefits of multi-constellation GNSS SBAS augmentations. Similar analysis is carried out by Zabic et al. [8] but with actual data in Copenhagen. They estimate the average satellite availabity in Copenhagen through extensive data collection and use simulation tools to predict the improvement in satellite availability with the addition of Galileo.

Swann, et al. discuss the qualitative benefits of location-based services, the architectural issues involved in multi-constellation systems, and the market aspects that need to be addressed for deploying multi-constellation systems [9]. They focus on the benefits of reliability of a combined GPS/Galileo signal where availability is at 99.7% in their Stuttgart analysis. In addition, they estimate the GNSS service provision market to be 135

billion Euros by 2015 with a significant portion of that residing in the transportation industry. This is significantly higher than what Lorimer's report quotes for the U.S. market by 2012, which is around $9 billion.

Vollath, et al. aimed to look at how NRTK and the third frequency to be offered by Galileo will interact [10]. They present the value of the Galileo third frequency in facilitating higher horizontal accuracy and increased distances between base stations among other things. NRTK, however, still proves to be more accurate in the vertical direction. Ultimately, they do not assess the monetary benefits, but only the technical reliability. They conclude that NRTK will not be replaced by the Galileo new third frequency, but that the two could be used as complimentary technologies.

Arthur, et al. delve deeper into the impacts of Galileo by going beyond cost benefit analyses and conducting specific input-output models [11] which actually predict economic output rather than just analyzing costs and benefits. They even go as far to suggest that some 'market externality' impacts, like induced effects, could be twice as large as the direct impacts. They also suggest how to enhance a CBA by including innovation effects (through supply-push or demand-pull forces), or market and social externalities. These types of analyses could be worthwhile as future work. They are not included in this report.

Brennan, et al. wrote National PNT Architecture: Interim Results to facilitate the decision making process on a national PNT architecture for the United States by 2025 [12]. It does not focus on costs or benefits in quantitative terms. It does however evaluate many different technological options to achieve their stated goals. Ultimately, they want to put together a transition plan from an "as is" architecture to a "should be" architecture. Unfortunately, this is not directly related to our CBA.

Existing C-HALO Type Deployments

In order to understand the existing C-HALO deployments and technologies, we reviewed the initiatives undertaken by the government agencies. The material here is based on reports [13] and [14] provided by the Federal Highway Authority. The earliest deployments were the Differential GPS (DGPS) base stations by the US Coast Guard for maritime services. These base stations broadcast the actual and measured pseudo-range differences of the received code measurements from the different satellites. These error measurements are used by GPS receivers to calibrate their own measurements resulting in accuracies as high as 1m under good line-of-sight conditions. The corrections are broadcast typically in the longwave frequency range between 285kHz and 325kHz. The U.S. Army Corps of Engineers (USACOE) later realized the benefits of accurate localization and efforts were made to increase the coverage of the DGPS base stations. This resulted in the N-DGPS or nationwide DGPS program under which a total of around 137 base stations were to be installed nationwide to provide accurate localization services. The defense establishment also found need for decimeter and centimeter level accuracies. This could be obtained by sending corrections to the carrier phase received by the DGPS stations, as the carrier frequency of GPS is 1000 times higher than the frequency of the modulated code sequence. Hence one could obtain very high accuracies by measuring the carrier phase. This technology came to be known as RTK or Real Time Kinematic positioning and the proposed system implementation by government agencies has come to be known as HA-NDGPS – High Accuracy NDGPS [13].

One of the challenges of HA-NDGPS is that the allocated bandwidth does not suffice for broadcasting the carrier measurements for all the satellites [14]. This requires compression of the phase measurements. This work is still in progress. Prototypes of this system were deployed and evaluated [13]. During deployment it was found that, if a receiver obtained corrections from more than one base station, a combination of the measurements provided higher accuracies. A more sophisticated combination could provide still higher accuracies, and this is the proprietary technology used in N-RTK or Network RTK, a service, provided by companies such as Leica, Trimble etc. The N-RTK service has two methods of operation [15]. The Virtual Reference Station (VRS) method as adopted by agencies like Trimble is a unicast system where the GPS receiver contacts a central server, which in turn computes the corrections from the set of receiver stations in the vicinity of the receiver and gives an estimate of the receiver's location. The Master Auxiliary Concept (MAC) method allows for a broadcast system wherein a single master reference station amongst a cluster of reference stations in a cell, broadcasts the corrections. The rover in turn interpolates these corrections to estimate the corrections at its location. The MAC method also allows for a two-way mode where the reference station calculates the corrections for the rover as in the case of VRS. In our opinion, the question of whether one would want to adopt a unicast system or a broadcast system depends on the application. For a large-scale application like Intelligent Transportation Systems, it might be desirable to have a broadcast system and have all the intelligent processing done at the GPS receiver as compared to a central server. If every vehicle is required to know its location accurately, it is more efficient to broadcast the error measurements to all the vehicles in contrast to every vehicle contacting a centralized server to compute its location estimate since the error measurements would be common to all the vehicles in a particular region of interest.

HA-NDGPS is the technology that is being standardized by the federal DOT as the technology of choice for achieving high accuracy positioning for ITS applications. The federal DOT has commissioned a couple of pilot programs to improve on this technology to achieve cm level accuracies nationwide. The pilot sites are in Maryland and Pennsylvania and the research is being headed by the Turner Fairbanks Highway Research Center. The current and planned coverage areas are in the map below:

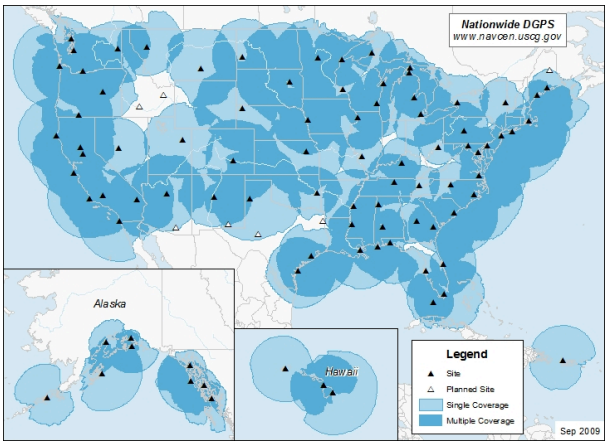

Figure 1: HA-NDGPS Coverage Area

Additionally, we have researched state run, cooperative and private run positioning and augmentation services. Most of these services are N-RTK corrections. Figure 2 shows the states with N-RTK deployments we have found as of December 2010.

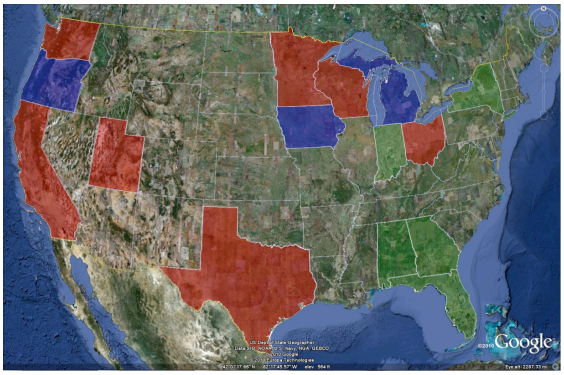

Figure 2: N-RTK Deployments Reviewed [4]

The red states denote N-RTK deployments partnered with Trimble, while the blue states denote N-RTK deployments partnered with Leica. The green states partners were either unidentifiable or only explored, but never actually deployed an N-RTK network. Within this group of states the State run programs and Private/Public Cooperatives are as follows:

State DOTs	**Public/Private Cooperatives**
Utah	Texas
Ohio	Washington
Iowa	Midwest (Indiana)
Oregon	Alabama
California	
Michigan	
Minnesota	
Wisconsin	

Throughout these deployments there are many similarities in infrastructure. The first implementations were in the early 1990s and have continued through the 2000s. From an infrastructure standpoint the industry standard seems to place N-RTK base stations 60km to 70km apart. Most of the deployments have around 50 to 80 base stations. Some of the cooperative deployments continue to grow due to increasing membership, and in addition, some of the nascent state DOT's deployments also have expansion plans in place. All of the deployments offer centimeter level accuracy within their network [4].

The networks differ in their access rules. Currently all state DOT networks charge no fee for usage, except for Utah, which just changed policies and began charging $400 annually. The cooperative networks typically charge between several hundred and several thousand dollars annually. On top of this, users must purchase a receiver and applicable cellular plan for the data flow. Cellular plans typically range in the order of $100 while receivers range from several hundred to several thousand depending on capability.

These costs seem bearable by markets such as Agriculture, Surveying, and Construction services, due to their high use of these state-run and cooperative networks. Only one state, Minnesota, had implemented and deployed N-RTK for transportation purposes. They use the network for snowplows and inner city bus routes [16]. Three states were questioned for cost information: Iowa, Ohio and Washington. These systems range between $50K and $115K in expenditures per base station to perpetuity. These costs are discussed in further detail in a separate section. To gain further understanding of the availability of C-HALO services, we review private services offered by Omnistar and Leica [17, 18 & 19].

Leica has SmartNet, which is N-RTK coverage, in many states across the United States. Based on SmartNet's service agreement [20, 21], Leica offers 1-2 cm horizontal accuracy and 2-3 cm vertical accuracy under conditions of good satellite coverage, good geometry, and low multipath environments. However we have not been able

to locate, from Leica, the percentage of time those conditions are satisfied within their areas of coverage. Typically their coverage is provided through private investment, and partnerships with other Leica network deployments. The service agreement [20] explicitly mentions that Leica geosystems disclaims warranty to the accuracy of the data created by or passing through the SMARTNET Reference Station Network. Omnistar currently claims 99% availability of C-HALO services in the United States. This is offered using DGPS technology and entails an annual subscription service as well as investment in a GPS receiver. The subscription services range from $800 for the least accurate (sub-meter) to $2500 for the most accurate (centimeter) per receiver. The receivers generally cost around $5000 and are available from Trimble, Novatel, Raven, Topcon and others.

BENEFIT ASSESSMENT

Our approach is to determine a suite of ITS applications that require a high accuracy location service, find the benefits of these applications, and associate them to C-HALO. The ITS applications analyzed are those listed by the FHWA [22]. A comprehensive list of these applications appears in [4]. This list is analyzed for its location accuracy requirements and we filter down the application list to 8 groups of applications. If the applications require 1m or less accuracy, the applications and their benefits are analyzed, and associated to C-HALO.

Each application is explored independently to determine the efficacy rate, and the monetary benefit from reducing accidents (and in turn injuries and fatalities), Vehicle Miles Traveled (VMT), travel times, emissions, and the like depending on the application. This type of methodology is similar to those used in other CBA's completed by the USDOT and other international governmental agencies. The method we use takes into account the cash flow estimates of the benefits over a 22 year period, and discounts those into "today's" worth via a discount rate that is proposed for this type of analysis by the congressional budgetary office. The analysis is similar to that adopted by the Allen Group [5].

The final list of applications can be seen in the table below:

ITS Applications	**Type**	**Included in Benefit Analysis**
Curve Speed Warning	Safety	Y
Forward Collision/Braking Warning	Safety	Y
Emergency Electronic Brake Lights		
Cooperative Forward Collision Warning		
Merge/Lane Change Applications	Safety	Y
Highway Merge Assistant		
Lane Change Warning		
Blind Spot Warning		
Blind Merge Warning		
Left Turn Assistant	Safety	Y
Stop Sign Movement Assistant	Safety	Y
Highway/Rail Collision Warning	Safety	Y
Intersection Collision Warning	Safety	Y
Corridor Management	Mobility	Y
Intelligent Traffic Flow Control		
Free-Flow Tolling		

ASSUMPTIONS

Some overall assumptions have to be made to estimate the benefits. Overall assumptions cover predictions we make about the national economy into the next 20 years, and general assumptions on how the new technology would be adopted by the ITS sector. We later on make application-based assumptions to estimate the particular efficacy of each application.

Technology Adoption Rate – The shape of this curve determines how quickly the fleet will adopt new technology, in this case C-HALO. The s-curve used in this analysis is leveraged from a report, by the Allen Group [5], which analyzes the benefits of high accuracy location data in non-ITS industries. The general shape of the curve is in Figure 3.

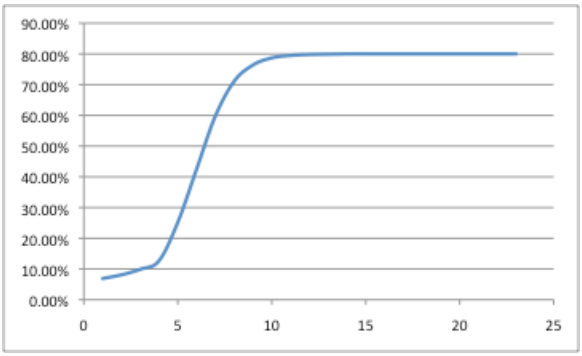

Figure 3: Technology adoption curve

This curve is applied over a project horizon of 22 years, 2008 – 2030. In calculating benefits, this adoption rate was typically used to determine the correct portion of benefits accumulated in a given year.

Discount Rate – This rate is used to discount future cash values to current day terms by taking into account inflation and a risk free rate of return, the higher the rate the more significant the discount to future cash values. For this analysis, a discount rate of 5 percent is used, and is taken from the Office of Budget and Management [23]. They also suggest using a range from 3 to 7 percent.

Value of Time – The value of time is used in quantifying reductions in delay into monetary benefits. Again, the Volpe study quotes two figures, one for local travel, $11.20, and the other for intercity travel $15.60. These figures are from the Office of the Secretary of Transportation [24]. In our analysis, we take both figures and average them since in our data we have both local as well as intercity travel. The resulting figure is $13.40.

Delay Growth – The delay growth is calculated using figures from the Traffic Congestion and Reliability Report prepared by Cambridge Systematics for the FHWA in 2005 [25]. Using a twenty-year historical data (hours of delay per traveler) and trend analysis, a growth rate of 6.5 percent is calculated.

SOURCES OF DATA

Accident Data – For the Safety applications, all accident data is culled from the GES database [26], which includes all types of accidents, not just accidents including fatalities. This database is then queried to ensure the appropriate accidents are being accounted for with regards to each individual application. Please see [4] for the querying methodology for each application class. We have also examined the FARS database [27], which includes fatal accidents.

Accident Growth Rate – The accident growth rate is used to project accident counts for years 2009 – 2030. The Volpe VII report projects accident rates based on VMT estimates and increased safety measures. These yearly accident rates are used to calculate the compound annual growth rate over the project horizon [24]. This rate is calculated to be -0.2 percent.

Fatality Worth – This value is used in determining the benefit of reducing the count of fatal accidents. The Office of Management and Budgets put forth a memorandum in 2008 that suggests to the DOT that $5.8 million be used for the value of a life. It also suggests using a range of $3.2 million to $8.4 million [28].

Injury Worth – These values are based on percentages of the fatality worth. Again there is a standard, and that is the Maximum Abbreviated Injury Scale. Typically there are 5 injury levels not counting a fatality [28]. In the FARS database only three levels of injuries are reported not counting fatalities. Therefore averages were taken first and second level and the third and fourth levels to determine the three percentages used in this analysis. The percentages used are in Table 1.

Table 1: Injury Worth Percentages

Injury Worth (% of Fatality Worth)	
Incapacitating	47.50%
Non-Incapacitating	5.80%
Possible/Light Injury	0.90%

SAFETY APPLICATIONS

As part of the safety analysis, seven applications are analyzed: Curve Speed Warning, Forward Collision Warning, Merge/Lane Change Warning, Left Turn Assistants, Stop Sign Movement Assistant, Highway/Rail Collision Warning, and Intersection Collision Warning. All of these applications are focused on reducing accidents, and in turn fatalities and other injuries. For all the applications below, the discounted yearly monetary benefit is calculated based on equation (1), where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Curve Speed Warning

Curve speed warnings would aid drivers in negotiating curves at appropriate speeds. This is aimed at reducing single and multi-vehicle accidents in curves due to unsafe speeds. To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the GES database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis. In 2008, there were 1048 fatalities, and ~29000 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective curve speed warnings could be. The three reports and results are summarized briefly below:

- Field Evaluation of the Myrtle Creek Advanced Curve Warning System (Oregon DOT 2006) – Empirical analysis of I-5 implementation near Myrtle Beach, over 75 percent of people reduced speeds entering the curves with dynamic message signage.

The FHWA report [24] uses this value as a measure of efficacy of the curve speed warning applications when assessing the benefits of wireless communication to ITS.

- Rural ITS Toolbox (FHWA 2001) – Empirical study for trucks in Colorado. Speeds were reduced by 25 percent.
- An Evaluation of Dynamic Curve Warning Systems in the Sacramento River Canyon: Final Report (CA DOT 2000) - Empirical analysis of five locations on
- I-5 in California, over 70 percent of people reduced speeds entering the curves with dynamic message signage.

Using these sources as references, we chose to use 40% accident reduction as a mid-level efficacy rate. A low level would be 20% while a high efficacy level would be 70%. For a matrix of the efficacy rates please see [4].

Using the formula (1) and a low efficacy rate, preliminary benefits of ~$54 Billion were estimated.

Forward Collision Warning

Forward collision warnings alert a driver when a forward vehicle brakes hard (deceleration is above a predetermined threshold). This is very similar to Cooperative Forward Collision Warning which is used to preemptively avoid rear-end collisions with vehicles in front of the subject vehicle. In 2008, there were 241 fatalities, and ~109000 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective forward collision warnings could be. The three reports and results are summarized briefly below:

- Evaluation of an Automotive Rear-End Collision Avoidance System (Volpe 2006) – A study that analyzed data from a field operation test and the results suggest that 10% of all rear-end collisions could be reduced.
- Integrated Vehicle Based Safety Systems: A Major ITS Initiative (FHWA 2005) – A study on IV systems that suggests these types of applications could reduce rear end, run off road, or lane change collisions by 48%.
- The Evaluation of Impact on Traffic Safety of Anti-Collision Assist Applications (Sala, Gianguido & Lorenzo Mussone, 1999) – A simulation study that suggests between 10% and 60% accident reduction could be attainable depending on the adoption rate of the technology. This is very interesting and one of the only studies that addresses changes in effectiveness due to technology adoption.

Using these sources as references, we chose to use 25% accident reduction as a mid-level efficacy rate. A low level would be 10% while a high efficacy level would be 50%. Using formula (1) and the low efficacy rate, preliminary benefits of ~$28 Billion were estimated.

Merge/Lane Change Warning

These warnings would alert a vehicle on highway on-ramps if another vehicle occupies its merging space (or in its blind spot). This is similar to Blind Merge Warning where warnings are used for vehicles attempting to merge with limited sight distance, and another vehicle is predicted to occupy the merging space. In addition, this system could warn the subject driver if a lane change is likely to cause a collision, triggered by turn signal activation. In 2008, there were 13 fatalities, and ~3500 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective merge or lane change warnings could be. The four reports and results are summarized briefly below:

- Integrated Vehicle Based Safety Systems: A Major ITS Initiative (FHWA 2005) – A study on IV systems that suggests these types of applications could reduce rear end, run off road, or lane change collisions by 48%.
- Freightliner to Offer Collision Warning on New Truck Line (Inside ITS 1995) – Empirical study of Transport Besner Trucking Co, which reduced its at-fault accidents by 34%.
- Dutch Field Operational Test Experience with "The Assisted Driver" (Alkim, Boostma, and Hoogendoorn 2007) – Empirical study of 20 vehicles in the Netherlands equipped with warning systems that were driven for five months. It found that unintentional lane changes were reduced by 35% on arterials, while it was reduced by 30% on highways.
- Run-Off Road Collision Avoidance Using IVHS Countermeasures: Final Report (NHTSA, 1999) – A simulation study that looked at lane departure warnings. Suggests passenger vehicle lane departures

$$B = (EffRate_j * Adopt_n * \sum(InjuryCount_{i,n} * Injury_i\% * FatalityWorth))/DiscountFactor_n \quad (1)$$

would decrease by 10%, while heavy trucks would decrease by 30%.

Using these sources as references, we chose to use 35% accident reduction as a mid-level efficacy rate. A low level would be 15% while a high efficacy level would be 60%. Using formula (1) and the low efficacy rate, preliminary benefits of ~$2.1 Billion were estimated.

Intersection Collision Warning

Intersection Collision Warning applications provide warnings to drivers that a collision is likely at the upcoming intersection either due to their own speed or inattention, or that of another driver. In 2008, there were 88 fatalities, and ~37000 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective intersection collision warnings could be. The two reports and results are summarized briefly below:

- Field & Driving Simulator Validations of System for Warning Potential Victims of Red-Light Violators (Inman, Vaughan TRB 2006) – A Field and Simulation study that tested participants in a driving simulator and on a closed track. In the simulator, 90% stopped or avoided the collision, while on the track, 64% stopped or avoided the collision.
- Intersection Collision Avoidance Study (FHWA Office of Safety 2003) – An in depth analysis of literature and operational concepts of specific ICAS systems, and they state that 100% reduction in accidents is not unrealistic, however a more conservative estimate would be a 50% reduction in accidents.

Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%. Using formula (1) and the low efficacy rate, preliminary benefits of ~$33 Billion were estimated.

Left Turn Assistant

Left Turn Assistants provide drivers information about oncoming traffic when trying to take a left-hand turn at an unprotected intersection. In 2008, there were 26 fatalities, and ~24000 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Since the application is very similar to that of intersection collision warnings, the literature used to determine an efficacy rate for that application were leveraged for this application as well. Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%. Using formula (1) and the low efficacy rate, preliminary benefits of ~$21 Billion were estimated.

Stop Sign Movement Assistant

Stop Sign Movement Assistants alert vehicles about to cross an intersection, after stopping, of cross traffic. In 2008, there were 110 fatalities, and ~10000 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected. Since the application is very similar to that of intersection collision warnings, the literature used to determine an efficacy rate for that application were leveraged for this application as well.

Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%. Using formula (1) and the low efficacy rate, preliminary benefits of ~$10 Billion were estimated.

Highway/Rail Collision Warning

Highway/Rail Collision warnings provide alerts to reduce the likelihood of a collision between vehicles and trains on intersecting paths. In 2008, there were 0 fatalities, and ~0 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected. Through another literature review, a report was found discussing how effective Highway/Rail Crossing Warnings could be. The report and results are summarized briefly below:

- Second Train Coming Warning Sign Demonstration Projects (TCRP Research Results Digest, 2002) – A demonstration study of two sites, one in Baltimore and the other in LA, where warnings were placed for approaching trains. 26% of drivers reduced the most risky behavior.

Using these sources as references, we chose to use 25% accident reduction as a mid-level efficacy rate. A low level would be 10% while a high efficacy level would be

50%. Using this formula and the low efficacy rate, preliminary benefits of ~$0 Billion were estimated.

MOBILITY APPLICATIONS

As part of the mobility analysis, two applications are analyzed: Intelligent traffic flow control and free flow tolling. Both of these applications are focused on reducing delay and require lane-level positioning accuracy to operate and therefore would benefit from a C-HALO nationwide deployment.

Intelligent Traffic Flow Controls (ITFC)

ITFC uses real-time data to adjust signal phases to an optimal level. These applications could also include Green Light Optimal Speed Advisory, which would provide the subject vehicle with the optimal speed given signal phase timing at upcoming intersections. To quantify the benefits of such a system two additional pieces of information are needed to complete the calculation. The first is to determine how much delay is currently realized at signalized intersections. This was done through a literature review, and Temporary Losses of Highway Capacity and Impacts on Performance (Phase 2), written by Oak Ridge National Laboratory for the Department of Energy, discusses sub-optimal signal timing specifically. Through surveying and significant quantitative modeling they determine that there is, as of 1999, ~295 million hours of delay at signalized intersections.

Lastly, the efficacy of these new systems needs to be estimated. Through another literature review, several reports were found discussing how much more optimal signal timing assisted in reducing delay. The three reports and results are summarized briefly below:

- Preliminary Evaluation Study of Adaptive Traffic Control System (LA DOT 2001) – Empirical study in LA with 375 intersections, reduced delay by ~21%
- Realizing Benefits of Adaptive Signal Control at an Isolated Intersection (Park and Change 2002) – A simulation study on a hypothetical intersection of two one-way streets. Reductions in delay were between 18-20%
- ITS Benefits: The Case for Traffic Signal Control Systems (Skabardonis 2001) – Empirical study of multiple California implemented systems, reductions of delay close to 25%.

Using these sources as references, we chose to use 15% delay reduction as a conservative efficacy rate. Using formula (1), preliminary benefits of ~$10 Billion were estimated.

Free Flow Tolling

Toll collection without toll plazas reducing stop and go traffic surrounding current toll plazas, also beneficial, but not included in this analysis is the fact that in tolling situations, costs are actually saved by not having to build facilities. In this exercise we only look at reduced delay. To calculate the delay reduced by free tolling systems, some metrics need to be deciphered. Average delay at a toll facility, the total revenue of all tolling facilities, and the average toll for toll roads in the U.S are three metrics needed to calculate total delay due to toll facilities. Again, this was done through a literature review, and Temporary Losses of Highway Capacity and Impacts on Performance (Phase 2), written by Oak Ridge National Laboratory for the Department of Energy, discusses average toll delay. Through thorough quantitative analysis, they determine the average tolling delay to be 11.9 sec per vehicle.

With this figure, only the number of vehicles would be necessary to determine overall delay. To determine the number of vehicles using toll facilities, total tolling revenues and average toll were sought. In the Highway Statistics 2007 published by the FHWA, the total revenues of toll facilities was $7.7 billion, while in the Toll Facilities in the U.S. August 2009, the average toll is calculated to be $3.89 (25). Using these two figures, an annual vehicle count of ~2 billion was determined. This was grown on a year-to-year basis at a rate of 1.65% (26).

Lastly, the efficacy of these new systems needs to be estimated. Through another literature review, several reports were found discussing how much free tolling systems reducing delay. The two reports and results are summarized briefly below:

- Evaluation of Impacts from Deployment of an Open Road Tolling Concept for a Mainline Toll Plaza (Klodzinski 2007) – Twenty-month empirical study done around UCF which reduced delays by approximately 50 percent.
- Operational and Traffic Benefits of E-Zpass to the New Jersey Turnpike (NJ Turnpike Authority 2001) – EZ-pass empirical study that showed 85 percent reductions in delay.

Using these sources as references, we chose to use 70% delay reduction as a conservative efficacy rate. Using formula (1), preliminary benefits of ~$0.6 Billion were estimated.

Efficacy Literature Caveat

The ITS application benefit numbers are from the RITA ITS Benefits database online. Since ITS funding is part of RITA's budget, we have found and checked benefit

numbers from some of these applications in documents from m the GAO (27), RAND (28), and CBO (29). These do not challenge the assumptions made and published by RITA with respect to the analyzed applications. The RITA database is the most comprehensive.

Summary of Benefits

After completing all these individual analyses, the sum of these benefits ranges from $160 billion to $320 billion. This range depends on whether one uses the low-level safety application efficacy rates or the mid-level efficacy rates. This translates into 1.1 to 2.2 percent of GDP. The safety benefits in the analysis dominate, making up over 90 percent of the total benefits calculated.

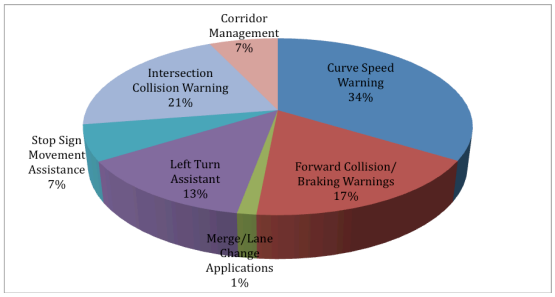

Figure 4: Benefits by Category

COST ASSESSMENT IN GOOD GPS AREAS

Here we quantify the new infrastructure investment required to realize a C-HALO service in areas with good GPS coverage based on N-RTK technology. This cost does not include the wireless communication technology between vehicles, but just the cost of deploying the infrastructure to provide the service. For the purposes of this analysis we explored the cost of implementing N-RTK infrastructure. This of course, is an upper bound on the cost estimate of the infrastructure since in reality some areas of the U.S. are already covered by N-RTK service, while others areas may not need it (i.e. some areas may already have C-HALO capability without N-RTK).

The present N-RTK system consists of a set of references stations and servers installed and maintained by companies/governmental agencies offering the service. Customers use the service by paying a subscription fee. The NRTK servers provide the rovers with the RTCM corrections as and when requested by the rover. A typical N-RTK system as implemented by companies like Trimble and adopted by the present DoT's, consists of the following components [29]:

1. N-RTK base stations with geodetic and communication capabilities
2. Server(s) that can handle incoming NRTK requests and RTK corrections, process the data and transmit the correction data to the rovers.
3. Communication links between reference stations and server(s) and the rovers and the server(s).

The capital costs involved in setting up such a system would include:

a) Hardware - NRTK reference stations (*) and the servers.
b) Software on the servers and reference stations. This should also have the ability to handle secure communication.
c) Design (hardware, site selection etc), testing and installation of the reference stations (*).
d) Predicted hardware and software upgrades (*).

Variable costs include

a) Hardware and software maintenance costs for the server and reference stations (*).
b) Rent/value of facility for the reference stations (*) and servers.
c) Link costs for the communication from reference stations to server (*) and from server to rovers.
d) Power supply to reference stations (*) and servers.
e) Customer support.

The cost estimates in Table 2 are for the installation and maintenance of a single base station and include the costs marked (*) in the NRTK system components.

N-RTK Base Station Cost Estimation

To begin estimating the infrastructure cost of deploying N-RTK infrastructure, discussions, via email and phone, were held with employees of three current N-RTK deployments, 2 state DOT's (Iowa and Ohio) and one Cooperative (Washington). During these emails and conversations the costs associated with infrastructure cost requirements, as well as maintenance and operating costs were focused on. We also obtained concrete documents on invoices and cost reports for the hardware, servers, services etc. from these DOT's [4]. These costs are summed and determined over the 22-year horizon using a 5% discount rate. The calculations are shown in Table 2.

	Cost Estimate (Per Base Station)
Hardware	**$20,000**
Software	$400
R&D	$300
IT	$120
Misc Hardware	$120
Servers	$90
Support/Maint	$1,000
Comm/Power	$1,000
Rent	$24,000
Other	$0
TOTAL per Tower	**$47,030**
PV of Horizon Cost	**$413,402**

Table 2: N-RTK Cost Estimation (No Other (Contingency) Costs)

This is the representative cost given average levels of all the above costs. There are low and high estimates for each cost category, including the useful life of the hardware, which ranges from 7 to 15 years. This useful life changes the 22-year horizon cost of the hardware. The range of infrastructure costs is from $220K to $615K per base station for the life of the system. Using a range of annual contingency expenses from $25K to $70K the range of infrastructure costs increases to $570K to $1.6M per base station for the life of the system. If one were to provide N-RTK coverage over the entire US land mass for the horizon of this project, approximately 2,730 base stations would be needed. Using this figure, nationwide N-RTK coverage would cost between $1.6 billion to $4.4 billion. This may be compared to benefits ranging between $160 and $300 billion from the Intelligent Transportation Systems Sector alone.

CONCLUSIONS

In this report we focused on estimating the benefits of a high-accuracy location service to the transportation sector and the costs of rolling out such an infrastructure. While accomplishing many things during this process, we realized that there are still many areas of research that could improve the analysis and enhance scope to incorporate more levels of detail. Areas of further explorations are briefly discussed below:

- *Communication Technology Research:*
  Further research needs to be done on how the actual augmentation services will be communicated to the vehicles and between vehicles. This analysis has not been included in this report, but is integral in realizing the benefits of the new ITS applications.

- *Benefit Refinement:*
  Ultimately, the benefits calculations could be expanded to include environmental benefits.

- *Technology Assessment:*
  To achieve a more thorough understanding of where N-RTK stands in terms of cost effectiveness a more complete technology assessment needs to be completed. As part of this, the cost of infrastructure for each technological alternative needs to be completed, as well as analyzing the capabilities of each technology. Once this analysis is complete, the technologies can be compared and a prudent decision going forward could be made.

- *Other Economic Stimulus:*
  Analysis could be completed on what type of economic development may be induced due to these applications, specifically the mobility applications since the main component of the benefits is saved time. Typically if users are saving time, they are using that time to create benefits in another industry or realm. These effects need to be explored more fully to get a better estimate of the full benefits of implementing C-HALO services.

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