# Proposal Cover Sheet - IDEA Programs

(Note: The total length of IDEA proposals shall not exceed 25 pages, including the cover sheet and all enclosures)

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<tr>
<th>Proposal Submitted to:</th>
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<th>NCHRP-IDEA</th>
<th>HSR-IDEA</th>
<th>Transit-IDEA</th>
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Title of Project: Detection of Aberrant Driver Behavior by Vehicle Motion Analysis

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<tr>
<th>Submission Date:</th>
<th>Sept. 3, 2004</th>
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IDEA Budget $79,046 + Cost Sharing $25,449
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Business Type: [X] Profit

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Brief Summary of Concept and Potential Impact on Practice:

A practical machine vision solution for the detection of aberrant driver behavior is proposed, based upon the identification of vehicle motions conforming to established visual cues acceptable as probable cause for interdiction. The system is applicable to interstate freeways, limited-access highways, and sections of roadways reasonably distant from intersections or cross-traffic. This approach utilizes video feeds from existing roadside surveillance cameras, and commercial off-the-shelf computer and video interface components. Computational requirements for real-time processing are considered in algorithm selection. A total system solution is proposed, including mechanisms for automatically alerting and providing visual evidence for situation assessment by law enforcement personnel in the field. Proof of concept work is proposed.

This system, if ultimately deployed, would be expected to have a significant potential impact in reducing the number of alcohol or drug impaired drivers, by providing always-on observation and assessment of all vehicles passing within the field of view of roadway surveillance cameras. By identifying and documenting high-probability cases prior to alerting law enforcement, the efficiency of limited enforcement resources may be enhanced.
Detection of Aberrant Driver Behavior by Vehicle Motion Analysis

Loragen Corporation, San Luis Obispo, California

SUMMARY OF CONCEPT

A practical machine vision solution for the detection of aberrant driver behavior is proposed, based upon the identification of vehicle motions conforming to established visual cues acceptable as probable cause for interdiction. The system is applicable to interstate freeways, limited-access highways, and sections of roadways reasonably distant from intersections or cross-traffic. This approach utilizes video feeds from existing roadside surveillance cameras, and commercial off-the-shelf computer and video interface components. Computational requirements for real-time processing are considered in algorithm selection. A total system solution is proposed, including mechanisms for automatically alerting and providing visual evidence for situation assessment by law enforcement personnel in the field. Proof of concept work is proposed.

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IMPACT ON PRACTICE

In 2003, 38,252 fatal accidents occurred in the United States. Of these, 15,251 or 40% were alcohol-related (1). While this percentage has decreased slightly since the advent of more aggressive enforcement of drunk driving laws, driving under the influence remains the single largest causal factor for fatal accidents on US highways (2). In addition, traffic crashes are the greatest single cause of death for ages from five through twenty-seven (3).

Commercial vehicle operators have traditionally been safer than the general motoring populace with regard to alcohol impairment, with only 2% of the 4,508 drivers of large trucks involved in fatal crashes in 2002 found to be alcohol-impaired (4). However, since 41% of all fatal accidents in 2002 were found to be caused by alcohol or drug impaired drivers, it is expected that this percentage of fatal accident involving heavy trucks were caused by DUI drivers of automobiles. Since accidents involving trucks are generally more severe, a possibly greater percentage of the 17,419 alcohol-related fatalities in 2002 (5) occurred in accidents involving heavy trucks. Traffic congestion caused by automobile accidents in general is known to have a profound but unquantified impact on the efficiency and cost of transport commerce.

Driver behavior associated with alcohol or drug impaired driving has been the subject of extensive research. One excellent summary of relevant research is available on-line at (6). This reference concluded that visual cues are the only non-intrusive means for detection of not only drunk drivers, but distracted or drowsy drivers as well, that collectively make up the large majority of drivers at fault for fatal accidents. The relative risk associated with each category for highways with speed limits over 50 mph is summarized in Figure 1, from (6). POV refers to “Principal Other Vehicle”, meaning the vehicle at fault in the accident.

Interdiction depends predominantly upon evidence consistent with legally acceptable probable cause to justify a vehicle stop. In most cases, this evidence is visual. Multi-agency research has contributed to improved interdiction success, in part, by providing patrol officers with useful and scientifically valid information concerning the behaviors that are most predictive of impairment. Continued aggressive enforcement of DWI laws will be a key to saving lives in the future (7). But available new enforcement methods are few, and often too intrusive. For example, in 1992 the Owner Operator Independent Drivers Association representing heavy truck operators sued the US Dept. of Transportation in an attempt to halt a pilot program for random roadside alcohol and drug testing (8). While the suit was unsuccessful, the message was clear: reasonable tradeoffs must be found that strike a balance between interdiction efficiency and disruption of highway operations.
Starting in 1979, the National Highway Traffic Safety Administration (NHTSA) sponsored research leading to the development of DWI (Driving While Intoxicated) detection standards, and has published these in the form of training materials, a DWI guide and a training video. The original 1979 guide to DWI visual cues was updated in 1997, and includes descriptions of behaviors that can be used by officers to detect motorists who are likely to be driving while impaired (9).

The researchers interviewed officers from across the United States and developed a list of more than 100 driving cues that have been found to predict blood alcohol concentrations, or BACs, of 0.08 percent or greater. The list was reduced to 24 visual cues during three field studies involving hundreds of officers and more than 12,000 enforcement stops. The visually detectable driving behaviors were classified in four categories:

1) Problems in maintaining proper lane position
2) Speed and braking problems
3) Vigilance problems
4) Judgment problems

The NHTSA reports that, on average, drivers exhibiting these visually detectable behaviors are DWI at least 35 percent of the time. Detection of more than one visual cue greatly increases this probability. For example, for observable weaving in or across lane lines, the probability of DWI is more than 50 percent. The combination of weaving cues and any other observable cue increases the probability of DWI to 65 percent. Observing any two cues other than weaving indicates a probability of DWI of at least 50 percent, although some cues, such as swerving, accelerating for no reason, and driving on other than the designated roadway, have single-cue probabilities greater than 70 percent (9).

**DWI cues related to problems in maintaining proper lane position:**
- Weaving,
- Straddling a lane line,
- Drifting,
- Swerving,
- Almost striking a vehicle or other object, and
- Turning with a wide radius, or drifting during a curve.
**DWI cues related to speed and braking problems:**
- Accelerating or deceleration for no reason,
- Unusually varying speed
- Excessively slow speed.

**DWI cues related to vigilance problems:**
- Driving without headlights at night,
- Failure to signal a turn or lane change, or signaling inconsistently with actions,
- Driving in opposing lanes or against traffic flow
- Slow response to warning signals or signs,
- Stopping in the lane for no apparent reason.

**DWI cues related to judgment problems:**
- Following too closely,
- Improper or unsafe lane change,
- Illegal or improper turn (too fast, jerky, sharp, etc.),
- Driving on other than the designated roadway.

**INVESTIGATIVE APPROACH**

We propose to develop, deploy and test a complete machine vision solution for the non-intrusive identification of possible aberrant driver behavior based upon real-time analysis of the movements of vehicles viewed by existing highways surveillance cameras. This system would typically be installed in the traffic management center (TMC) in which all surveillance camera feeds are available. It would serve as an “extra set of eyes” to monitor video feeds, and alert TMC or law enforcement personnel only in cases in which aberrant behaviors or incidents are detected with a high (user-variable) degree of confidence.

While the literature is extensive, most of the research on image processing of high-speed roadway scenes has emphasized tracking algorithms or processing hardware improvements. It is only within the past few years that the technology has reached the point of being able to extract trajectories reliably, and do so in real time. These advances have enabled the recent development of incident detection algorithms and enforcement algorithms, both of which typically look for unexpected velocities to activate an alarm. But there has been little research into automatically classifying behavior based on observed vehicle trajectories.

Recent advances in low-cost/high-performance computer and video technologies have made possible computer vision applications that, only a few years ago, were impossible or unacceptably costly. Applied to transportation management and traffic safety, these computational performance advances have enabled new horizons in automated surveillance and automated detection. Computer-vision-based detection systems are now in common use for signal actuation at intersections and traffic flow data collection on highways. A prominent example of a second generation machine vision application is the V2SAT (Video Vehicle Signature Analysis and Tracking) system developed for the California Department of Transportation (Caltrans) by Loragen Corporation. Fourteen nodes of this system are currently deployed in the Caltrans Detector Test Bed, located on I-405 in southern California, and are being used to classify and track the progress of every vehicle on the freeway between two test sites, using machine-generated visual signature vectors (10,11).

A logical progression from this development is the application of machine vision to assist law enforcement officers in the prescreening of the aforementioned visual cues. With wide-spread deployment of video surveillance cameras already in place, the prospect of machine-based 24-hour observation and automated alert generation for all cameras is timely and compelling. The effectiveness of law enforcement in DWI interdiction may be greatly enhanced above current methods. For perspective, the effectiveness of detection by random traffic enforcement stops at night has been found to be about three percent (12).

Not all NHTSA-classified visual DWI cues are detectable by observation of vehicle behavior alone. Many of the classified visual cues are pertinent only to surface streets, especially intersection behaviors. In preliminary research conducted by the authors, it has been concluded that only 18 of the 24 classified cues are detectable by machine vision from a fixed camera angle video feed. However, this subset represents the highest
probability indicators. These are indicated in Table 1 below, along with the probability that a driver exhibiting each behavior is legally DWI from (13), and an initial assessment of the difficulty of mechanization based upon preliminary algorithms developed by the authors.

Table 1. Machine Vision Detectable Visual DWI Cues, with DWI Probability, Derived from (3).

<table>
<thead>
<tr>
<th>Beh. Class</th>
<th>Visual Cue</th>
<th>DWI Prob</th>
<th>Comments</th>
<th>Machine detection difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turning with excessive radius</td>
<td>65%</td>
<td>More applicable to surface streets, but detectable on highway curves.</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>Straddling lane line</td>
<td>65%</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>Almost striking an object or vehicle</td>
<td>60%</td>
<td>Includes forced evasive action by another vehicle</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Weaving</td>
<td>60%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>Driving on other than designated roadway</td>
<td>55%</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>6</td>
<td>Swerving</td>
<td>55%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>Speed slower than 10 MPH below limit</td>
<td>50%</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Stopping without cause in traffic lane</td>
<td>50%</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>9</td>
<td>Following too closely</td>
<td>50%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>10</td>
<td>Drifting with respect to lane center</td>
<td>50%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>11</td>
<td>Tires on Center Lane or Lane Marker</td>
<td>45%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>12</td>
<td>Braking erratically</td>
<td>45%</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>13</td>
<td>Driving into opposing traffic (inc. wrong way on ramp)</td>
<td>45%</td>
<td>Requires camera view of onramps and undivided highway sections</td>
<td>Low</td>
</tr>
<tr>
<td>14</td>
<td>Signaling inconsistent with driving actions</td>
<td>40%</td>
<td>Requires trailing and restrictive camera angle</td>
<td>High</td>
</tr>
<tr>
<td>15</td>
<td>Traffic collision</td>
<td>35%</td>
<td>Wide range of possible incidents makes detection selective</td>
<td>Low-high</td>
</tr>
<tr>
<td>16</td>
<td>Abrupt/unsafe/illegal lane change</td>
<td>35%</td>
<td>Includes rapid multi-lane change</td>
<td>Moderate</td>
</tr>
<tr>
<td>17</td>
<td>Accelerating or decelerating rapidly</td>
<td>30%</td>
<td></td>
<td>Low-moderate</td>
</tr>
<tr>
<td>18</td>
<td>Headlights off at night</td>
<td>30%</td>
<td>Requires approaching and restrictive camera angle</td>
<td>Low-moderate</td>
</tr>
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Detection Methodology

The technical challenges associated with the use of video imagery for detection begin with the video camera and the sensing environment:

1. Wide range of ambient illumination conditions, over 70dB. Day/night/transition, diffuse or harsh lighting. Few surveillance-type video cameras have dynamic ranges exceeding 30 dB (17).

2. Vehicle occlusion. Reduced problem with high camera placement and steep view angle, but installations become costly an/or impractical).

3. Stationary shadows. Shadows from overcrossings, poles, roadside structures, trees, etc.


5. Video artifacts. Especially vertical or horizontal smear from bright points in image such as headlights or chrome glint. These create false video information which make image analysis very difficult.

6. Variable surface reflectivity. Complicates image backgrounding, a critical step in isolation of vehicle image from overall scene.
7. Processor and video capture throughput. Limits frame processing rate and ultimately the sophistication of algorithms.

These limitations are unavoidable, and fundamentally restrict both the utility and accuracy of video detection systems in any roadway application. Our understanding of these limitations has evolved from our prior experience conducting FHWA and Caltrans evaluations of video cameras (14), alternative imaging sensors (15,16), video image processing systems for traffic flow measurements (17,18), and video detection systems for signal actuation at intersections (19,20).

A compounding factor for the present application is the limited field of view of a typical roadside video surveillance camera. It is expected that, at best, a 1000 foot (10 seconds at 66 mph) interval of observation is possible for high camera placements (> 45 ft), with a 500 foot interval more likely for cameras mounted to overcrossings, for example, Figure 2. As will be discussed later, this limits the reliability of motion analysis algorithms since fewer motion features can be observed compared with longer periods of observation. Despite these limitations, if the objective is to identify only the most obvious aberrant behaviors, as well as actual traffic incidents, occurring in the camera’s field of view, the detection task becomes feasible, especially when conceived as a prescreening aid to law enforcement who will make the ultimate decision to act or not, based upon the video evidence.

Once a video stream has been acquired and digitized at full frame rate (60 video fields per second), the detection of aberrant vehicle motions by machine vision requires three fundamental algorithmic tasks:

1. Vehicle tracking

The sampled motion history of every vehicle in the camera’s field of view must be determined by analysis of every video frame (or every video field). The position, perimeter and velocity (all 2D measurements) for each vehicle are calculated for each video frame (actually, each video field at 60 fields/sec). The result is a discrete position-velocity vector as a function of sampled time for every vehicle of interest in the roadway scene. The problem of multiple target acquisition and tracking has been studied by many researchers for at least the past 25 years. Common to all approaches is the extraction of cohesive objects from fixed backgrounds, using a variety of approaches to deal with changing view of the object while in motion, and all the concomitants of inconsistent ambient illumination: variable background, static and dynamic shadows, reflective glint, saturation, drop-out, color-change, and video image artifacts such as smear and comet-tail. Ultimately, a vector of the time and/or velocity history for each object in image coordinates is generated, which is subsequently corrected to roadway coordinates by trigonometric correction based on knowledge of the orientation of the camera with respect to the road surface. Other characteristics of the object may be included in the vector to assist in robust tracking – chromatic (color) information in the form of hue and saturation, and approximate volume and perimeter of each object.

2. Motion analysis of object vectors

The roadway topology and constraints must be externally provided with the aid of a computer mouse to mark surfaces at known positions and heights with respect to the camera position, and to trace roadway dimensions and features such as lane lines. Subject to these defined constraints, probabilistic reasoning methods are used to identify vehicles moving in a potentially aberrant was with respect to the physical constraints as well as other vehicles. Indeed, the most egregious behavioral situations involve vehicle-to-vehicle interactions, for example, a vehicle motion that appears to cause a reactive motion by one or more other vehicles. The position-velocity history for each vehicle is analyzed, to identify with an acceptable degree of confidence, one or more of the previously-discussed visual cues considered admissible as probable cause for further investigation by law enforcement.

3. Detection, recording and alert law enforcement

Detection limits for each class of behavior may be operator-adjusted to avoid excessive false detections. Once a pre-determined probability threshold is exceeded for a particular vehicle, the video sequence containing the detected vehicle is digitally recorded in compressed form, with the vehicle highlighted. This
video sequence is transmitted to appropriate law enforcement in the field, which may confirm or reject the machine decision, and may elect to personally observe or intercept the vehicle. Cooperative detection of the same vehicle at multiple observation sites by more than one DDDS units may strengthen field conclusions prior to the decision to intercept. This additional capability requires automated vehicle re-identification capabilities, using signature matching algorithms of the type we used in V2SAT system deployed in the Caltrans detector Testbed on I-405 in Irvine, California.

**Vehicle tracking methods**

The effectiveness of the detection method is heavily dependent upon the accuracy and reliability of the method(s) used for the tracking of the multiple vehicle (objects, targets) as they pass through the field of camera view. The magnitude of this task is apparent from observation of a typical view from the position of a moderate-height surveillance camera, for example, Figure 2. In this sample view, from our V2SAT installation on I-405, over twenty potentially trackable targets are in view.

![Figure 2. View of multi-lane freeway from luminaire mount for surveillance camera.](image)

Fortunately, vehicle tracking is a mature research topic within machine vision. A large number of solutions have been posited, and some successfully deployed. The literature in this area is extensive, and a some commercial software packages are available, for example (21). Tracking acquisition must be robust, since the period of observation for a vehicle may be as brief as a few hundred feet or a few seconds (e.g., 500 feet for traffic traveling at 66 mph). Different detection algorithms are generally used for tracking daylight hours (whole-vehicle detection), and at night (tracking headlights or tail lights. One partial summary of methods is contained in (22). In the work proposed, we intend to apply one or more established methods for the vehicle tracking task, although we have not yet determined the optimal approach for this application. Selected published methods that we have considered are summarized below:

**Model-based tracking**

Expected features in the scene are identified, typically geometric shapes or “deformable snakes”. These are individually re-identified in successive image frames base on temporal proximity, forming a progression of successive coordinates (23). A modified version of this approach may include chromatic information from the
Object. This approach seems to work best when the perceived object shape, orientation and angle of view are invariant for the duration of the frame sequence and at any position in the scene. “Perceived” also implicates the effects of ambient outdoor illumination, which due to shadows, changing illumination angle, reflected glint, and sensory image artifacts related to saturation, can distort and sometime obliterate the expected model shape, causing a loss of track or false tracking trajectories. Processing can be done directly in image coordinates. Computational load is light-to-moderate, increasing linearly with the number of objects, making it acceptable for PC-class processing hardware. While very effective in automation applications with standardized illumination and viewing angles, this method has considered sufficiently robust for practical vehicle tracking for the intended detection application.

**Feature-based tracking**

Objects are identified as cohesive groups of fine “features”, physically related to object edges, perimeters, discontinuities, or point light sources. Feature groups are tracked over the frame sequence. Robustness is gained from the fact that not all features need to remain present to retain the object in track, and the method is generally tolerant of gradual changes in special relationships between the features (24,25). This method has been found to be particularly effective for tracking of vehicles under the constraints of ambient illumination and variable object orientation (26). It has also been deployed in simplified form for exact vehicle positioning prior to feature extraction for generation of vehicle signature vectors (27). Cohesive objects are extracted from the fixed background by frame differencing, and unified by identification of features such as vertices and points of discontinuity which move together in the field of view.

For the present application, an approximate object centroid may be determined for each object by treating feature points as the equivalent of point masses. The motion of this centroid frame-to-frame represents the time-position history of each vehicle in the field of view. A vector of the time history for each object in image coordinates may be generated, which is subsequently corrected to scene coordinates by trigonometric correction based on knowledge of the orientation of the camera with respect to the road surface. Other characteristics of the object may be included in the vector to assist in robust tracking – chromatic (color) information in the form of hue and saturation, and approximate object volume.

Computational load is moderate and highly variable, increasing linearly with the number of detected object features and the number of objects.

**Velocity-based tracking**

Used in applications requiring the measurement of the time history of the local velocity vector of an object or field of objects, usually for motion analysis rather than position tracking. Optical flow methods are used, and velocity calculated from frame-to-frame differences. Accurate velocity measurement requires conversion from image to scene coordinates based upon structural constraints (e.g., the road surface for vehicle tracking). Incremental position may be reconstructed by discrete integration, but as a practical matter would be inefficient compared with methods intended to track position (28,29).

**Coherent motion layer decomposition and analysis**

Successive video frames are decomposed into separate motion layers, each a field of relatively consistent motion. May also exploit the temporal coherency of motion layers and the domain constraints on shapes (30). Computational requirements high. Reported to be very robust in cluttered scenes, and for tracking of multiple targets subject to complex motions or interactions.

**Blobification and centroid tracking**

Following background differencing, cohesive clusters of pixels satisfying (possibly dynamic) threshold criteria for intensity or chromatic change are enclosed in a closed curve or “blob” of fixed order to isolate objects from the scene. Volume (mass), shape and expected motion criteria may be used to qualify legitimate objects vs clutter. A centroid may be calculated as the center of mass of each blob, and the frame-to-frame motion of the centroid provides an approximate position history of the object. Blob tracking is well-suited to multiple target tracking, and relatively robust to noise and image artifacts, which tend to be transient and fail to meet blob validation criteria. This method is also amenable to multi-spectral data fusion, and has been used by a.
number of traffic detection systems (18), by the authors for the performance evaluation of a broad range of imaging sensors (15,31). For the present application, this method, possibly in conjunction with feature-based tracking, seems promising (32). Computational requirements are moderate to high, increasing linearly with the number of objects, and the size or complexity of each object.

**Hybrid methods**

The concurrent use of more than one method has the potential to improve robustness or sensitivity. Indeed, many recent advances appearing in published literature seem to represent the incorporation features of multiple methods. Relevant to the present application, feature tracking combined with enhance model tracking may have particular merit in the tracking of selected objects in a large field of clutter. Data fusion between multiple sensors operating in different spectral bands may well benefit from hybrid algorithms. And velocity tracking methods may be of value in the analysis of the motion of a particular object, in conjunction with position tracking. Computational requirements may increase disproportionate to the requirements of the individual detection methods, due to the burden of object alignment and communications between processing threads.

**Motion analysis of object vectors for classification of driver behavior**

Motion analysis based on video frame sequences is also a well-established research area, supporting a wide range of applications including industrial automation, human kinesiology, sports performance enhancement training, military target identification and tracking, and medical analysis, e.g., automated motile sperm counts (33). Work in this area related to highway vehicle motion analysis is less advanced, with applications primarily in accident reconstruction (34), non-intrusive measurement of traffic flow metrics and detection of traffic incidents (35,36). The identification of visual cues based on vehicle motion indicative of an impaired driver has been a topic of considerable research in human behavior, as discussed earlier. However, the automated detection of these visual cues by machine vision is a relatively new area of study, still primarily in the theoretical stages and not yet mechanized as a practical working system. One notable exception, with more general objectives, is the National Highway Traffic Safety Administration (NHTSA) System for Assessment of Vehicle Motion Environment (SAVME). The SAVME system uses an array of pole mounted video cameras and a image processing system to extract trajectories at a test intersection to quantify the specific motions that vehicles exhibit during successful collision avoidance maneuvers, and to provide baseline non-crash driver performance data (37).

The time-position-velocity history for each object being tracked is inherently noisy and prone to failures to acquire as well as false acquisitions. A number of recent contributions have provided valuable contributions to overcome these problems. The application of Kalman filters as predictors or classifiers was advanced by (38,39,40). Tracking and motion analysis via optical flow have also been proposed for real-time vehicle obstacle avoidance (41). The use of 2D transform methods for motion characterization has been suggested by a number of researchers (42,43). In our preliminary work, we have applied least square polynomial curve-fitting in two dimensions as a means to reduce noise and loss-of tracking for position and velocity histories produced by a combination of feature and blob tracking. Assuming a 500 foot average field of observation, we found that a polynomial order of at least seven is required when acceleration histories are to be extracted, as required for detection of near-collision cues.

The computational requirements for multiple-target motion analysis are very high, increasing exponentially with the number of targets when vehicle interactions must be considered. PC-class computer performance is only recently at a level sufficient to perform complex computer vision tasks in real time, but it remains doubtful that a single high-performance processor could handle the computational load of both vehicle tracking and motion analysis in real time. Fortunately, these are separable processes that can be distributed between two or more processors. The concept work we propose will handle video data acquisition and vehicle tracking on one computer, and pass vehicle track vectors to another processor for motion analysis and detection.

In preliminary work (44), we have achieved a measure of success in identifying basic vehicle motions with respect to constraints using time histories of relatively simple geometric measurements and pattern-matching methods. For example, we have implemented real-time algorithms to detect poor lane discipline and weaving.
based on deviations from the mean vehicle path as defined by the trajectories of recent vehicles in that lane. According to the NHTSA (3), these simple motions constitute the largest and most probably class of DUI indicators, including behavior classes 1,2,4,5,6,10 and 11 in Table 1. Also in preliminary work we have successfully identified some vehicle-to-vehicle interactions from synthetic vehicle tracks, corresponding to aberrant behavior classes 3,9,13 and 15 by tracking the relationship between the position and velocity of each vehicle. The graphical measurements which form the basis for detection of some of these motion cues are illustrated in Figure 3.

![Figure 3. Graphical measurements used to detect some motions indicative of high-risk driving.](image)

Detection of a class 4 (weaving) motion is illustrated in lane 1 of Figure 3. Within the period of observation, the vehicle has deviated excessively from the mean vehicle path in both directions. It has also crossed a lane line and returned (Class 6), and on average is drifting from the lane center (Class 10) and is briefly “driving on “other than the designated roadway” (Class 5). The risk score associated with the combined detection of these classified motions would be sufficient to trigger an advisory for this vehicle.

In lane 2 of Figure 3, two vehicle are following too closely (Class 9), and the rear-most vehicle is decelerating at an excessive rate (Class 17), which in combination with its proximity to the second vehicle may indicate a near collision condition (Class 3).

Based on their position, direction and velocity histories, the estimated trajectories of the vehicles in lanes 3 and 4 converge, indicating an imminent collision (Class 3). In fact, the contact of their respective blobs suggests that a collision may have already occurred. If a collision did not occur in this case, the rapid deceleration (Class 17) and swerving motion (Class 4) necessary to avoid a collision would supplement the risk total for this vehicle to a level sufficient to generate an advisory.

The lead vehicle straddling lanes 3 and 4 demonstrates a Class 2 violation, which if persistent over the entire field of view would be assigned a high risk factor, possibly generating an advisory. Relative distance and velocity relationships are updated for each frame in corrected scene coordinates. Reasonableness bound checking may be required for noisy tracking data. While these calculations are simple, the number required for each time sample at 60 video fields per second is potentially very large. Computational requirements appear to be lower bounded by a binomial relationship, since pair-wise tests for vehicle interactions are involved, as well as vehicle-vs-constraint tests. This will be verified rigorously during the course of the proposed work. We have tentatively concluded that the computational requirements associated with 2D transform-domain methods are prohibitive for these relational tasks, and not necessarily appropriate, although this merits further investigation.
Detection and the decision to alert

The decision to generate an advisory, and subsequently to alert an operator or law enforcement, involves a mapping process which takes into account the number, type and severity of the potentially aberrant motions detected. We propose the use of fuzzy logic methods which appear to be particularly appropriate for this application, since detection decisions may not necessarily follow from simply thresholding the results of continuous cost (or loss) functions. Some considerations are discontinuous, such as admissible pairing decisions associated with interactions between proximate vehicles.

Fuzzy membership functions are defined for each aberrant motion class, accounting for the relative truth associated with the detection. Conditional “truth” of each membership function is processed through a fuzzy rule base, using an appropriate conjunction method (e.g., maximum confidence or multiplicative). Conditional output truth is determined by mapping to binary output membership functions (alert/not-alert). Defuzzification may be accomplished by either a modified centroid (center of gravity) method or simple direct comparison of the relative truth of the alert and not-alert output classes. An overview of the proposed decision process is illustrated in Figure 4.

![Figure 4. Fuzzy logic detection decision process.](image)

Example of possible implications (rules):

Rule No.
1. IF NOT swerving AND NOT drifting AND NOT following too closely … AND NOT near collision THEN no alert
   ....
   i. IF swerving AND drifting AND NOT following too closely … AND NOT near collision THEN no alert
   i+1. IF swerving AND drifting AND following too closely… AND NOT near collision THEN alert
   ....
   n. IF swerving AND drifting AND following too closely… AND near collision THEN alert

The order N^2 fuzzy rule base will be large but straightforward. The effectiveness of this approach seems to depend heavily upon the intuitive investment in the definition of input membership functions. The exceptionally high computational requirements of directly implemented fuzzy logic may require implementation as a fuzzy associate memory or multidimensional map. We are not yet in a position to conclude that this is the best approach. Design of the decision process will follow tests using actual data generated by the tracking and motion analysis algorithms from actual road data.

It is important to keep in mind that this application is intended only to yield decisions based upon probability thresholds. There is no expectation that this or any other form of non-intrusive behavior classifier could provide 100% detection accuracy. Considering the known and anticipated limitations of the imaging environment, the tracking methods, and the proposed motion analysis approach, reliable evaluation of the
motion of even 50% of all vehicles is unlikely. Considering the large number of vehicles passing through a surveillance camera’s field of view (typically 6000 vehicles/hour on major Los Angeles freeways), the decision process must be extremely conservative, admitting only the highest risk confidence cases for verification by a Traffic Management Center operator or law enforcement personnel. For such cases, a full-motion video record of the detected situation, showing the vehicle of vehicles involved highlight, is communicated to the operator or officers in the field. Using standard video compression methods (e.g., MPEG 4), communications in real time over private or IP-based wireless networks is feasible. Ultimately, this system is intended to serve only as a pre-screening aid to help extend the effectiveness of limited traffic management and law enforcement personnel. It may be reasonable to expect, however, that once known to the public, the deterrent value of a machine vision detection system which evaluates 24/7 all vehicles passing a particular site may greatly exceed its technical performance.

System Description

A highly simplified compensate hardware/software block diagram appears in Figure 5. For brevity, it is referred to as the Drunk Driver Detection System (DDDS).

![Figure 5. DDDS Simplified Hardware/Software Processing Diagram.](image-url)
Workplan

The complete development, deployment, testing and successful commercialization of the proposed system will require the following tasks. The proposed conceptual work consists of Tasks 1 through 11 only.

1. Field site and camera placement selection. Assessment of optimal location based upon required field of view, camera angle, avoidance of vehicle occlusion and shadow effects, and availability of convenient camera mount standards.

2. Selection of sensing hardware, including assessment of optimal spectral band. Update preliminary study of optimal sensing hardware based upon recent technology developments. Identify imaging requirements and translate these to camera specifications. Select appropriate spectral band of operation based upon system requirements. Select optimal optics for required fields of view.

3. Acquire preliminary video test data. Acquire videotape imagery from selected test locations, using several fields of view, camera angles and elevations. Generate examples of aberrant behavior motions with assistance of CHP on restricted highway.

4. Specify, fabricate and integrate development hardware. Select and integrate computer vision software development platform. Select and integrate video acquisition and digitization subsystem components.

5. Select, mechanize, test and refine algorithms for robust multiple vehicle tracking. Building upon prior work, study and develop best practical method for concurrent acquisition of up to 30 targets in image stream. Develop stable centroiding methods for robust position and velocity vector generation.

6. Develop computationally efficient geometric correction algorithms. Adapt and implement existing algorithms for correction of image coordinates to roadway coordinates.

7. Develop position-time vector extraction methods and appropriate data structures. Update preliminary work to mechanize optimal vector representation, storage, processing and data structures.

8. Develop, test and simulate behavior classification paradigms. Build upon preliminary work to mechanize algorithmic methods for detection of each aberrant behavior cue.

9. Optimize and implement architecture for associative rule base. Design best practical means for implementing classifier rule base. Detection algorithms implemented via rules governing individual vector characteristics relative to roadway constraints, as well as inter-vehicle interactions.

10. Adapt V2SAT algorithms for non-standard camera angle and field of view. V2SAT video signature analysis and tracking methods will be used for vehicle re-identification site-to-site. Existing vector detection and correlation methods will be adapted for use with large field of views and multiple targets.

11. Develop robust aberrant behavior decision engine. An ultimate decision mechanism will be designed and coded, which will utilize associative memory outcomes to arrive at alert/no-alert decision. Method of operation is equivalent to fuzzy ‘conjunction’ operation, although associative memory not restricted to classical fuzzy logic constraints.

12. Adapt V2SAT communications hardware and protocols for DDDS communications requirements. Existing wireless networking hardware and software will be adapted for communications between field units and TMC / operators’ console. Includes bi-directional communications data and compressed images.

13. Design / implement TMC console user interface. User-friendly graphical interface will be implemented for operators’ console. Will provide means for real-time parameter optimization, security features, and system diagnostics.

14. Laboratory test DDDS modules and system subgroups. Preliminary video test data acquired under 3 will be used to test, debug, refine and improve initial system and software components in laboratory.
15. Specify and prototype mobile communications hardware. Mobile communications hardware, for installation in CHP vehicles or at selected field sites, will be selected and integrated into a prototype system for field testing.

16. Develop and test mobile communications software. Data and image communications software will be developed and mechanized for use with hardware developed under Task 15.

17. Preliminary field tests. Initial testing of experimental system in field, using live video feeds.

18. System refinement/re-engineering. Experience gained in preliminary field and laboratory tests will be used to guide required or desired improvements, and implement additional features requested by operations and enforcement personnel.

19. Final field test. Field testing of refined experimental system using live video feeds, including selective CHP interdiction of detected violators.

20. Data reduction and analysis of effectiveness. Test data will be reduced to assess system detection accuracy, false detection rate, and reliability. Data will be reduced to composite metrics of accuracy and effectiveness.

21. Prepare final report. Compiled data and results of field and laboratory tests, including all observations and operational assessment feedback from CHP and operations personnel, will be reported. Review and revision process will provide for input from all involved parties.

Cited References

5. Center for Disease Control, "Impaired Driving", http://www.cdc.gov/ncipc/factsheets/driving.htm
10. Real-time view, Caltrans Detector Testbed and V2SAT system at http://www.testbed.uci.edu:8080/about.do
11. V2SAT, Operators Manual / Final report plus addendum


Detection of Aberrant Driver Behavior by Vehicle Motion Analysis

Loragen Corporation
Transportation Electronics Group
KEY PERSONNEL and FACILITY

C. Arthur MacCarley

Principle Engineer, Loragen Corp.  Professor of Electrical and Computer Engineering, Cal Poly, San Luis Obispo.  Ph.D., 1987, Electrical Engineering, Purdue Univ.  Registered Professional Engineer since 1980.  Former (2000-2003) Director of Cal Poly Computer Engineering Program.  Previous positions at American Bosch, University of Denver Research Institute, and Hughes Aircraft Digital Communications Laboratory.  25+ years experience in transportation electronics, practical video and computer vision systems, highway sensors/detectors, embedded controls and data communications.  PI on three current and over 30 prior Caltrans, FHWA and DOE funded projects including computer vision and advanced detection on highways, and technical evaluations of ITS systems.  Winner of 1997 Northrup-Grumman Research Award, and 1997 TRW Research and Education Award.  Over 25 academic and student-selected awards during 16 years at Cal Poly.  100+ related journal and conference papers and published reports on highway applications of advanced electronics and computers.  

Benjamin Coifman

Currently holds a joint appointment in the Department of Electrical Engineering and the Department of Civil and Environmental Engineering and Geodetic Science at the Ohio State University. He has been working to address the deficiencies in conventional traffic surveillance and control since 1995. The result of this work has been a better interpretation of traffic data, new aggregation methodologies for traffic detectors that provide greater accuracy, aggregation methodologies to extract new information from traffic detectors, vehicle reidentification techniques using the existing infrastructure to match vehicle observations between multiple point detectors and extend traffic surveillance to the entire roadway, development of non-traditional vehicle detection technologies, and data validation techniques to ensure traffic detectors are functioning properly. In the course of this work, the principal investigator developed the traffic detector component of the Berkeley Highway Laboratory (BHL), providing real-time vehicle actuations from eight detector stations to the University of California in real-time. In conjunction with the BHL, the vehicle reidentification system is now operating in real-time and on behalf of PATH, it was recognized by the ITS America award for The Best ITS Research in 2000. Dr. Coifman also received the NSF CAREER award in 2002 for traffic research.

Bryan Mealy

Research Associate, Loragen Corp.  Assistant Professor or Electrical and Computer Engineering, Cal Poly, SLO.  Ph.D., 2002, Electrical Engineering, Univ. of California, Santa Cruz.  Expertise in image processing and computer vision.  Prior related experience with Sierra Imaging, as designer of digital camera operating and image management software for HP, Toshiba, and other OEMs.  15 journal and conference publications.  
http://www.ee.calpoly.edu/~bmealy/

Chris Ackles

Senior Engineer, Loragen Corp.  M.S. 2003, Electrical Engineering, Cal Poly, San Luis Obispo, California.  Expertise in real-time programming and software engineering.  Lead software engineer on multiple projects for the California Department of Transportation, including the V2SAT (Video Vehicle Signature Analysis and Tracking) system, currently deployed in the Caltrans Detector Testbed.

Facilities and Experience - Loragen Corporation

Loragen Corporation is a small R&D company dedicated to highway applications of advanced electronics, computer and network technology.  Located in San Luis Obispo, California, Loragen was incorporated in 1997, but has operated under private ownership since 1991.  Loragen has a permanent staff of nine employees.  Three of the six employees, including the proposed project principal investigator, are professors of engineering or mathematics at the California Polytechnic State University, San Luis Obispo.  Four are students in computer engineering, electrical engineering, transportation engineering and statistics.  Additional faculty and students are employed as project needs arise.  Loragen serves as a mechanism by which projects with commercial potential may be developed by faculty and students at Cal Poly, which is primarily an undergraduate teaching university.  Current and recent research clients include U.S. Department of Energy, the California Department of Transportation, the University of California at Berkeley, Hughes Santa Barbara Research Center, the US Naval Electronic Warfare Center, Isuzu Motor Company, Ltd., and Wavetek San Diego.  

Detection of Aberrant Driver Behavior by Vehicle Motion Analysis
Loragen Corporation facilities include a complete video component and machine vision development and testing laboratory, including a large archive of traffic video in visible, infrared and millimeter-wave spectral bands, complete facilities for prototype electronics design and fabrication, including computer-aided design tools, a mechanical fabrication shop, advanced workstations for Linux, Windows and real-time software development and simulations, an automated engine dynamometer and emissions testing equipment, and in-house mail, web and ftp servers. Web site: http://www.loragen.com

The Loragen principal engineer and proposed project director, C. Arthur MacCarley, has an academic appointment as a professor of electrical and computer engineering at Cal Poly State University, San Luis Obispo, California. He is currently on academic leave.

Current and recently-completed projects include:

Loragen Corporation is completing the fifth year of a five-year program to evaluate the effectiveness of a large fully-automated driver warning system located in Interstate 5 near Stockton California. This required the design and deployment of advanced data acquisition instrumentation for the direct assessment of driver behavior in response to warning messages dynamically displayed by a network of 9 changeable message signs, in response to visibility or traffic conditions. Real-time view at http://caws-evaluation.loragen.com

**Video-based Vehicle Signature Analysis and Tracking, Phases 1, 2, 3 (1997-2005).** Computer vision system developed and deployed for automated detection and characterization of vehicles for tracking and re-identification purposes. System proven to acquire 99+% of vehicles correctly, and is used as reference for verification of all other sensors in the Caltrans Detector Testbed on I-405 near Irvine, California. Development work required solutions to a wide range of lighting and traffic conditions.

**Data-fusion study and data synchronization for the Caltrans Detector Testbed (2004-2005)**
Loragen is responsible for the development and operation of a system that acquires a video image for every vehicle passing through two 7-lane sections of I-405, at the moment of detection by a wide range of sensors under test in the Caltrans test bed. Video images are used to verify detection.

As part of a project to assist Caltrans Information Technology Group with the reduction of state-wide telecommunications costs, Loragen developed software to analyze and audit monthly SIBS (Statewide Integrated Billing System) telephone and data communications bills. Referred to as the “Bill Analyzer”, the application allows users to track, verify, and investigate all monthly recurring and special costs appearing on monthly Calnet statements. Using the internal accountability features of this application and procedures recommended by Loragen, Caltrans Division of Traffic Operations is implementing internal accountability for all telecommunications costs as a pilot cost-saving effort for the agency.

**Advanced Fuel Quantity and Rate Sensing for Diesel Fuel Injection Control (1996-99).** A US Department of Energy Energy-Related Inventions Program grant supported the development and commercialization of an advanced sensing and signal processing system for automotive diesel injection control that significantly reduces particulate and NOx emissions. This project follows 1989-92 NSF-funded research which established proof of concept.

**Machine-Vision-based Thermal Detection of Vehicle Operating Mode In Support of Hughes SBRC Smog-Dog Product Development (1996-98).** Developed a proprietary method for remote non-intrusive discrimination of automobile cold-start vs hot-operational mode, and acceleration mode. This infrared machine-vision system will become a part of the Hughes Smog Dog™ remote emissions detection system, which uses free-air spectrometry to measure tailpipe emissions of vehicles passing at high speed on highways.

**Pony Express RBI Electric Bus Project (1992-97).** (At Cal Poly) The Poly Pony Express Project involved the design of an electric transit bus using replaceable battery packs in a Rapid Battery Interchange (RBI) configuration. RBI allows quick replacement (under 1 minute) of the battery pack, virtually eliminating the downtime needed to recharge. The original development consortium included Pacific Gas & Electric Co., the California Energy Commission, SLO Transit, Caltrans, and Delco-Remy Division of General Motors.

**Advanced Traffic Control Field Operation Test, City of Anaheim (1994-99).** Dr. MacCarley and colleagues at USC and UCI served as the PATH FHWA (US Department of Transportation/Federal Highway Administration) FOT Detection of Aberrant Driver Behavior by Vehicle Motion Analysis
evaluation team, appointed to monitor an advanced traffic control field operational test being conducted by the Caltrans, the City of Anaheim and Odetics Inc.

Integrated Freeway/Arterial Traffic Control Field Operational Test, City of Irvine (1994-99). Dr. MacCarley and associates also served as the PATH/FHWA evaluation team monitoring the Irvine Integrated Ramp Meter and Arterial Signal Control Field Operational Test conducted by Caltrans, the City of Irvine, NET Corporation, and Farradyne Systems Inc.

OTHER RELATED PROPOSALS

None

COST SHARING

As indicated in the budget and Attachment 2, Loragen Corporation will directly cost share $25,449 of the overall project budget of $104,495. Cost share is in the form of professional labor and indirect costs associated with each of this contribution.

REPORTS and BRIEFINGS

As indicated in the budget and Attachment 2, one trip is budgeted for travel by the principal investigator to Washinton DC to brief the IDEA Committee on the outcomes and details of the project. In addition, it is anticipated the several journal and conference publications will follow from this work, published in appropriate technical forums, such as the TRB Annual Meeting, Transportation Research Record, and the IEEE Transactions on Image Processing and/or ITS.
## DETAILED BUDGET (see also Attachment 2)

Detection of Impaired Drivers by Vehicle Motion Analysis

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<tr>
<th>Personnel</th>
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<tr>
<td>Project Director (MacCarley)</td>
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<td>Research Faculty (Mealy)</td>
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Consultant - Vehicle Tracking
Ben Coifman, Ohio State University

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<td>Phone and network services</td>
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Equipment

| Processor, network and interface hdwr | 4,500 |
| Software: compilers, libraries, support | 2,000 |
| Video hardware, lab and field equip   | 2,400 |

Supplies, Materials, Services

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Total Direct Costs

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Facilities and Indirect Costs

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<tr>
<td>22%</td>
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<td>20,860</td>
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Total Budget

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<tr>
<td>Total Requested from Sponsor</td>
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*22% TDC indirect cost rate based on facility lease, insurance, utilities, state and local taxes and licenses, facilities and equipment maintenance and repair, amortization of laboratory and operating equipment, percentage of ongoing business administration costs.
## IDEA BUDGET SUMMARY

**Project Title:** Detection of Aberrant Driver Behavior Based on Vehicle Motion Analysis  
**Principal Investigator:** C. Arthur MacCarley  
**Organization:** Loragen Corporation, San Luis Obispo, California  
**Phone:** 805 781 8461  
**Project Duration (Months):** 12

### Personnel:

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<th>Sharing</th>
<th># hours</th>
<th>$/hour</th>
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<td>Principal Investigator</td>
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<td>74.50</td>
<td>$18,625</td>
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<td>Research Faculty (Bryan Mealy, Cal Poly, SLO)</td>
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<td>58.95</td>
<td>$2,358</td>
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<tr>
<td>Other staff (Computer Engineer, Research Assistants, Clerical Support)</td>
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**Subtotal:** $35,368  

### Consultants and Subcontractors:

- Ben Coifman, Ohio State University, 40 hrs.  
**Subtotal:** $4,000

### Materials & Equipment:

- Network and interface hardware ($4,500)  
- Video hardware ($2,400)  
- Purchased software packages, IDE, compiler ($2,000)  
- Technical supplies, mtrls, services. Clerical supplies ($4,100)  

**Subtotal:** $11,900

### Other Direct Costs:

- Network services and telecom ($1,800)  
- Travel – fields sites ($700)  
- IDEA Briefing, Washington DC. ($1,300)  

**Subtotal:** $3,800

### Overhead Costs:

- (22 %)  

**Subtotal:** $14,254  

### General and Administrative:

- (0 %)  

**Subtotal:** $0

**Total Cost:** $104,495  

### Proposed Cost Sharing

- Direct (cash) contribution from proposing organization: $25,449
- In-kind contribution from proposing organization: $_______
- Direct funding from other sources (specify): $_______
- Value of staff, etc., contributed by other sources: $_______

**Total Project Budget:** $104,495 (Total)  

**Requested:** $79,046

**Signature:** __________________________  
**Date:** Sept. 3, 2004

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Detection of Aberrant Driver Behavior by Vehicle Motion Analysis
Attachment 3. Liability Statement—Revised August 1997

This signature of an authorized representative of the proposing agency is required on the following unaltered statement in order for the IDEA Program to accept the agency's proposal for consideration. Proposals submitted without this executed and unaltered statement by the proposal deadline will be summarily rejected. An executed, unaltered statement indicates the agency's intent and ability to execute a contract that includes the provisions below.

Proposing Agency: Loragen Corporation, 3576 Empleo St. Unit 1, San Luis Obispo, CA 93401

Name C. Arthur MacCarley  Title Principal Engineer

Signature Date Sept. 3, 2004

CONTRACTOR LIABILITY

(a) The parties agree that the contractor and its employees and agents ("Contractor") will be primarily responsible for performing the work required under the contract, and shall therefore be legally responsible for, and shall indemnify and hold the Academy harmless for all claims asserted against the Academy, its committee members, officers, employees, and agents, by any third parties, whether or not represented by a final judgment, if such claims arise out of or result from Contractor's negligent or wrongful acts in performing such work, including all claims for bodily injury (including death), personal injury, property damage, and other losses, liabilities, costs, and expenses (including but not limited to attorneys fees).

(b) With respect to entities of State government that are subject to State law restrictions on their ability to indemnify and hold harmless third parties ("Restricted State Entities"), the obligation to indemnify and hold harmless the Academy in Paragraph (a) shall apply to the full extent permitted by applicable State law. In addition, each Restricted State Entity executing this contract represents and warrants that no part of any research product or other material delivered by such Restricted State Entity to the Academy ("Work Product") shall include anything of an obscene, libelous, defamatory, disparaging, or injurious nature; that neither the Work Product nor the title to the Work Product will infringe upon any copyright, patent, property right, personal right, or other right; and that all statements in the Contractor's proposal to the Academy and in the Work Product are true to the Contractor's actual knowledge and belief, or based upon reasonable research for accuracy.

(c) The term "wrongful act" as used herein shall include any tortious act or omission, willful misconduct, failure to comply with Federal or state governmental requirements, copyright or patent infringement, libel, slander or other defamatory or disparaging statement in any written deliverable required under the contract, or any false or negligent statement or omission made by Contractor in its proposal to the Academy.

(d) The obligations in paragraph (a) of this clause to indemnify and hold harmless the Academy shall not extend to claims, damages, losses, liabilities, costs, and expenses to the extent they arise out of the negligent or wrongful acts or omissions of the Academy, its committee members, officers, employees, and agents.

(e) Both the Academy and Contractor shall give prompt notice to each other upon learning of the assertion of any claim, or the commencement of any action or proceeding, in respect of which a claim under this paragraph may be sought, specifying, if known, the facts pertaining thereto and an estimate of the amount of the liability arising therefrom, but no failure to give such notice shall relieve the Academy or Contractor of any liability hereunder except to the extent actual prejudice is suffered thereby.

(f) The Academy and Contractor agree to cooperate with each other in the defense of any claim, action, or legal proceeding arising out of or resulting from Contractor's performance of the work required under this contract, but each party shall control its own defense. The Academy shall also have the option in its sole discretion to permit Contractor or its insurance carrier to assume the defense of any such claims against the Academy.

(g) The obligations under this clause survive the termination, expiration, or completion of performance under this contract.