**EXHIBIT A**
**SCOPE OF SERVICES**

# DEVELOPMENT AND DEMONSTRATION OF A COST EFFECTIVE IN-VEHICLE LANE DEPARTURE AND ADVANCED CURVE SPEED WARNING SYSTEM

## BACKGROUND

Lane departure by a single vehicle on a curved road is a major safety risk. There are some infrastructure based solutions to warn drivers of lane departure or warn about an upcoming sharp curve but generally these systems are cost prohibitive. Similarly, there are some in-vehicle lane departure and/or curve speed warning systems available today, but almost all of those are implemented only in luxury vehicles due to their high cost. Furthermore, most of these systems are vision based which rely on image processing of pictures taken by the cameras installed on the front or rear ends of the vehicle. These systems work reliably only when road markings are clearly visible, a condition unlikely to be met during adverse weather and lighting scenarios. Similarly, there are some lane departure warning systems using Global Positioning System (GPS) technology but these systems use differential GPS receivers with centimeter level accuracy along with high resolution road maps which add to the cost. In this project, we propose to develop and demonstrate a lane departure warning system which can also provide an advance curve speed warning, using ordinary GPS receiver technology and commonly available low resolution mapping data. The University's proposed system will utilize the high relative accuracy of an ordinary GPS receiver between two adjacent locations to determine the direction of travel or trajectory of a moving vehicle to issue a lane departure or an advance curve speed warning. The University's proposed system will be cost effective as well as will be easy to implement. Some of the implementation paths for our proposed system are by using it as an additional feature in an existing navigational system or as a standalone smartphone app, or it could be integrated in a Dedicated Short Range Communication (DSRC) onboard unit.

## OBJECTIVE

Almost half of the fatal accidents are caused by lane departure of a single vehicle speeding on a curved road or slowly drifting away from its lane due to countless reasons including driver error, distractions or drowsiness. Horizontal curves on United States roadways have about three times the crash rate as compared to tangent sections. In a Minnesota crash study, it was reported that 25-50% of the severe road departure crashes in Minnesota occur on curves, even though curves account for only 10% of the total system mileage. An advance curve speed and lane departure warning to the driver has potential to save lives. There are some lane departure warning systems available commercially but either those are too costly and/or have some performance limitations as discussed in literature review section at the end. In this project, the University will develop and demonstrate a lane departure warning system which can also give an advance curve speed warning to the driver. The University's proposed system will use an ordinary GPS receiver as well as the road maps containing only the road curvature information which is commonly available in all navigation devices as well as in any smartphone via Google Maps. The University's system will not only be affective in adverse weather scenarios but will also be cost effective. After successful development and demonstration of the proposed system, it will be ready to be added as an additional feature in any existing navigational devices or can be used as an app in a smartphone. Our developed system will positively impact many drivers especially those driving in Minnesota rural areas on sharp curves potentially saving lives.

## SCOPE

The University plans to develop and demonstrate a lane departure and advance curve speed warning system that will warn a driver of unintended lane departure on a straight or a curved road. Furthermore, our system can also give an advance warning to the driver ahead of approaching a sharp curve if driving at a faster speed than recommended for the upcoming curve. The University's designed system will generate warning for the driver in an audible sound or by activating a vibrating device.

The University's system will utilize GPS technology to determine lane departure. Generally, absolute position accuracy of an ordinary GPS receiver is in the range of 3-5 m which is not sufficient to determine any lane level drift in a vehicle's trajectory needed for lane departure warning system. However, the relative GPS accuracy is much higher and can be used for determining relative trajectory of a single vehicle. This concept is illustrated in Figure 1, below, where three and four adjacent GPS locations of a fast moving vehicle taken by a 10 Hz GPS receiver are shown as red dots, respectively, for a straight and a curved road. The true positions of the vehicle are shown as green dots but because of the GPS error, the GPS acquired location of the vehicle could be anywhere in the bigger dashed circle. However, the bulk of GPS error is caused by atmospheric disturbances. This error on all adjacent GPS positions will remain the same because atmospheric disturbances will remain constant over a wide area. Therefore, any residual GPS relative error will be only due to device specific sources and confined to smaller dashed circles as shown in Figure 1.

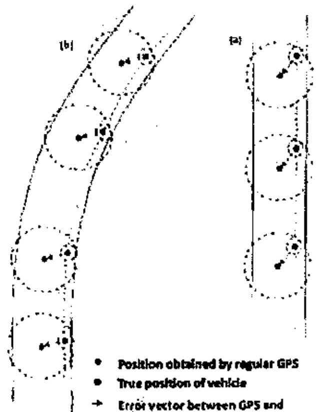


Figure 1: Conceptual diagram showing relative GPS accuracy versus absolute position accuracy for (a) a straight and (b) a curved road

Additionally, in the absence of any multipath interference, most of the device specific error will also not change much over adjacent GPS readings because adjacent readings are taken by the same GPS receiver within a short period of time producing a net relative GPS error comparable to that of the differential GPS. Therefore, the relative trajectory acquired by an ordinary GPS receiver turns out to be highly accurate. To confirm this hypothesis, we acquired a trajectory of a fast moving vehicle on straight and curved roads with an ordinary GPS receiver and the results are shown in Figure 2, below. The GPS acquired trajectories have no wiggles, which confirms the University's hypothesis that the relative accuracy of two adjacent locations acquired by an ordinary GPS receiver is much higher than the absolute position accuracy of each single location.

Figure 2: A trial of vehicle trajectory acquired by ordinary GPS receiver. Red dotted line is GPS acquired trajectory.

Using the highly accurate relative trajectory concept described above, the University will develop the proposed lane departure and advanced curve speed warning system as shown in Figure 3, below. This will consist of a GPS receiver along with the GPS antenna and an onboard unit. For this project, we will use a DSRC device as an onboard unit because it has a built in GPS receiver and the required processing power needed to implement our developed algorithms. There will be no DSRC communication needed in this project but a DSRC onboard unit, as the University's project could be integrated in a DSRC onboard unit as well. The University will develop the proposed lane departure and advance curve speed warning system in three different phases as described below.

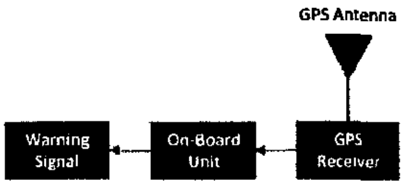


Figure 3: Block diagram of the proposed lane departure and advanced curve speed warning system

1. **Lane Departure Warning on a Straight Road**: In the first phase, the University will design and develop a lane departure warning algorithm for a vehicle travelling in one of the lanes on a straight road as shown in Figure 4, below. The GPS receiver will periodically acquire vehicle's GPS coordinates, which will be processed in the onboard unit in real time to update the relative trajectory of the vehicle. Different parameters like deviation angles ($\Theta_1$ and $\Theta_2$) and vertical distances to lane boundaries ($d_1$ and $d_2$) will be estimated periodically and updated in the onboard unit. The University will design an algorithm which will use these parameters to estimate if the vehicle has drifted away from a straight lane using deviation in its relative trajectory. This processing will take place in the onboard unit which will also generate a warning signal to activate an audible sound or a vibration alert.

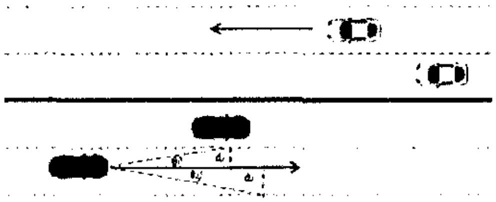

Figure 4: Lane departure warning scenario on a straight road.

2. **Lane Departure Warning on a Curved Road**: In phase 2, the University will update our designed algorithm to estimate the lane departure on a curved road as shown in Figure 5, below. For the curved road, the University will need road curvature information as a reference to design lane departure warning algorithm. The road curvature information is a small subset of commonly available road maps present in any navigational system or can be extracted from a Geographical Informational System (GIS). The University will extract road curvature information from one of these sources and store it in the onboard unit for access in real time. After the onboard unit acquires a GPS position of the vehicle, it will first determine which part of a particular road, the vehicle is traveling on so that it can access corresponding road curvature information stored in the onboard unit to implement our redesigned lane departure warning algorithm for the curved road. Once this algorithm is developed and tested, it will become a more general lane departure warning algorithm to be used for both curved and straight roads.

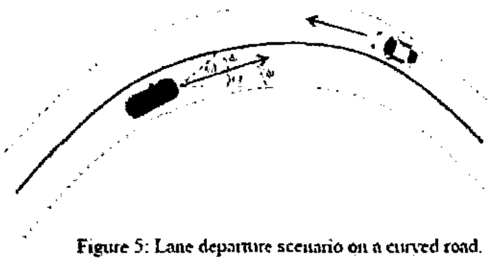

Figure 5: Lane departure scenario on a curved road.

3. **Advance Curve Speed Warning:** In this phase, the University will add another feature to the lane departure warning system to enhance its capability to warn the driver ahead of time if he or she is approaching a sharp curve while driving at a higher speed than recommended for the upcoming curve as shown in Figure 6, below. The road curvature information in the onboard unit (to be added in phase 2) will be used to issue such a warning. The speed of the vehicle will be updated in real time and the road curvature in front of the vehicle will be evaluated periodically to see if a sharp curve is ahead. If so, an advance warning will be issued depending upon vehicle's speed, its distance, d, from the start of the curve and the degree of curvature of the upcoming curve. For this kind of warning, we will still use an audible signal or vibration alert in this project but when implemented in a navigational device, a smartphone, or integrated in a DSRC onboard unit, a different kind of visual warning can be issued as well.

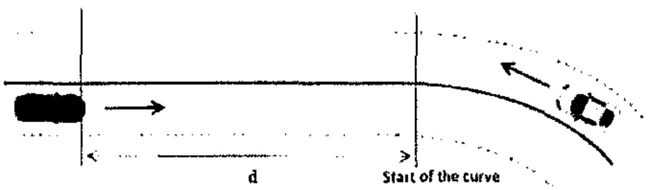


Figure 6: Advance curve speed warning scenario

After development of the lane departure warning system in three phases described above, the University will demonstrate the full system functionality on an actual road. After successful demonstration, it will be ready to be added as an additional feature in a navigational device or for development of a standalone smartphone app. We will promptly file for any intellectual property claims before proceeding to that route.

## WORK PLAN

### Task Descriptions

**Task 1: Develop and Demonstrate Lane Departure Warning System for a Straight Road**
The University will develop an algorithm for the lane departure warning system for a single lane on a straight road and implement this algorithm in an onboard unit which will be equipped with a GPS receiver. The University will also attach a warning signal (audible or vibration) device with it and demonstrate the functionality of this part of the system. As part of this task, the University will also do a statistical evaluation of our algorithm to determine the probability of false alarms and true misses.

**Task 2: Develop and Demonstrate Lane Departure Warning System for a Curved Road**
The University will develop an algorithm for the lane departure warning system for a curved road and implement this algorithm in an onboard unit. The University will also demonstrate the functionality of this part of the system under this task. As part of this task, the University will also do a statistical evaluation of our algorithm to determine the probability of false alarms and true misses.

**Task 3: Develop and Demonstrate Advance Curve Warning Algorithm**
The University will develop an algorithm for the advance curve warning and integrate this algorithm in an onboard unit to make a complete lane departure and advance curve speed warning system.

**Task 4: Demonstration of the Developed Lane Departure and Advance Curve Warning System**
In this task, the University will demonstrate the full system functionality of the complete system with all three features developed and implemented in first three tasks.

**Task 5: Compile Report, Technical Advisory Panel Review and Revisions**
The University will prepare a draft report, following MnDOT's publication guidelines, to document project activities, findings and recommendations. This report will need to be reviewed by the Technical Advisory Panel (TAP), updated by the University's Principal Investigator, and then approved by the Technical Liaison before this task is considered complete. Holding a TAP meeting to discuss the draft report and review comments is strongly encouraged. TAP members may be consulted for clarification or discussion of comments.

**Task 6: Final Published Report Completion**
During this task, the Approved Report will be processed by MnDOT's Contract Editors. The editors will review the document to ensure the document meets the publication standard. The University's Principal Investigator will then prepare the Final Report and submit it for publication through MnDOT's publishing process.

### Task Deliverables

| Task: | Deliverable(s): |
|---|---|
| 1: | Lane departure warning algorithm for a straight road, and partial system demonstration (video and/or pictures), and a brief summary report. |
| 2: | Lane departure warning algorithm for a curved road, partial demonstration of the system (video and/or pictures), and a brief report. |
| 3: | Advance curve warning algorithm, demonstration, and a brief report. |
| 4: | A report documenting final results and demonstration video or pictures of complete systems. The University will also demonstrate this system to anyone interested to spend some time in the field. |
| 5: | A Draft Report and Final Report Approved for Publication. |
| 6: | Final Published Report. |

**PROJECT SCHEDULE**

| | 2016 | | | | | | 2017 | | | | | | | | | | | | 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months:** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| **Task 1** | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | |
| **Task 2** | | | | | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | |
| **Task 3** | | | | | | | | | | | X | X | X | X | X | X | X | X | | | | | | | | |
| **Task 4** | | | | | | | | | | | | | | | | | X | X | X | X | X | X | | | | |
| **Task 5** | | | | | | | | | | | | | | | | | | | | | X | X | X | X | | |
| **Task 6** | | | | | | | | | | | | | | | | | | | | | | | | | X | X |

| **Task:** | **Draft Deliverable Due Date:** | **Final Task Approval Date:** |
|---|---|---|
| **1:** | December 31, 2016 | February 28, 2017 |
| **2:** | June 30, 2017 | August 31, 2017 |
| **3:** | October 31, 2017 | December 31, 2017 |
| **4:** | February 28, 2018 | April 30, 2018 |
| **5:** | April 28, 2018 | June 30, 2018 |
| **6:** | | August 31, 2018 |

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