WORK-ZONE SAFETY ITS

Technical Analysis
and System Proposal

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16. Abstract

This interim report presents the broad concept for an *adaptive* traffic signaling system for work zones based on a *distributed* system of traffic speed sensors and traffic signaling devices. Both the sensors and the signals are seen primarily as rather simple, inexpensive, short-range devices deployed in substantial numbers at the work zone in the form of "smart barrels." Such barrels would nominally have the appearance of today's common, work-zone traffic-control barrels. Each barrel would communicate with "supervisory" computers that would process the distributed speed measurements and dispense commands for appropriately adjusted and distributed signaling based on existing speed differentials. The system is intended to be readily deployable, requiring little more effort than currently needed to set up today's systems of traffic control devices at work zones.

The document discusses what is seen as probably the most challenging technical problem of such a system, a sufficiently inexpensive, but technically capable traffic speed sensor. In successive sections, the document reviews detector requirements, existing detection technologies, technologies selected for evaluation, and a plan for prototype testing and evaluation. A bibliography of technical and commercial references on sensor technologies is included. Concepts for the signaling devices are discussed in the companion interim report by John Sullivan, *Work Zone Safety ITS: Human Factors Analysis And Pilot Research Proposal*, UMTRI, May 2004.

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1. INTRODUCTION

This document is an interim report by the University of Michigan Transportation Research Institute to the Federal Highway Administration under Contract DTH61-01-C-00049, Work Zone Safety ITS.

Estimates of the increased crash risk in work zones have varied widely from 26% to 168% depending on the circumstances. Despite the lack of quantitative precision, it is evident that work zones increase crash risk. The main objective of the Work Zone Safety ITS project is to develop a technology that directly reduces the incidence of work zone crashes.

Contributing factors cited in work zone crashes include the speed differential between two vehicles, irregular maneuvers, and speeding in challenging locations. Of these, speed differential is the most obvious explanation for the prevalence of rear-end collisions in work zones. A simple theory of work zone risk suggests that as traffic density in a work zone increases, traffic slows down in the heavily congested areas, causing a backup of slow-moving traffic upstream of the congested area. The speed differential between slow-moving traffic and the traffic moving at posted speeds becomes a hazard because of the driver's uncertainty about *where* it occurs, the *magnitude* of the speed differential, and the *span* of roadway over which the differential is observed.

This document first presents the broad concept for an *adaptive* traffic signaling system for work zones based on a *distributed* system of traffic speed sensors and traffic signaling devices. Both the sensors and the signals are seen primarily as rather simple, inexpensive, short-range devices deployed in substantial numbers at the work zone in the form of "smart barrels." Such barrels would nominally have the appearance of today's common, work-zone traffic-control barrels. Each barrel would communicate with "supervisory" computers that would process the distributed speed measurements and dispense commands for appropriately adjusted and distributed signal intensity based on existing speed differentials. The system is intended to be readily deployable, requiring little more effort than currently needed to set up today's systems of traffic control devices at work zones.

Following the presentation of the system concept, the document discusses what is seen as probably the most challenging technical problem of such a system, a sufficiently inexpensive, but technically capable traffic speed sensor. In successive sections, the document reviews detector requirements, existing detection technologies, technologies selected for evaluation, and a plan for prototype testing and evaluation.

This document concentrates on the speed-sensing and speed-data-processing aspects of the system. Concepts for the signaling device are discussed in the companion interim report by John Sullivan, *Work Zone Safety ITS: Human Factors Analysis And Pilot Research Proposal*, UMTRI, May 2004. Among the more promising concepts is a pair of alternately blinking lights mounted on the barrel where "intensity" adjustment would be manifest in blink rate and duty cycle. In interpreting this document, the reader is advised to simply assume such a signaling device.

2. CONCEPT OF THE WORK-ZONE SAFETY ITS SYSTEM

The work-zone safety ITS system presented here is intended to provide distributed speed-advisory signaling which automatically adapts to the current traffic flow situation in the work zone. As shown in figure 1, the system is primarily based on the notion of a "smart barrel," a device similar in appearance to today's work-zone traffic-control barrel but containing a short-range traffic-speed sensor, a simple but adjustable signaling device and short-range communication equipment for interfacing with supervisory computers. Such smart barrels would be distributed in large numbers and at relatively short intervals throughout the work zone—as ordinary traffic-control barrels are distributed. The distributed traffic-speed data would be received and processed by the supervisory computers to provide rapid, real-time adaptation of the distributed signals as appropriate for the existing speed differential through out the work zone.
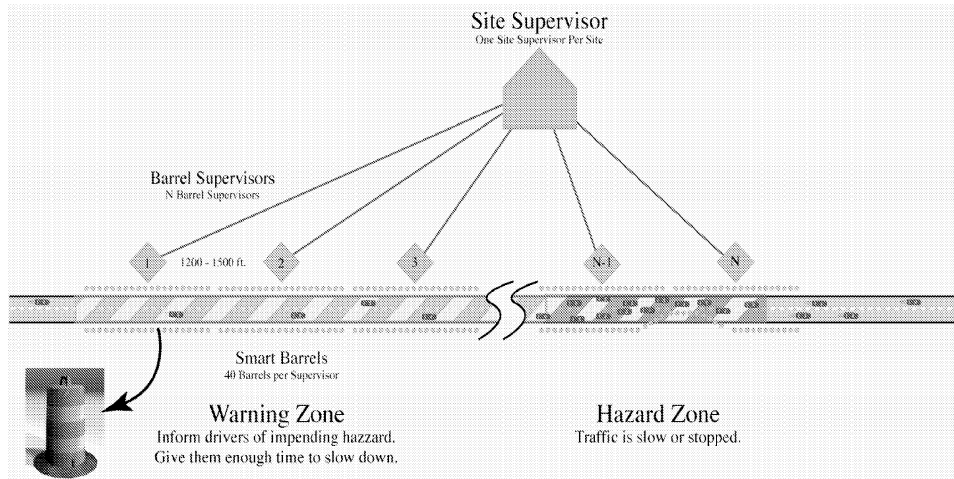

Figure 1. System concept

2.1 SYSTEM CONFIGURATION

The system consists of *smart barrels*, *barrel supervisors*, and a *site supervisor*.

Smart Barrel

Figure 2 shows the major elements that comprise a smart barrel. A low-power microcontroller contains a local clock that is synchronized to GPS time via inputs from the barrel supervisor. It has program logic and hardware interface elements to derive speed from the detector(s) and control the on/off state of the signals (LEDs). It should also be able to go into a low power sleep mode when low traffic density permits. A message containing the barrel identification, time, and vehicle speed is sent when a vehicle (or portion of a vehicle) is first detected. Closely spaced vehicles may not require a new communication.
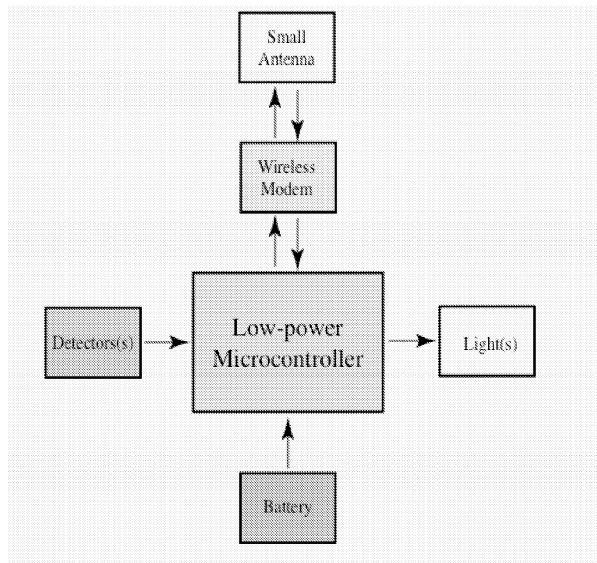
Figure 2. Configuration of a smart-barrel

Individual barrels will not include GPS hardware. However, each barrel's LAT/LON will be determined during set up (see section 2.2). A "tilt" sensor will be contained in each barrel to warn the supervisor if the barrel has moved since setup.

Each barrel would be powered by its own battery providing long-term operation on a single charge. Low-power communications ability is essential for this to succeed. For purposes of explanation, an actual radio module will be described here even though a fully communicating system may be beyond the scope of this phase of the project.

The Wi.232DTS (Radiotronix) embedded wireless module combines a high-performance DTS spread-spectrum transceiver and a protocol controller to create a transparent wireless solution to replace conventional RS-232/422/485 wiring. It can be used in point-to-point, point-to-multipoint, or multipoint-to-multipoint applications. Its footprint is less than one square inch and cost is estimated at $20 in production quantities. The module is designed to interface directly with standard UART signals from a microcontroller. It can use a printed-circuit board antenna or an external 1/4-wave whip antenna. In this application, the set of barrels "attached" to a *barrel supervisor* would share a single data channel and part of the maximum data rate of approximately 150 K Baud. The set of barrels and their supervisor should be in line of sight within a maximum range of 1000 to 1500 feet. Thus the number of barrel supervisors is determined by barrel spacing and the terrain.

The detectors should reliably sense the speed of vehicles in the immediately adjacent lane. Stopped vehicles are not directly transduced but are deduced (see section 2.3). Detectors should also consume as little power as possible and be immune to variations in weather, vibration, and other disruptive influences as found in a typical roadside application.

Barrel Supervisor

The barrel supervisor acts as a gateway between its barrels and the site supervisor. It could be attached to the back of a sign that is also used to signal drivers. The main parts are diagrammed in Figure 3. The heart of this system is a low-powered embedded PC chosen because of the experimental nature of the system development and ease of programming. A final product might use a simple microcontroller. The system contains one or two of the same wireless modules that are in the smart barrels. In addition, it needs a higher-power (longer range radio) modem to talk to the site supervisor. The higher power consumption of this system will probably require a solar panel to charge the battery.
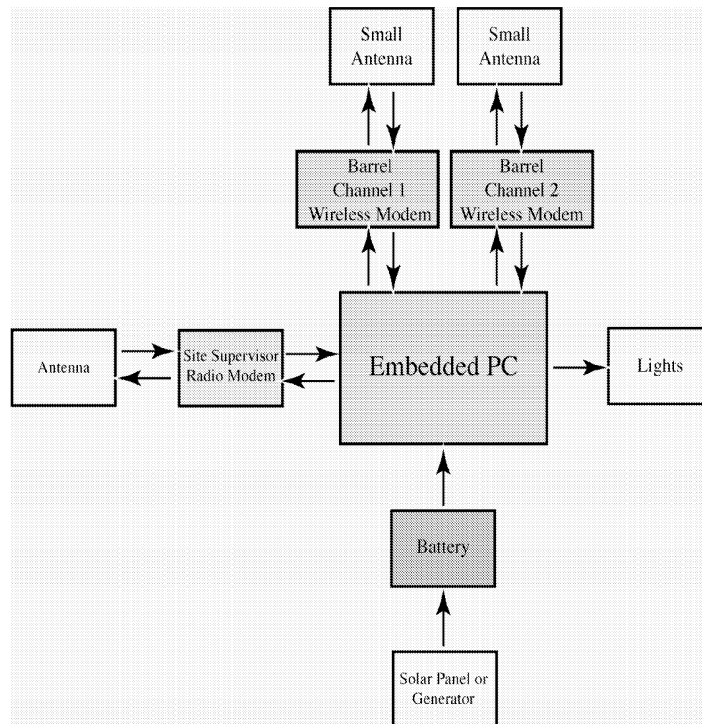

Figure 3. Configuration of a barrel supervisor

The barrel supervisor collects speed readings from the barrels and forwards them to the site supervisor. It also receives signal commands and time synchronization messages from the site supervisor and relays those to its barrels. It would also participate in setting the barrels to a low-power standby state and then reawakening them when traffic approaches.

Site Supervisor

The site supervisor is the brains of the system. A possible hardware configuration is shown in Figure 4. It has a GPS receiver to synchronize its clock and to locate it and the smart barrels. A GPRS cellular modem is provided for reporting to funding or managing agencies. Since all of the barrels have Lat/Lon coordinates (established upon setup), automatic reporting of work zone location, extent, and traffic conditions is possible.
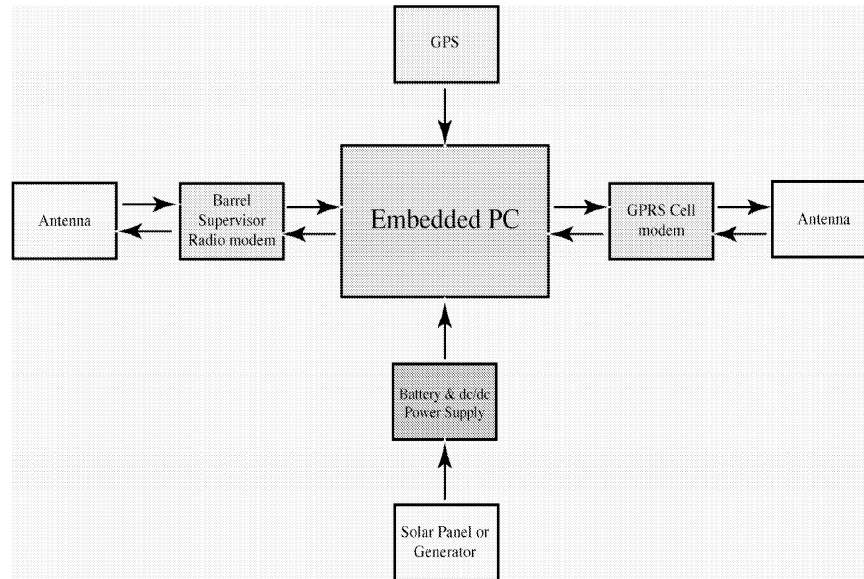
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Figure 4. Configuration of the site supervisor

The site supervisor receives time-stamped, ID'ed speed readings from the barrels via the barrel supervisors. The algorithms described in the next section create signaling commands that are sent out to the barrel supervisors and then to the barrels or other connected driver warning or communication devices.

2.2 SETUP AND CALIBRATION

Barrels are turned on and placed along the lane(s) of travel with attention paid to proper alignment relative to the traffic lane of interest. When a set of barrels has been placed, a configuration box is used to send an initialization message to the barrels to tell them to switch their radios to the proper channel and then to enter a low-power active standby mode. After the barrel supervisors and site supervisors are powered and initialized, the barrels are switched to active mode and begin speed sampling.

Next the barrels need to be located. A laptop computer with a 10 or 20 Hz differential GPS is placed in a suitable vehicle. The vehicle is driven three times (in each lane of interest) over the length of the deployment. GPS time, altitude, latitude, and longitude are collected and written to file or files on the laptop hard disk. The files are then transferred to the site supervisor computer via an ethernet connection. The site computer imports these files and uses the times in the file to connect the vehicle path to the time-stamped speed data collected from the barrels. Thus "the barrels" are located on the map. (Note that, more precisely, it is the position of the *vehicle* at the moment the barrel senses its speed that is actually determined. This, in fact, is the more desirable location information.) Distances and grades between barrels is then calculated and stored for use in system operation (see section 2.3). The site supervisor can now start its normal operating algorithms.

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2.3 OPERATION

Determining signal intensity based on distributed speed measurements

Actual development of full system software is beyond the scope of this phase of the Work Zone Safety ITS project. Nevertheless, it is necessary to "develop" system algorithms at least at the conceptual level in order to have a basis for design of the hardware elements discussed above. The following discussion presents the structure of the core algorithms at this basic level. For the moment, these concepts are limited to single-lane traffic, although we believe they will be readily adaptable to multilane situations.

Signal intensities (presumably to be manifest as blink rates) to be displayed at each individual signaling device are expected to be set primarily on the basis of the deceleration required of faster-moving traffic to avoid collision with slower-moving traffic ahead, but with additional adjustment based on over-speeding relative to the posted speed limit.

Addressing the deceleration basis first, signals would not be activated unless the required deceleration exceeded a minimum threshold. When required deceleration did exceed the minimum, signal intensity would be adjusted, either proportionately or in steps, to progressively higher levels up to a maximum associated with upper deceleration threshold. Although the specific thresholds of deceleration remain a matter of study (in the simulator) and would, at any rate, be adjustable in a final system, our expectation would be for a minimum threshold of about 0.05 g (0.5 m/sec^2) and an upper threshold of about 0.15 g (1.5 m/s^2). This expectation derives from recognizing that (1) the deceleration capability of heavy trucks, not passenger cars, is the more important reference and (2) our understanding of the distribution of braking deceleration of trucks in real use. It also should be noted that, in practice, deceleration thresholds would be adjusted for the grade. That is, on descending road segments, the thresholds would be reduced in accordance with the downward grade and, similarly, increased on ascending road segments.

A similar adjustment of intensity would be based on over speeding relative to the posted speed limit. In a fashion analogous to the deceleration procedure, this calculation would define a minimum threshold of over speed and an upper threshold and vary intensity in proportionately (or step wise) across the range they define.

Finally, of course, the actual intensity setting used would be the higher of the respective results of the deceleration and the over-speed criterion.

Data-collection and processing

Figure 5 presents a highly generalized flow diagram of the data-collection and calculation process envisioned for the site supervisor. The process is shown as a continuous loop whose cycle time would be on the order of 10 Hz or more.

As the first step of the process at the top of the figure, speed data is collected from each of the distributed speed sensors. These data include the speed value, the sensor ID

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(providing location) and a time stamp. Note that if traffic speed and density are relatively high, a given sensor may well have made more than one measurement in the preceding cycle period. On the other hand, other sensors may have had no vehicles pass by during the cycle period, in which case they would transfer no new data.

Following data input, each new data point is checked for validity. This is primarily a "reality check" to remove spurious data. Each new data point would be compared with current and recent data from neighboring sensors and "impossible" readings would be discarded. Valid data would be added to the data record.
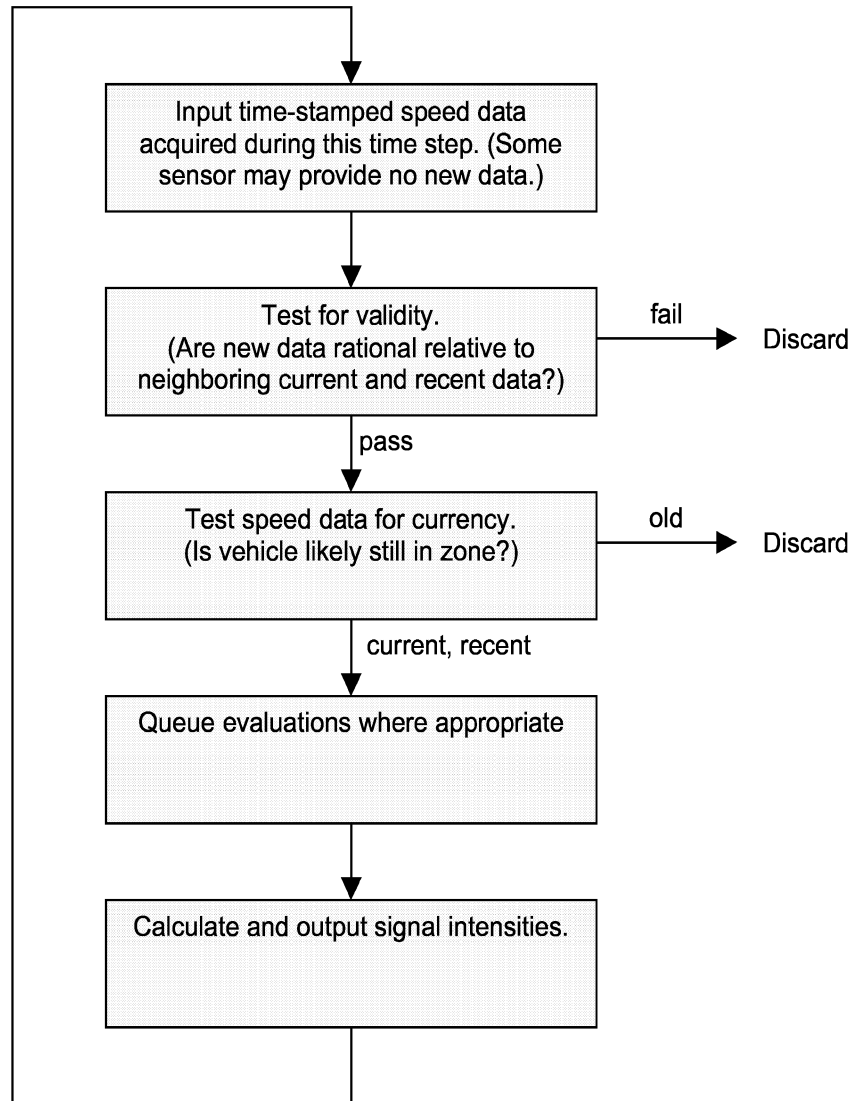

Figure 5. Generalized flow diagram of speed-data collection and signal-intensity calculations

The data is then checked for "currency." That is, given the measured speed, the distance between sensors, and the time elapsed since the measurement, is the vehicle which generated the measurement likely still in the measurement zone. Where traffic is moving slowly or stopped, a measurement taken by a given sensor would stay current for a substantial time and many many process cycles. Where traffic is moving rapidly, a

measurement may derive from a vehicle which passed completely through the measurement zone within a single cycle period. Data for vehicles still in the zone of measurement would be designated as "current" in that zone. New data would be current in either the zone of measurement or a down-stream zone where the vehicle is predicted to be. Where multiple data are current for a single zone, the maximum (or perhaps average) speed would be used to represent the zone. The data record would also retain at least several "recent" readings from each sensor zone (primarily for use in the validity check). Finally, if there is no "current" speed value for the first barrel (upstream) of the system, an "expected" speed, based on the recent history of speeds of entering vehicles would be assigned as the current speed for the first zone.

The data can then be further processed to evaluate the queue growth where this is appropriate. Whether or not this is worthwhile undertaking is largely determined by the spacing of sensors. Where sensors are relatively closely spaced (on the order of the stopping distance of vehicles at the nominal speed of travel, or less), queue evaluation is not necessary. For example, with sensors in every smart barrel and barrels spaced by the often-used rule of spacing in feet equal to two times the speed in miles per hour, queue evaluation would not be needed. That is, large differences in speed between adjacent sensors would constitute an un-salvageable situation; to be effective, warnings would have had to be sent and responded to at previous sensor/signal locations. Where spacing between sensors approaches an order of magnitude greater than stopping distance, queue evaluation *may* be appropriate. In this situation, large differences in velocity may exist between adjacent sensor positions that could be manageable and might benefit from adjustment of signal intensity depending on estimates of end-end position between the two sensors. On the other hand, it can be reasonably argued that, since the signaling device located at the lead sensor represents the last opportunity to warn of the forthcoming queue, the intensity of this signal should be high regardless of the distance to the queue. Queue evaluation is a conceptually simple process wherein vehicles entering the zone (i.e., passing the lead sensor) and leaving the zone (passing the second sensor) are counted in order to keep track of the number of vehicles in the zone. Using a representative vehicle spacing in the queue, the tail of the queue relative to the second sensor can be estimated. A modest complication arises from estimating how many of the vehicles in the zone are still in relatively free motion prior to reaching the queue.

The final step in the processing cycle is the calculation and output of the signal intensities for each zone. Figure 6 presents the nomenclature used in the explanation of that calculation that follows which deals with areas of closely spaced sensors and signals. The figure shows that there are (n+1) smart barrels in the system, each here assumed to have a speed sensor and a signaling device and numbered from 0 through n, B_0 being the first barrel. A full matrix of the distances between barrels is known, a priori, the distance from the barrel i to barrel j (where j > i) being designated $d_{[i][j]}$. Each barrel also has an associated elevation (e_i), speed value (s_i), and signal intensity (r_i).

Assuming close spacing of the smart barrels, per the previous discussion, determining signal intensity proceeds as follows:
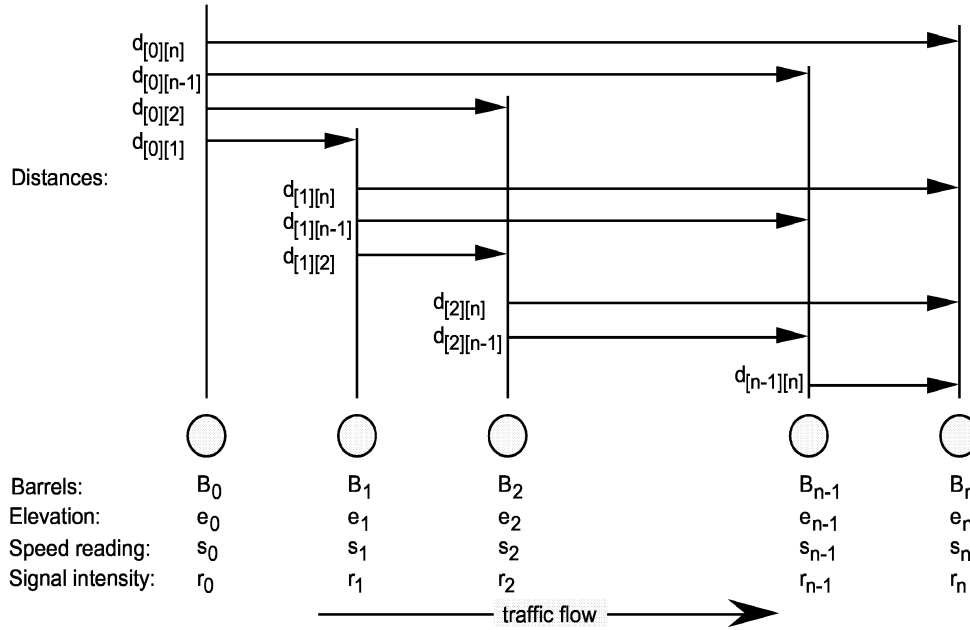
Figure 6. Nomenclature

For positions $i = 0$ through $(n-2)$ *for which the speed readings* (s_i) *are current*, a matrix of decelerations $(dec_{[i][j]})$ can be calculated according to:

$$dec_{[i][j]} = 0.102 \frac{\left(s_i - s_j\right)^2}{2\left(d_{[i][j]} - s_i t_{lag}\right)} + grd_{[i][j]} \qquad (1)$$

for all $j > i$ and where:

$dec_{[i][j]}$ is the deceleration, in gravitational units (g),

$d_{[i][j]}$ is a constant (predetermined at the time of set up) and is the distance between barrels i and j, in meters,

s_i, s_j are the speeds at barrels i and j, in meters/second,

t_{lag} is a constant representing the total time lag (system latency and driver reaction), in seconds,

$grd_{[i][j]}$ $= (e_i - e_j)/d_{[i][j]}$, predetermined at the time of setup, is the average downgrade between barrels i and j,

e_i, e_j are the elevations at barrels i and j, in meters, and

0.102 is the conversion constant for deceleration, in g per m/s^2.

Note that in equation 1, the first term on the right side is the actual required deceleration and the second term on the right side is an adjustment for average road grade, increasing the apparent acceleration demand on downgrades and decrease it on upgrades, thus providing the grade compensation discussed previously.

From these values, the "required deceleration" for the vehicle currently passing barrel i $(dec_{req[i]})$ is the maximum of the set $dec_{[i][j]}$, i.e.:

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$$dec_{req[i]} = \max\left[dec_{[i][j]}\right]_{j=i+1}^{n} \qquad (2)$$

This required deceleration, along with the speed of the vehicle relative to the posted speed, would be used to establish the signal intensity *assigned to the next barrel*, $r_{[i+1]}$. As outlined previously, when dec_{req} exceeds a minimum threshold, the associated intensity would be adjusted, either proportionately or in steps, to higher levels up to a maximum intensity associated with an upper deceleration threshold. Also, the differential speed of the vehicle above the posted speed (i.e., s_i-s_{posted}) would be compared to a another set of thresholds to determine an intensity setting based on over-speed. The maximum of two intensities so determined would actually be used.

For barrels where the intensity is not calculated by the preceding procedure (i.e., the positions i+1 where s_i is not current), the signal intensity would be set equal to that of the preceding barrel. The process would be progressive such that a currently calculated intensity would propagate down the line until reaching a position where a different intensity had been calculated (i.e., a position where a different vehicle established the rate).

Finally, where it may be advantageous for paired sets of speed sensor and signaling device to be widely spaced, the "smart barrel" concept would require slight modification. Namely, where spacing is so wide that the next barrel is not readily visible, the signal device must be spaced down stream from its associated speed sensor in order that the adaptive signal, calculated on the measured speed, could actually be displayed to an isolated vehicle passing the station. Thus a widely-spaced "barrel" would actually have to be a pair of barrels, or perhaps a single barrel followed by an associated barrel supervisor with an incorporated signaling device. The calculation of signal intensity would, however, proceed on the same basis as indicated above, perhaps with the addition of queue evaluation in the intervening zone to the next "barrel."

3. REVIEW OF DETECTION TECHNOLOGIES/ PRODUCTS

Most of the existing traffic detection and surveillance products are targeted to either signalized intersections or freeway applications. The intersection products detect vehicle presence and are used to activate traffic signals. Inductive loops buried in each lane are the most common detector. Direct speed sensing is not the primary measurement. Freeway applications emphasize vehicle counting and classification, and usually report average speeds.

The non-intrusive sensors are usually mounted on existing structures (signs, bridges, mast arms, and poles) and get their power from 110 or 230 volt connections to the power grid or use DC power supplied by traffic control cabinets. The power consumptions range from 1 to 160 watts. Large size, restrictive mounting requirements, or excessive power consumption preclude using many of the existing products examined below. Some of the sensor technology, however, can be adapted to be used in this application.

3.1 ACTIVE INFRARED

An active infrared sensor sends out infrared light generated by a LED or laser diode and measures the time required to reflect off an object and return to an infrared detector or array of detectors. The Autosense (Scwartz Electroptics) series of sensors scan across multiple lanes and can provide 3D imagery to classify vehicles. Speed can also be calculated by measuring the time it takes the vehicle to cross detection zones. The Traffic observation module (MBB Sens Tech) does not scan but uses two to six laser beams to create several detection zones. These sensors mount 20 to 25 ft above the road. They are very accurate but much higher in cost ($5000-$10000) and energy consumption (40 to 160 watts) than the other technologies.

A scaled-down solution that uses infrared emitters and detectors in a side-looking configuration is discussed in section 4.

3.2 PASSIVE INFRARED

All matter above absolute zero emits radiation in the far infrared part of the spectrum. The amount of radiation is a function of the object's temperature, size, and structure. Passive infrared sensors measure this radiation. A non-imaging detector has a wide field of view and can detect a vehicle's presence or velocity (with more than one sensor or detection zone). An imaging sensor contains a two-dimensional array of detectors and so can indicate presence, speed, and classification. The IR 254 (ASIM Technologies Ltd) has four detection zones, mounts overhead to 33 ft, costs $955 and consumes just 0.3 watts.

Passive infrared is a promising technology for this application because of its low power consumption, cost, and an adaptability to a side viewing detector. Many security products use infrared motion detectors. A speed sensor is described later in section 4.1.

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3.3 PASSIVE ACOUSTIC

A passive acoustic sensor detects sound (primarily tire noise) from approaching vehicles with a two-dimensional array of microphones. The array is mounted on a pole 20 to 40 feet above the ground beside the road. SmartSonic and SAS-1 sensors are two passive acoustic products. They both have trouble with slow-moving vehicles and stop-and-go traffic. They are primarily recommended for measuring free-flow traffic at speeds above 30 mph and therefore are inappropriate for a work-zone application.

3.4 ULTRASONIC

Ultrasonic air sensors emit a burst of sound pulses at a frequency between 25 and 50 KHz. Distance is calculated by measuring the time it takes the beam to return after reflecting off the target. Two closely spaced emitters can permit speed measurement. Sensors can be overhead or side mounted. The TC-30C (Microwave Sensors) is a an ultrasonic ranging sensor that indicates vehicle presence. It costs $559 and consumes 3 to 4 watts. There are dozens of ultrasonic emitter, transducer, and integrated sensor manufacturers whose products are used in object detection in commercial and industrial applications and are fairly inexpensive. An ultrasonic detector that also measures the Doppler frequency shift of a reflected signal is available for purchase.

The two main problems with these types of detectors are high power consumption (relative to the passive technologies) and the challenge of running them at high enough burst rates to detect fast-moving vehicles.

3.5 MAGNETIC

Magnetic sensors use a dual-axis flux-gate magnetometer to measure the Earth's magnetic field. When a vehicle approaches the detector, the vehicle distorts the magnetic field and the sensor detects this change. Both the SPVD-2 (Self-Powered Vehicle Detector – Midian Electronics) and the Groundhog Permanent Count Station (Nu-Metrics) use this method. They are packed in plastic canisters and buried in the roadway. The SPVD-2 is powered by a 13.5 Volt, 17 amp hour alkaline D-cell pack that can last 4 to 5 years. The sensor sends vehicle arrival and departure messages to an above-ground receiver via a 47 MHz FM radio modem. This sensor technology is passive and consumes very little power which satisfies one of the primary requirements in the smart barrel application.

Banner Engineering Corp. has recently introduced the M-Gage S18M Vehicle Detection Sensor which sells for $209 in quantities of one. This product uses a 3-axis magnetometer and is targeted for both above- and below-grade installations. Background condition and sensitivity adjustments allow tailoring the sensor to the applications magnetic environment, object properties, and desired range. Several sensor manufactures (Honeywell, Crossbow, and Fraunhofer-Institut Photonsche Mikrosysteme) sell two and three axis magnetometers. As discussed in the section 5, we will evaluate magnetometers mounted on plastic barrels to sense velocity.

3.6 MICROWAVE

Continuous microwave devices use the Doppler principle —the change of frequency of a wave reflected from a moving object is proportional to the objects speed— to directly measure the speed of a vehicle. The available systems (TDN-30 by Whelen Engineering, TC-20 by Microwave Sensors, and DRS1000 by GMH Engineering), are configured to be used in an overhead mount or an elevated side mount. Typical power consumption is 2 to 6 watts and single unit cost is $1000 to $2000. It might be possible to mount a radar device on top of a barrel facing towards oncoming traffic. The high cost, high power consumption, and possible interference problems with multiple radars in the same location would make this only a fallback solution.

3.7 VIDEO

Video image processing promises the richest data set of traffic measurements including vehicle detection, speed, classification, headway, density, and volume. A camera sends an image to a video processor which digitizes it and applies various detection and tracking algorithms to extract the applicable measurements. Cameras can be side or overhead mounted. The Autoscope Solo (Econolite Control Products) even integrates the camera and processor into one package. Video systems are probably the hardest to install and calibrate correctly of all detector technologies. The lack of portability, high cost, and the high power consumption (20-50 watt range) make them unsuitable for this application. The dirty construction environment and changing road features might also prevent their use.

4. SELECTED TECHNOLOGIES FOR EVALUATION

After accurately measuring vehicle speed, low power consumption is the next most desirable feature of a speed sensor technology that will run off of batteries. UMTRI will evaluate the sensors from lowest to highest power usage, i.e., passive infrared, magnetic, active infrared, and ultrasonic.

4.1 DUAL PASSIVE INFRARED

An infrared detector consists of a lens, a filter opaque to visible light, and a sensing element. Figure 7 illustrates how a dual sensor measures speed. The difference of the sensors is the quantity of interest. Infrared sources seen by both sensors are removed from the signal. As a vehicle passes the barrel, the heat is detected first in sensor #1 and then in Sensor #2. The sensor separation (18 inches) divided by the time between the peaks equals the vehicle speed. Sensor height, lens field of view, and gain sensitivity will be varied to attempt to sense only targets in the immediate adjacent lane.
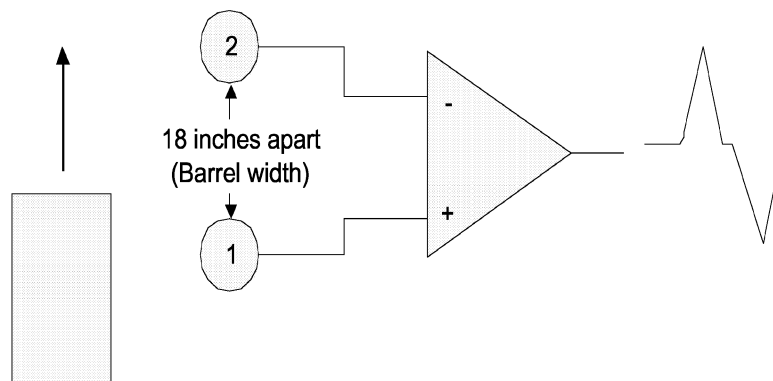
Figure 7. Differential Sensor Configuration

4.2 DUAL 3-AXIS MAGNETOMETER

The dual 3-axis magnetometer will be configured similar to the infrared solution depicted above. This makes it easier to cancel out the magnetic field changes caused by local metal objects and the normal daily field fluctuations. A 3-axis magnetic sensor hybrid (Honeywell HMC2003 – 3 permalloy magneto-resistive sensors with onboard signal conditioning) on each side of the barrel. The six signals (x1, y1, z1, x2, y2, and z2) will be digitized and the corresponding magnitudes (square root of the sum $x^2 + y^2 + z^2$) of the magnetic variations will be subtracted as above. As above, sensor heights and sensitivities will be adjusted to optimize the result. The six direction component signal will also be examined in case the speed algorithm needs to be improved.

A pair of the Banner Engineering M-Gage S18m detectors will also be evaluated. This detector has only a vehicle detected (yes/no) output and therefore the two sensors

will not be connected differentially as above. Instead, the time between detection activations will be used directly in the speed calculation

4.3 DUAL ACTIVE INFRARED

As shown in figure 8, dual presence sensors determine speed by observing the time period between the two signals.

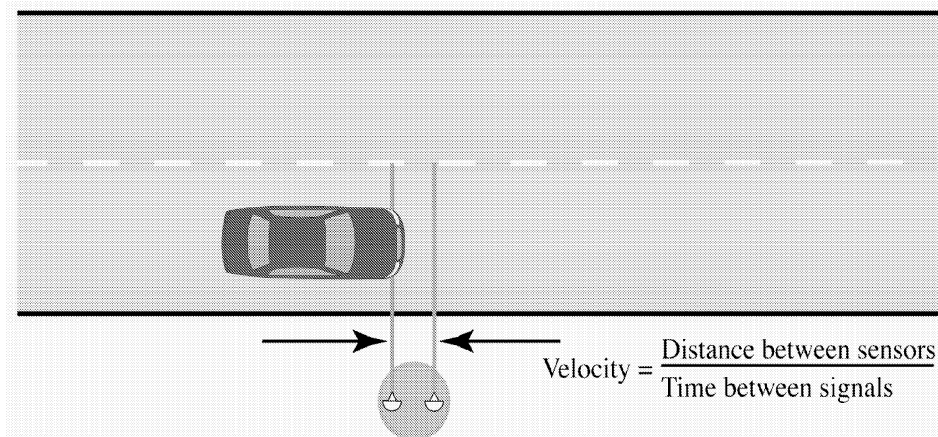$$Velocity = \frac{Distance\ between\ sensors}{Time\ between\ signals}$$

Figure 8. Speed measurement with dual presence sensors

Packaged active red or infrared sensors are available from several companies that target automated assembly or conditioning machines. A diffuse reflective sensor consists of an irradiating (usually infrared) element and an element photosensitive to the irradiated light in the same unit. The emitted light reaches the detector after being reflected from an object. Variation in the color and texture of the object will change the amount of reflected light and hence the detection range. Output light is modulated to differentiate it from external sources such as sunlight. Units are available with an output signal proportional to the distance to the object or a logical output that indicates an object is within a specified range. This technology consumes more power than the above two and also is much more sensitive to ambient conditions. Speed is calculated from the time it takes an object to travel between the two sensor beams.

4.4 PULSED DOPPLER ULTRASOUND

This solution is different from the side looking configurations already examined because it uses only one sensor mounted on the barrel that is focused towards oncoming traffic as shown in Figure 9. A single piezoelectric transducer is used to transmit series of pulses and then receive the reflected signal. Units are available with frequencies in the 30-50 KHz range, beam widths from 8 to 30 degrees, and ranges to 50 feet.
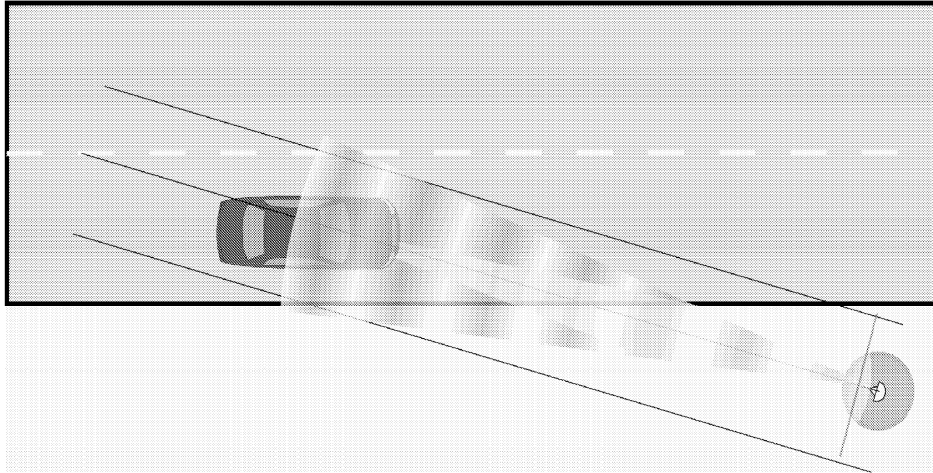
Figure 9. Speed measurement with pulsed Doppler ultrasound

A microcontroller can calculate range by measuring the time lapse between the outgoing pulses and the reflected pulses. Speed can be calculated by measuring the frequency of the returning pulses and subtracting it from the outgoing frequency to yield the Doppler frequency. Because the speed of sound in air is a function of temperature, the ambient temperature must be measured and used to correct ranges.

The HE661 (Hexamite) signal conditioner interfaces with the company's line of ultrasonic sensors and outputs the range to the closest object and the speed of the object traveling at the maximum speed within the operating boundaries.

4.5 DUAL ULTRASONIC PRESENCE

Finally, two pulsed ultrasonic sensors (at lower power outputs than the above) can be mounted in the same configuration as the active infrared solution. Here each would detect only vehicle presence and the speed would be calculated from measuring the time it takes to travel between detectors. Possible interference between sensors might require some electronically controlled phasing or a mechanical separation (although the barrel could be enough).

5. SENSOR EVALUATION AND TESTING

UMTRI intends to evaluate and test the selected sensor technologies in a two-stage process made up of (1) evaluations of the selected technologies in controlled testing situations until two or three are deemed acceptable and (2) a limited field test of the more promising sensors identified by the evaluation.

UMTRI will purchase or assemble one speed sensor of each of the five selected technologies. Each sensor will be evaluated in a set of controlled experiments until two or three are found worthy of further testing. Data will be collected using UMTRI's existing Data Acquisition System (DAS). Target vehicles will be UMTRI-owned vehicles driven past the sensors in accordance to a matrix of prescribed speeds and ranges. Target vehicle speed will be measured independently with conventional radar gun. Within practical limits, tests will be conducted under varying environmental conditions as appropriate for challenging the particular sensor. Test sites will be limited to UMTRI or University property and local roadways.

The data records of these evaluation tests will be examined and analyzed to choose the set of the two or three most promising sensors. These sensors will then be deployed in a limited field test wherein the sensors will operate unaccompanied for periods of several days at each of at least two road sites. At least one site will be characterized by repeated queue and by the expectation of variable speeds at least through the mid- to slow-speed range. Such a site might be an actual work zone but could also be near a stop light on a nominally fast-moving urban arterial.[1] At least one other site which will insure high-volume high-speed traffic will be employed, e.g., a nearby limited-access roadway.

The sensors will be installed in one, or perhaps two conventional traffic-control barrels. Data again will be gathered using existing UMTRI DAS. In addition to the sensor data, we will collect reference vehicle speeds using a conventional radar speed detector and a continuous video record using video camera and the frame-grabber/video storage feature of the UMTRI DAS. As an additional source of "truth" data, we will also drive UMTRI vehicles, with their own DAS system, though the test site on multiple occasions during the field test. Data collected on the vehicle will include GPS position and time as well as the obvious vehicle speed. GPS data will allow reliable matching of speed measured on the vehicle with speed measurements at the field-test sites. Of course, video taken at the site and synchronized with site data provides and additional cross check.

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[1] In our original proposal, we proposed that sites for field testing would, in fact, be work zones. But on further reflection, and as implied by this example, it is not clear that this is necessary nor perhaps even advantageous.

6. BIBLIOGRAPHY

Banner Engineering Corp, "M-Gage S18m-Vehicle Detection Sensor", Data and Application Sheets, 2004. www.bannerengineering.com

Caruso, Michael J. and Lucky S. Withanawasam "Vehicle Detection and Compass Applications using AMR Magnetic Sensors." *Honeywell SSEC*, 1999. www.ssec.honeywell.com.

CTC & Associates LLC, WisDOT RD&T Program "Evaluating New Sensor Technologies for Actuated Signals." Report prepared for Bureau of Highway Operations Division of Transportation Infrastructure Development, December 2003. http://www.dot.wisconsin.gov/library/research/docs/tsrs/tsrsignalsensors.pdf.

Culler, David E. and Wei Hong. "Wireless Sensor Networks." *Communications of the ACM* 47, no. 6 (2004): 30-33. http://portal.acm.org/portal.cfm.

Goode, Barbara G., ed *Wireless for Industry: Supplement to Sensors Magazine* Summer 2004. www.sensorsmag.com/wireless.

Hill, Jason, Mike Horton, Ralph Kling, and Laksman Krishnamurthy "The Platforms Enabling Wireless Sensor Networks." *Communications of the ACM* 47, no. 6 (2004): 41-46. http://portal.acm.org/portal.cfm.

Klein, Lawrence A. *Sensor Technologies and Data Requirements for ITS*. Boston: Artech House, 2001. http://www.artechhouse.com.

Martin, Dr. Peter, Yuqi Feng, Xiaodong Wang, "Detector Technology Evaluation." Department of Civil and Environmental Engineering, University of Utah Traffic Lab, 2003. http://www.trafficlab.utah.edu/.

Middleton, Dan, Deepak Gopalakrishna, and Mala Raman "Advances in Traffic Data Collection and Management." One of three white papers that support a series of workshops on Data Quality, which were held in March 2003. The EDL numbers for the full set of white papers are: 13766, 13767, 13768. Prepared for Office of Policy, Federal Highway Administration, Washington, DC, 2003. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13766.html.

Middleton, Dan, Ph.D., P.E. and Rick Parker "Vehicle Detection Workshop, Participant Notebook." Texas Transportation Institute, The Texas A&M University System, 2000. http://rce.tamu.edu/docs/RCE_PDF_Vol_I/Tamu/Middleton.TM08.pdf.

Mimbela, Luz Elena Y., Lawrence A. Klein, Ph. D., P.E., Perry Kent, John L. Hamrick, Karen M. Luces, and Sylvia Herrera "A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems." The Vehicle Detector Clearinghouse, 2000. http://www.nmsu.edu/~traffic/.

Minnesota Department of Transportation, Office of Traffic, Security and Operations, and SRF Consulting Group, Inc.. "Portable Non-Intrusive Traffic Detection System

(PNITDS): Research of Existing Portable Systems." 2003. SRF No. 4869.
http://www.dot.state.mn.us/guidestar/pdf/pnitds/ExistingSystems.pdf.

Montgeomery, Steve J. "Wi.232DTS User's Manual, Rev 1.0." Radiotronix Inc., 2002.
http://www.radiotronix.com/datasheets/Wi.232 User's Manual rev1 2.pdf.

Szewczyk, Robert, Eric Osterweil, Joseph Polastre, Michael Hamilton, Alan Mainwaring, and Deborah Estrin "Habitat Monitoring with Sensor Networks." *Communications of the ACM* 47, no. 6 (2004): 34-40. http://portal.acm.org/portal.cfm.