Cell-Probe

An Operational Field Test
in Metro Detroit
to Evaluate
the Mobile Cellular Phone
as a Traffic Probe

Submitted by

The Michigan Department of Transportation

and Partners

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1.0 Introduction

This is to propose an IVHS Field Operational Test in Metropolitan Detroit to evaluate a technology which automatically finds the location of individual cellular phones so that phone-equipped vehicles may serve as traffic probes. The field test has been developed over the last twelve months by a joint effort of the Michigan Department of Transportation and the University of Michigan, with assistance from a number of industrial partners. The proposed test is prompted by four observations, namely, (1) technology appears to be available for locating the cellular phone by processing the incoming radio energy transmitted from the mobile unit, (2) the mobile phone thus enables a host vehicle to serve as a traffic probe when the location data are sampled over time, (3) the installed base of mobile phones in the U.S. will imminently support areawide traffic surveillance in every American city since the population of cellular phones now exceeds 9,000,000 units and is growing at a rate of 23% per year, and (4) a "probe-solution" for areawide surveillance represents a compelling national need since in-situ traffic detectors are only thinly deployed at present and are very difficult and expensive to extend throughout the multijurisdictional road network. Accordingly, this proposal is based upon the conviction that our subject is substantive, a field test of the technology is warranted, and the significance of this test to the national IVHS program is profound.

This test concept was previously presented to FHWA within a larger package of Michigan IVHS initiatives in response to the first round of inquiry on the IVHS Corridors program. Now, with FHWA's posting of the Federal Register notice of July 20th, we are pleased to submit a proposal for the Field Operational Test which has been titled, "Cell-Probe." Since the earlier presentation of this project, a coalition of private partners has been assembled, another possible supplier of the phone-location technology has been identified, and the means for evaluating the technology has been expanded. We also recognize, and will later discuss, the broader possibility that the cellular phone infrastructure may constitute a primary component of a national IVHS architecture enabling much of the functionality that has been conceived for Advanced Travel Information Systems (ATIS.) Noting the prospect for synergy, we have drawn in an especially strong cadre of telecommunications partners so that the potential integration of both location and data communications functions via cellular can be evaluated as an institutional and market issue.

The following discussion frames the broad concept and background for a Cell-Probe test, in Section 2, and explains the pertinence of this effort to the national program in Section 3. In Section 4, we present an overview of the test system, itself, as it would be deployed in a selected sector of Metro Detroit. Section 5 presents a preliminary plan for executing an evaluation of the location technology in the real urban road environment. In Sections 6 and 7 we show the respective schedule and budgeting plans that attend the field operational test. In Section 8, the plan for management of the overall project is presented.

2.0 Background for Cell-Probe

The rationale behind the proposed project is addressed below. The considerations go from the generic issue of traffic surveillance based upon probes to the use of the conventional cellular phone as the means to access the nation's largest probe fleet. The coincidental movement of cellular services toward digital packet data transmission is also discussed insofar as this development tends to make cellular service providers keenly interested in the synergy offered by the location function.

Surveillance by means of "Vehicles-as-Probes"

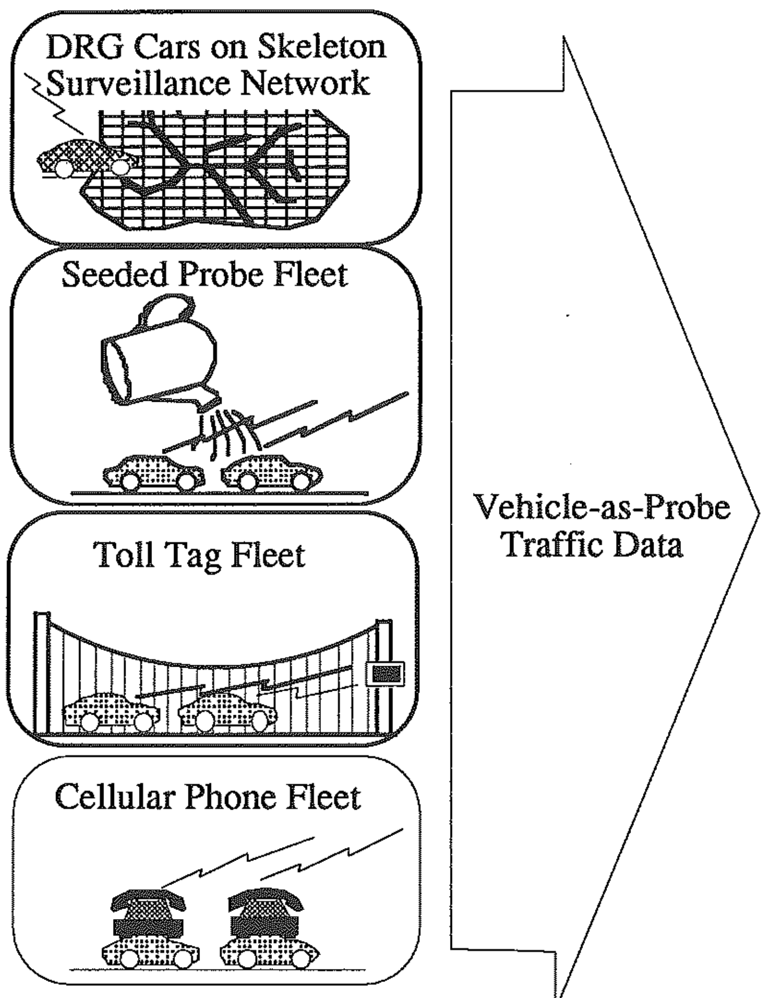
A key requirement for Advanced Traffic Management Systems (ATMS) and many ATIS functionalities is real-time traffic surveillance and characterization. The conventional and emerging technologies for detecting individual vehicles so as to deduce the state of traffic generally involve the in-situ placement of sensors along the right of way. Using inductive loops, for example, some 32 miles of Detroit freeways are currently detectorized and an approximate 200 mile extension of such coverage is planned over the next few years. At a cost in the range of $1/4 million per mile, however, detector coverage of the areawide network of freeways and major arterials would run in the vicinity of $700 million for all of metro Detroit. Recognizing the high per-mile costs of such hard-wired traffic surveillance and its low probability of deployment across the 108 jurisdictions of this community, there is a strong interest in examining any wide-area surveillance concept that could feasibly produce traffic data without point-by-point installations along each roadway. This general outlook has lead to a focussed interest in the concept of "vehicles-as-probes". And, of course, the argument behind this interest applies to virtually all urban communities in America.

By the probe scheme, the instantaneous location of individual vehicles is determined and communicated to central computers. The time-sampling of location data from thousands of vehicles operating continuously throughout a metropolitan area would yield a characterization of flow across the network. The collected data would be used in the detection of incidents, the generation of motorist traffic advisories via changeable signs or voice message transmissions, the adaptive timing of intersection and ramp control signals, the production of link-times characterizing the road network for use in dynamic routing systems, the support of highway planning efforts, and so on. While hard-wired surveillance would still be needed in certain applications such as lane-specific turn signalling, queue length measurement and the like, the vehicle-as-probe concept offers the possibility of network-wide coverage and the prospect of origin-to-destination logging of trip behavior. The question is, how can we get probe information from a large fleet of vehicles in the U.S. anytime in the foreseeable future?

Since all "dynamic route guidance" (DRG) concepts require automatic vehicle location, we find that one way the vehicle-as-probe method of surveillance can be achieved is through certain navigator-based systems that also give traffic-responsive route guidance to the motorist. The architecture of Orlando's Travtek system, Chicago's "Advance" system, and Siemen's "Ali-Scout" system, as examples, all incorporate this feature. There is an obvious "chicken and egg" problem, however, in offering such DRG services based upon traffic data from a large fleet of probes. Namely, how do you offer a quality level of traffic-adaptive routing without a large population of probes for measuring traffic flow? Although data fusion can facilitate the detection of incidents and the generation of qualitative traffic information, there is a general need for *quantitative* traffic data, particularly link travel times—and if probes are to yield the data, a large equipped fleet must be in the field.

Accumulating a fleet, of course, requires time over which new equipment sales are integrated to achieve penetration of the total population. In Japan, for example, estimates suggest that it will have taken seven years, from 1987 to 1994 for the highly successful navigator sales in passenger cars to have totalled 1% of the population of all Japanese motor vehicles.[1] So, the achievement of even a 1% population of vehicles having some innovative device on board is difficult. But, analyses for planning the Advance Project in Chicago showed that a 1% fleet equipped to serve as probes would give only a single travel-time estimate on 60% of all arterial links every twenty minutes.[2] Accordingly, probe densities well above 1% are thought to be needed for timely surveillance, but even that level requires almost 2 million vehicles in the U.S.

We see four basic options for "priming" or otherwise accessing a probe fleet.[3] They are illustrated below. Firstly, hard-wired surveillance of expressways could provide a certain



Alternatives for Priming a Probe Fleet

"skeleton" coverage of high-volume facilities so as to attract the purchase of DRG systems by eager users whose vehicles might, subsequently, serve as probes and gradually expand to provide wide-area coverage of a large arterial network. In the beginning, however, since there are no probes and virtually no data on arterials, adoption rates would be low such that a very long process of probe-penetration might be involved.

As a second option, a fleet of high-use vehicles might be "seeded" with location and communication equipment and thereby serve as a starter probe fleet, again with the possibility of luring in general users that will, themselves serve as probes. The City of Toronto, for example, is pursuing this approach via equipment on its large fleet of transit buses. The probe fleet, in this case, is odd insofar as buses do not travel along all routes or at representative speeds. The bus fleet is also a small percentage of the population, such that the initial probe data are sparse. Clearly, this concept will apply more favorably in one community that in another and coverage will be limited to the density and distribution of the seeded fleet.

A third option, currently being examined in the Transcom program in New York/ New Jersey, employs the private vehicles that have already been equipped with transponders for paying bridge and tunnel tolls in a community having a relatively high rate of adoption of such devices. The transponders are detected as probes elsewhere in the street network as they pass by roadside read-only devices that have been salted in the rest of the street system. This probe concept only works where toll facilities abound and it requires the linking of an extensive network of tag-reading equipment on freeways and arterials.

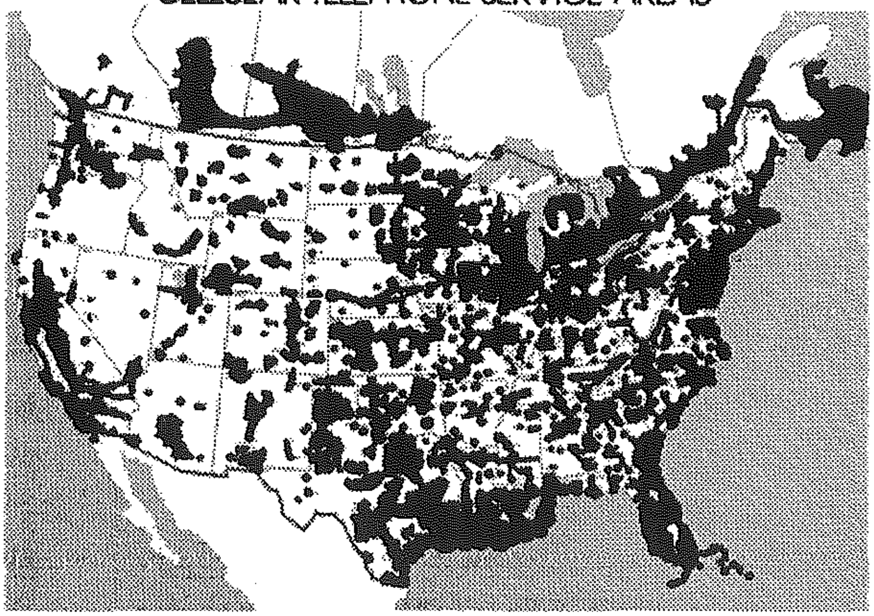
The fourth approach, employing the conventional cellular phone as the probe-detection medium is that which is proposed for evaluation in the Cell-Probe project. This is the only known approach in which a robust fleet of probe-capable vehicles currently exists. The enormous installed base of mobile phones, distributed nationwide and across Canada, plus coverage factors to be discussed below, make the cellular phone a prime opportunity. The question will be, how well does the location technique work when employed for traffic surveillance?

Vehicles with Cellular phones as location probes.

Shown below is a map of the cellular service coverage in the U.S. and Canada as of early 1992. The darkened zones represent the current areas being served. Because of recent court rulings concerning cellular service to rural America, the franchise holders must also provide coverage in un-served regions soon or lose the rural portions of their allocation.

Thus, much of the open area is expected to receive coverage within the next two years. Nevertheless, the cellular phone infrastructure currently provides essentially total coverage of metropolitan America. Thus, the coverage needed to support the urban traffic surveillance application is more or less complete in this country. As mentioned in the

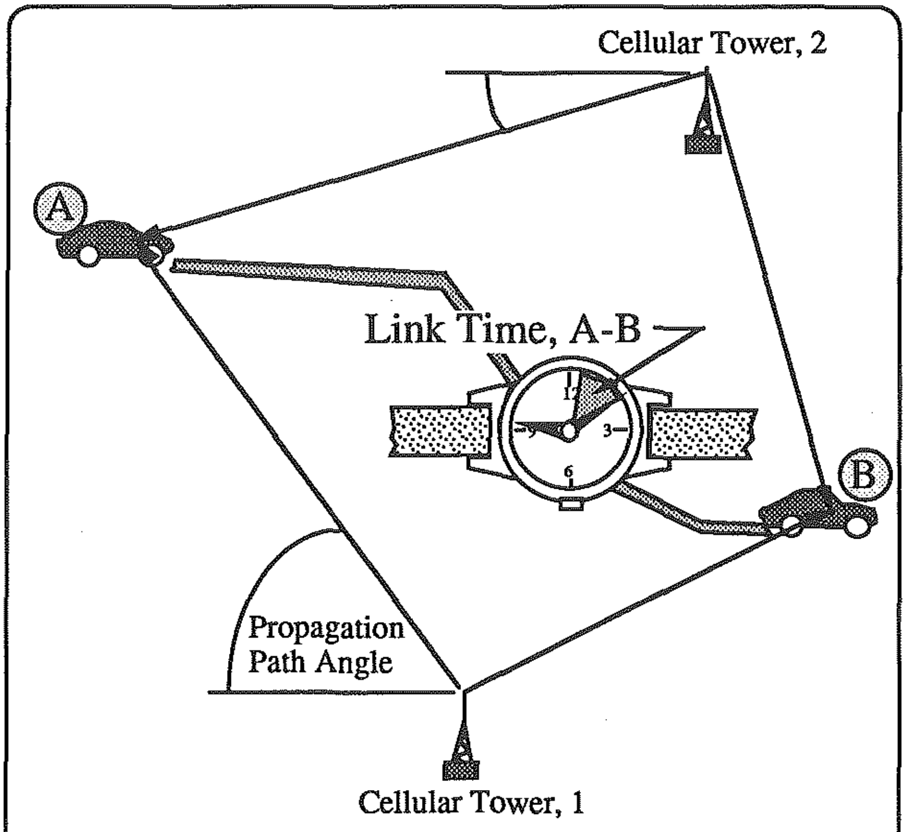
CELLULAR TELEPHONE SERVICE AREAS



introduction, approximately 9,000,000 cellular phones are currently in service in the U.S. By 1995, the cellular industry projects approximately 16,000,000 users, yielding approximately 13,000,000 mobile phones deployed on-board vehicles. Using metropolitan Detroit as a specific commmunity example, industry estimates in June of 1992 showed that there are currently 260,000 cellular subscribers yielding an estimated 208,000 vehicle-borne phones on any given day.[4] With 2,618,000 motor vehicles registered in the tri-county region of metro Detroit, we note that one in every 12.6 vehicles in the metro area can nominally serve as a probe today.[5] At current rates of market growth, more than one in ten Detroit area vehicles would be a probe candidate by the time of commencing field tests in early 1994, per the proposed project. By way of contrast, the Toronto bus fleet will constitute less than one in every 650 vehicles in the same time frame.

The key to using the cellular phone fleet for traffic surveillance rests in a technology by which radio transmissions from the mobile phone are received such that the coordinates of their source becomes located. Recent demonstrations by KSI, Inc. of Annandale, Virginia have shown that cellular phone signals can be received at 3-element antennas situated in adjacent cell sites and, with the aid of a statistical processing method, can closely locate vehicles whose mobile phone is turned on (i.e., activated, but not necessarily engaged with a call.) The KSI technology, called Direction-Finding Localization System (DFLS) has been used as the basis for cost estimation of equipment in this proposal, although an open-bid selection of a technology provider is proposed. Another party, a division of E-Systems in Vienna, Virginia has declared its intention of verifying a similar measurement capability by the time that a technology supplier would be selected for the Cell-Probe field test.

In a most general sense, the figure below illustrates the concept of locating a given vehicle over the time it takes to travel the road link from point (A) to point (B). At each vehicle location, the signal propagation paths or the times of signal arrival that are observed at two or more cellular receiver towers within a few miles of one another are then combined in a central computer to locate the vehicle. The approach operates on the radio signal produced by the conventional cellular phone, both in its current analog form of signal modulation and in the digital forms of signal modulation that are now being tested by the cellular industry.



Traffic Surveillance via Cellular Phones

The traffic surveillance function is also enhanced by a behavioral anomaly that has been observed in owners of mobile phones—i.e., a large fraction of all phone-equipped vehicles generates a call within a few seconds of arrival at the site of a major traffic obstruction. (Apparently, people are calling ahead to say they'll be late or are otherwise using the delay to make a call.) Thus, the information content that comes through cellular phone location is boosted by the clustered call activity that appears wherever major incidents occur.

As for cost, early estimates by KSI, Inc. for equipping individual cell sites in a test configuration were $350K per site. We are advised, however, that reduction of these costs to a figure below $100K per site is probably straightforward, as the technology moves from the prototype stage to production. Thus, for example, supporting the 100-cell infrastructure of metro Detroit may cost on the order of $10 million for full implementation. The contrast with an estimated cost of $700 million for hard-wired detection of freeways and major arterials in this community is notable.

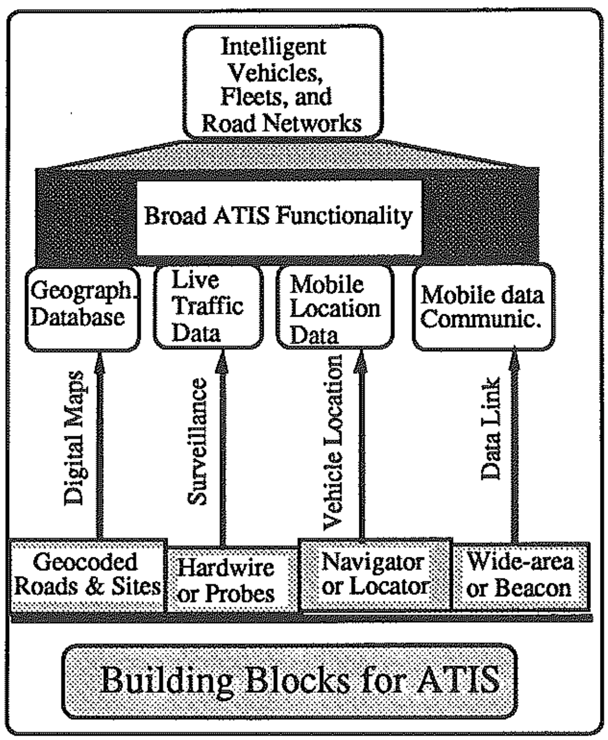
The Synergy for IVHS if Location is Combined with Other Services via Cellular

In addition to the prospect for aggregating phone location data to derive traffic flow measures, new services could be provided to cellular subscribers if both traffic data and individual vehicle locations are obtained. For example, it is thought to be relatively simple to set up a computerized calling service advising individual users of traffic tie-ups that have been detected ahead, on their current roadway.

The location technology would also support an automatic Mayday function for summoning help to the precise site of a highway emergency. In fact, if vehicle location is availed by tracking on mobile phone transmissions, the most basic element of vehicular navigation might be provided without the purchase of extra on-vehicle equipment. And if cellular-equipped cars simply became the permanent national probe fleet, then DRG services could be offered via a broadcast radio system, downlinking the highway travel time data in a one-way transmission to on-board routing devices.

One current effort within the cellular phone industry involves the move to offer "data over cellular" services. In May of 1992, nine cellular carriers joined with IBM to develop and promote Cellular Digital Packet Data (CDPD) capability based upon frequency-hopping electronics that target the unused time windows within the carrier's segment of spectrum for packet data transmission.[6] The possible services are highly varied, including point-to-point individualized transmissions as well as point-to-multipoint "broadcast" style data bursts. Short packets can even be transmitted as "datagrams" via so-called connectionless services that do not require establishing a call with the mobile unit, in the conventional sense.

Together, these observations suggest that the cellular phone may offer a path toward achievement of at least two and perhaps three out of four essential building blocks for ATIS functionality as shown below. That is, the cellular phone may enable traffic surveillance, individual vehicle location, and a digital packet data link. The fourth building block, the



digital map database, will already be provided through commercial products. If the three basic functions at the right of this figure can be delivered via the cellular phone, the timetable for fielding ATIS-level products and services could be dramatically accelerated.

At this juncture, the cellular telephone industry is already working hard on its move toward digital compression of voice-related services and its development of packet data capability. As for the location technology, the industry shows a keen interest in the function although they consider the technology as yet unproven. They also know nothing about highway agencies and cannot weigh the prospect of partnering with them for deploying a technology having joint public and private value. Nevertheless, if a capable phone-location technology is proven to exist, the possibility for its implementation with joint investment by the cellular industry seems high, depending upon installed cost and market-growth expectations. Thus, the outlook for synergy between the public need for traffic surveillance and the private interest in broad ATIS functionality via cellular is compelling. We conclude that, given the various options for probe deployment, and the special case offered by the cellular phone, an intensive examination of the phone-as-probe option should be an element of the national IVHS pursuit.

Cellular Telephone Locator (CTL) Technology

In this proposal, we will refer to the inclusive term, Cellular Telephone Locator, or CTL, in discussing the generic technology for generating longitude and latitude coordinates of a conventional mobile cellular phone. To our knowledge, the DFLS technique developed by KSI Inc.[7] is the only method that has been demonstrated for location of the unmodified cellular phone, although a similar claim has been made and a demonstration promised by the Spring of 1993 by Engineering Research Associates, a Division of E-Systems, Inc.[8] Information supplied by these two organizations indicates that both will be in a position to respond to an RFP by which CTL equipment is procured for the Cell-Probe project.

By way of background, it is recognized that many techniques other than CTL technology exist for vehicle location using radio waves in some manner. Other corporations and commercial products offering location techniques include the following:

- II-Morrow, Trans Track, Qualcomm, Ominet, Starfind, Code-Alarm and others which offer a location package based upon the Loran-C radionavigation infrastructure;
- Blaupunkt/ETAK, Philips, Sumitomo Electric, Nippondenso, GM, Motorola, Zexel, and others who have built dead reckoning, map-matching navigation devices, some of which are being augmented with GPS receivers and any of which can be uplinked to a traffic center via a suitable mobile data transmitter;
- Geostar, Qualcomm, Pioneer, Starfind, Telesat, Ominet, METS, Navstar-GPS, and others who have built equipment either for receiving signals from the GPS satellite constellation or have employed other types of satellites supporting time difference of arrival (TDOA) or time of arrival (TOA) schemes of location;

- Teletrac, Pinpoint (Array), Lojack or others who have built terrestrial networks of specialized transceivers, not using the mid-800 MHz cellular telephone band of frequencies, for conducting either TDOA or variations thereof for locating specially-equipped vehicles, primarily as a theft-protection service.
- Hughes Network Systems, which has demonstrated a TOA method employing spread-spectrum signalling as an overlay on the cellular phone band of spectrum.[9] This technique does not operate on the conventional cellular telephone and thus cannot employ the existing fleet of mobile phones. Thus, it is not considered among CTL technologies, as defined above.

Moreover, all known alternatives to the CTL technologies of KSI or E-Systems require in-vehicle equipment which is not in common service. That is, the corresponding probe fleets are understood to be very small fractions of the current fleet of conventional cellular telephones.

Adaptability of CTL Technology When Voice Becomes Digitally Modulated by Cellular
One issue for the long-term involves the adaptability of CTL technology (whether KSI's or E-Systems' or any other supplier's technology) to the digital forms of cellular modulation that are moving rapidly into deployment during the nineties. The context for this issue is that the cellular industry is pursuing new ways to compress voice transmissions so as better utilize its spectrum, as the costumer base and demand for services grows. While virtually all cellular services are currently being delivered via analog modulation per the AMPS standard, the move to digital modulation is inevitable, and is already underway

The standard for a first form of digital modulation, called Time Division Multiple Access (TDMA), has been established and is currently being deployed in some areas. This type of modulation compresses the digitized voice information into small bursts of data and orchestrates the transmission from individual phones at precise time "slots" within a periodically-repeated time "frame." For the duration of any single slot on an assigned frequency channel, the transmitted energy is arriving from only one phone. Thus, location of a specific TDMA phone using the direction-finding method requires that the localization processing be synchronized with the time slot assignments. KSI states that the duration of each slot, approximately 6.5 milliseconds, is sufficiently long that a DFLS location can be obtained within a single slot. Processing over multiple slots serves to enhance the accuracy via statistical integration. Southwestern Bell, McCaw, and other carriers are believed to be moving into TDMA deployment presently. The new generation phones to be sold in

TDMA service areas in the future will support both the AMPS and the TDMA protocol in order to assure full-coverage service throughout the protracted period of transition.

A second generation of digital modulation is expected in the form of so-called Code Division Multiple Access (CDMA.) The coding scheme will support an even denser population of phones transmitting simultaneously with uncorrelated signals spread across a common frequency band. The spread-spectrum code for controlling this approach is precisely defined and is used to "de-scramble" the signals, so to speak, at the receiver site. If the DFLS direction-finding processor, or another alternative, is controlled using the same master code, the technique is thought to be fully applicable to the location of CDMA-modulated phones. PacTel, and other carriers who operate in very high-demand service areas are considering some form of CDMA deployment within the next few years in order to satisfy their customer growth expectations.

One additional variation in cellular communications is the adoption of the N-AMPS scheme which essentially confines the conventional analog modulation form within a narrower channel bandwidth. This technique also expands the spectrum utilization, modestly, but it appears to support radiolocation techniques in the same manner as with the conventional AMPS protocol. U.S. West is one large cellular carrier that is employing N-AMPS as a measure for meeting the growing demand for services.

Accordingly, it appears that the principle behind DFLS location, and thus any alternative that is indeed competitive, will apply to all of the anticipated forms of cellular signal modulation, assuming that the locator's receiver and processor is integrated into the carrier's operations in order to synchronize with and employ the codes used in digital modulation.

3.0 How a Cell-Probe Topic Fits into National Program Priorities

We have just described, in narrative form, the relationship between the Cell-Probe Program and the national IVHS program. To varying degrees, the deployment of a wide-area, traffic surveillance system based on the Cell-Probe concept will positively contribute to most of the IVHS functional areas. Now we simply tabulate, for easy reference, the features of the Cell-Probe Program and the manner in which they serve the national IVHS initiative.

Benefit to travelers in rural areas

Cellular service, as a result of recent court rulings, will most likely be extended to rural America. Once this occurs and because the location of vehicle can be determined, the system elements for providing rural travelers with advisory/warning messages and navigational information will exist. Furthermore, these same travelers can request, and be provided with, emergency service as a result of knowing the vehicle's location. The traveler will not be required to own any special navigational equipment.

Advanced traveler information systems

Once an individual vehicle's location and the current state of the traffic are known, then it is feasible and practical to offer traveler information services. In addition to informing cellular-equipped vehicles about their present location, computerized traffic advisory services and automatic Mayday functions could be provided. In the event that cellular-equipped vehicles become the national probe fleet, then DRG services could be provided by broadcasting current travel-time data. It is important to note that, cellular phones, and systems that exploit their existence, provide three critical building blocks for ATIS, surveillance, vehicle location and data communications.

Advanced traffic management systems

The Cell-Probe concept will allow the deployment of real-time, wide-area, traffic surveillance systems without incurring the cost, both installation and maintenance, of point detection systems currently in use. Although Cell-Probe will not totally eliminate the need to provide hard-wired surveillance for special applications, it should provide sufficient data for a large fraction of the ATMS functions (incident detection and management, providing traffic advisories, signal timing control).

Alternative surveillance and detection capabilities

The Cell-Probe concept offers a very promising technique for implementing the alternative surveillance technique, "vehicles-as-probes". This system will be capable of functioning in real time and provide much of the data required by any traffic management system. It has been observed that there is a spatial clustering of mobile phone calls wherever major incidents occur. This phenomenon, when observed at the traffic center, may very well prove to be another incident detection mechanism that can be exploited.

Systems for commercial vehicles

Commercial vehicle operators, to the extent that they equip their fleets with cellular phones rather than other navigational equipment, could profitably exploit the vehicle location information resident at the traffic management center. This should be very attractive capability for this community, particularly with the introduction of "data over cellular" services, because with one device, the cellular phone, the fleet operators can obtain services that presently require equipment dedicated to each service.

4.0 Overview of Cell-Probe Operational Test

An operational field test is proposed in which test vehicles equipped with cellular phones and additional "reference-location" equipment will be tracked over portions of the metro Detroit street network. The tracking data will be consolidated within computing facilities at MDOT's Metropolitan Transportation Center (MTC) and processed in such a way that its utility to support traffic surveillance is evaluated. The test requires detailed design of the field test, procurement of a CTL technology via an RFP, installation of the selected equipment, conduct of field testing, study of implementation issues, and evaluation of results. The overview is fleshed out, below, with emphasis upon the central issue of evaluation.

The Elements of Evaluation

The basic accuracy of CTL-measured vehicle coordinates (that is, the direct location data) will be assessed through comparison with reference measurements transmitted from each test vehicle to the MTC by way of a trunked mobile radio system. Employing a digital map of Detroit streets within the MTC processing system, data from the multiple test vehicles will be overlaid on the street grid. Software that compiles multiple samples of vehicular movement over time then permits evaluation of the probe data for characterizing traffic flow. The probe-based flow data will be validated against conventional detectorized surveillance data when the vehicles are operated along three freeway segments that are hard-wired into the MTC's traffic management system.

As sketched in a System Concept Figure on the next page, the Cell-Probe test provides for installation of one CTL supplier's technology in four cell sites owned and operated by our primary commercial partner, Ameritech Mobile Corporation. Ameritech is the Regional Bell Operating Company exercising a cellular franchise in metro Detroit. Each of the four cell sites will be equipped with a package capable of receiving up to six cellular inbound

Cell-Probe System Architecture

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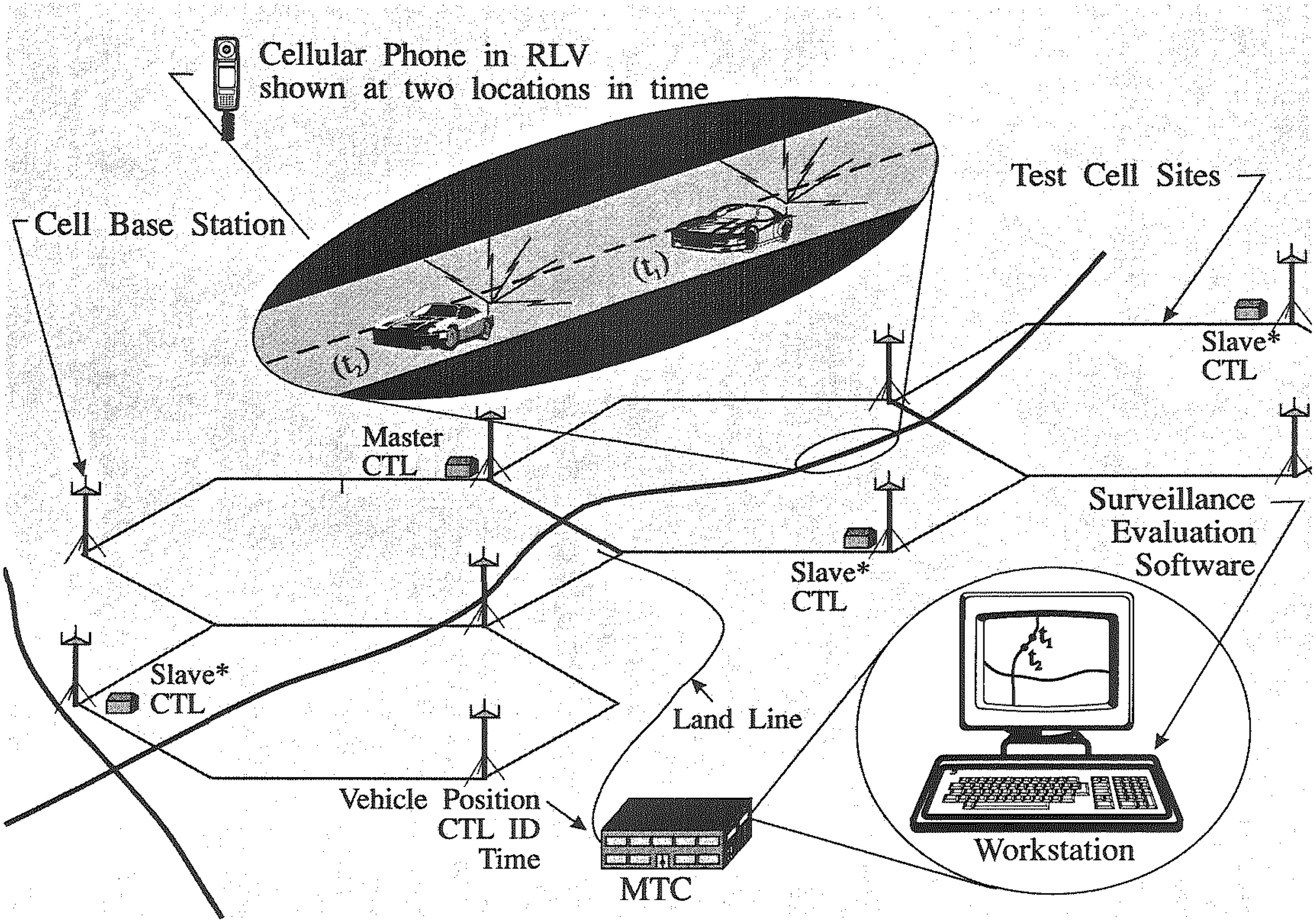


(mobile-to-base) channels at a time. Six Reference-Location Vehicles (RLVs) will be equipped with cellular telephones, reference-location systems, and the trunked radio transceiver. Although the installation details will depend upon the CTL system design, we envision that the four CTL packages will comprise a master and three slave stations by which the master combines the data of all four stations to yield vehicle coordinate and temporary identification data from each vehicle. The master can be located in the field, as shown, or at the MTC. The data are transmitted by land line to the MTC, probably via a protocol that involves polling by the MTC computer. A "Surveillance Evaluation Software" (SES) package at the MTC obtains a sampling of the vehicle coordinates, such as illustrated at times t1 and t2, in order to compile measures of link travel time. Link times deriving from both CTL data and reference data will be produced. The essential grist of the CTL evaluation is then provided by the comparison of location and traffic flow measures obtained through CTL data and through the "reference" sources.

The project also provides for examination of a set of detailed questions regarding the optimum utilization of CTL data. Location data obtained from cellular phones opeated by the general public will be examined to study the localized calling phenomena that attend major incidents. Insofar as freeway incidents are independently detectable at the MTC via the system of hard-wired detectors and surveillance cameras, separate confirmation and characterization of incidents will accompany the study of calling behavior.

The study will also include examination of the alternative methods of sampling phone location. Mobile phones which are engaged in a call, for example, permit continuous sampling while phones that are turned on, but unengaged, can only be sampled via their autonomic response to control channel queries. Sampling strategies will consider update frequency, the dwell time needed to sample accurately, and the loading of both the control channel resource and the CTL reception capacity. Strategies of preferential sampling based upon the need to search only for "exception data" on selected freeways and arterials are also to be considered.

The project will include a traffic modelling exercise in which the influence of probe sampling variables on the accuracy of traffic flow characterization will be evaluated. The modelling exercise will especially focus on the effects of probe sampling on arterial link times, where the traffic response to signal timing is represented, and can be varied.

Looking to the feasibility of implementing a CTL technology on an areawide basis, the proposed operational test will include a parallel examination of the institutional issues, through the cooperation of the multiple partners. This effort will address the full gamut of considerations involved in deploying CTL equipment that (a) is integrated with a cellular provider's infrastructure but, (b) enables areawide traffic surveillance by the local traffic management center. Both in- and out-of-region cellular carriers will serve on the team that considers issues of implementation strategy.

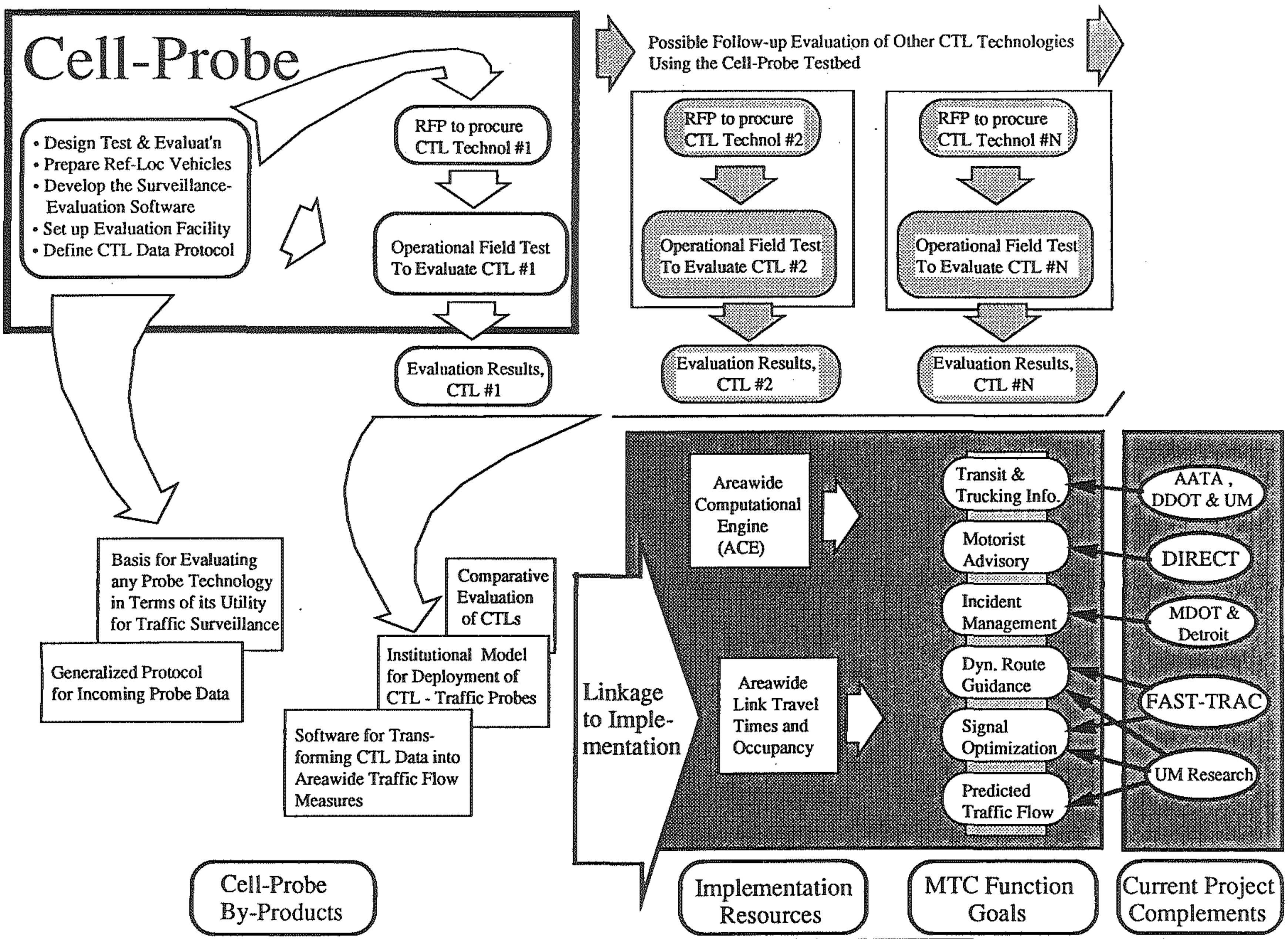
Cell-Probe and the Strategic Development of the Metro Detroit Corridor

The Cell-Probe project fits well into the long-term plan which is developing for implementation of IVHS in southeastern Michigan. While Cell-Probe is simply an evaluation exercise whose outcome is unknown, we rationalize the pursuit of this field test by the long-term payoff which would accrue if encouraging results are obtained. That is, if a CTL technology is found to enable good quality surveillance, then Cell-Probe will have been our (and perhaps, the nation's) single most important link to achieving areawide ATMS and ATIS services. This view is sketched on the next page, in the context of our vision for the MTC.

The Figure shows that, at the upper left, Cell-Probe is designed to yield the immediate product of a CTL evaluation. Subsequent evaluations of competing CTL technologies (numbers 2 through N) could be handled readily, since the Cell-Probe testbed would already be in place and its methodology already refined. *By-products* of such evaluation are shown trickling down at the lower left corner of the figure. Cell-Probe would yield:

- an improved basis for evaluating probe technologies, generally, (i.e., not only those based upon the cellular telephone)
- a generalized protocol and format for specifying probe data
- comparative data evaluating the competing CTL's (when more than one are tested)
- institutional models for deploying a CTL for traffic surveillance
- software, developed initially as an evaluation tool, but convertible at a later stage as the tool for transforming probe data into traffic data.

The long-term outcome, upon deployment of a CTL infrastructure, is the attainment of the key *implementation resource* that is represented by areawide link travel times and occupancy data. This fundamental, real-time, information base supports everything else. Together with the "Areawide Computational Engine", ACE, (i.e., the large-scale processor yet to be developed for supporting real-time traffic prediction and control) the traffic data



Strategic Developments Linked to Cell-Probe resource will support the string of *MTC Functional Goals* which embrace a broad set of ATMS and ATIS services. Complementing these functional objectives are other research and field test projects, shown at the right, that are currently underway as elements of the Michigan thrust into IVHS.

Moreover, we do not see the Cell-Probe project as an isolated effort. Rather, it is prioritized here in light of the long-term needs for IVHS implementation—both in Michigan and nationally—and in light of our other initiatives.

5.0 Preliminary Test Plan for Cell-Probe

Although the very first task of the Cell-Probe Project is to develop a detailed design of the operational field test, the following constitutes a preliminary plan upon which the proposal is based. The preliminary plan is premised upon certain overall objectives and expectations which are stated below.

Overall Objectives

The principal objective of Cell-Probe is to determine the utility of cellular phone location data, when suitably sampled and processed, for use as traffic surveillance information and to assess the potential for areawide implementation of such a function.

An ancillary objective is to assess the utility of CTL data for locating individual vehicles in support of Advanced Traveler Information Systems (ATIS) which require automatic vehicle location.

Assumptions and Expectations

It is expected that CTL technology will vary in its performance as a function of the topographical makeup of the area covered. Depending upon occlusions, signal reflections, and perhaps other factors, it is expected that adjustments will be required in the temporal sampling and statistical processing of multiple RF transmissions from a given vehicle in order to achieve the desired quality of surveillance over all topographies and road types.
Insert Figure showing the linkage of Cell-Probe to Future Implementation in the MTC

The principle CTL performance issue may involve multi-path ambiguities in areas with tall buildings, (corresponding loosely to the constraint on GPS performance due to satellite signal occlusion within "urban canyons"). To date, individual vehicle locations using DFLS technology have been effectively demonstrated in a community having low-height residential and office structures, although a few buildings range up to twelve stories high. Accordingly, we expect that probe locations may be rather easily measured on most suburban road systems and in communities developed with light industry, requiring only rudimentary means of sampling and statistical processing. Zones of development matching this profile appear to occupy more than 90% of the telephony cells comprising the metropolitan Detroit community. To achieve traffic surveillance via the Cell-Probe concept in heavily built-up areas, however, such as the central business district of Detroit, significant advancement in the technology may be needed.

As for temporal coverage of the road system through the movement of phone-equipped probe vehicles, it was noted earlier that a probe density of at least 5% of all vehicles is present in the United States today and that this number is growing at approximately 1% of the total fleet, per year. It is assumed that the phone-equipped fleet of vehicles that will be operating in 1994 in metro Detroit, a high-subscriber service area, will be at least 9% of all vehicles. On the basis of prior research on probe densities needed for good traffic surveillance, the expected probe fleet is assumed adequate for supporting a move toward areawide implementation, should the Phase One Cell-Probe tests show very positive results..

Additionally, it is recognized that the population of phones being carried by pedestrians is growing and that intelligent processing is required to distinguish a "phone-on-wheels" from a "phone-on-foot." We expect that the distinction will be made by inspecting a short history of each phone's travel speeds (i.e., most phones-on-foot will never exceed a speed of 2 mph.) Having identified that a certain phone is moving at, say, 5 mph or above, subsequent samplings of location from that phone will be interpreted as data from a traffic probe until such time as the vehicle's movement is otherwise disqualified.

Other probe anomalies are also anticipated. Since a phone-equipped vehicle may pull over and park while the phone is still turned on, or the driver may undertake other actions unrepresentative of nearby traffic, intelligent processing will be required to trap such phenomena and temporarily disqualify the vehicles as traffic probes.

Another issue is that of the total computational load that may be required to support the derivation of traffic surveillance data from many vehicles simultaneously across the metropolitan area. Since the location data from each probe would be handled more or less independently of that from other probes, it appears that the architecture for computing surveillance could be heavily parallelized. In any case, it is recognized that assessment of the processing volume implied by wide-area deployment is a significant requirement for the project.

Moreover, it is the purpose of the Cell-Probe project to evaluate the suitability of CTL technology for supporting vehicle-as-probe surveillance and for individual vehicle location—over a range of road types and community topographical structures. The project will illustrate performance levels using an evaluation-supporting software that will be developed in the course of the project. In a forecasting sense, however, we must also predict the surveillance potential of CTL technology that may derive when a mature state of surveillance-transformation software is later attained.

A Project in Three Phases

The CellProbe Project has been laid out in three phased activities, as follows.

- Phase 1 is to assess current performance of a CTL technology for traffic surveillance over a four-cell network that contains samples of different road types and topographical features. It's primary goal is to answer the question, "What is the potential that a mature version of this technology will deliver areawide traffic surveillance?" While Phase 1 is planned as a 20-month project, the first year effort will complete the preparation of a field test system. Data collection and evaluation of test results would be conducted in the final six months.

- Based upon an encouraging answer to the above question, Phase 2 is to assess the refinements needed for full application of CTL technology to areawide traffic surveillance, while deriving bottom-line answers to the question, "What will be the coverage, quality, cost, and implementation plan for achieving metro-area traffic surveillance via CTL?" Phase 2 is seen as an 18-month effort.

- Based upon showing a favorable path to implementation of Cell-Probe in metropolitan Detroit, Phase 3 is to execute the pre-deployment steps which would result in readiness of MDOT's Metropolitan Transportation Center (MTC) for full-scale operations. Phase 3 will commence based upon joint commitments to proceed toward implementation and will be accompanied by the process of technology refinement identified above. Phase 3 is projected to require 20 months.

Looking across the three phases, the project moves from a feasibility finding to a deployment assessment and then to the preparations that would lead up to deployment, itself.

Test Site for Phase One

Shown on the next page is a sketch of the central portion of the City of Detroit in which we propose to set up the initial test network for Cell-Probe. The basic network of four cell-sites will be selected from among the seven current Ameritech sites shown. Each of the sites entails a cellular antenna installation approximately 120 ft. above the ground, and associated switching equipment. The indicated portion of the metro area is attractive because it offers:

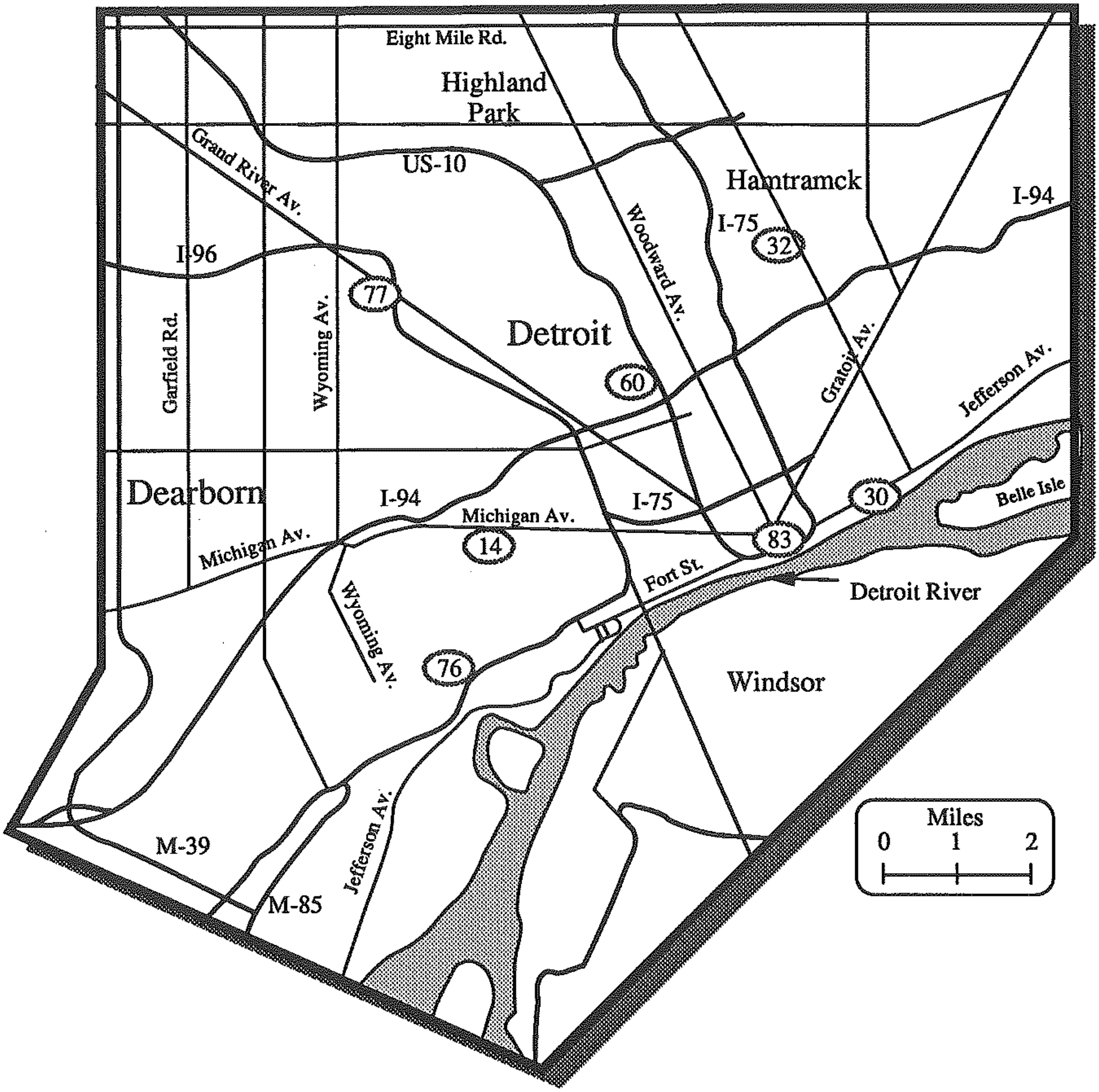
a) the greatest mix of structural topography. Note that the central business district of Detroit essentially surrounds cell site No. 83, providing approximately 10 buildings ranging from 12 to 45 stories high. Just east of cell No. 60 is the New Center area, providing a smaller group of buildings in the 8 to 20-story range. Most of the rest of the coverage area entails buildings which are under four stories in height.)

b) a good mix of freeway and arterial streets. Emanating from site No. 83 are Jefferson, Michigan, Grand River, Woodward, and Gratiot Avenues, each of which is a six-lane, with center-turn, major arterial on a radial grid. The indicated zone also provides for the hub of the freeway network, with Interstates, 75, 96, and 94, plus the major northwest freeway link, M-10, interlacing through the area.

c) the detectorized and video-surveillance portion of the Detroit freeway network. The 32 miles of current detectorization lies within the illustrated zone, covering portions of I-75, I-94, and M-10.

d) the immediate proximity of the MTC, which is located 1/2 mile northwest of cell site No. 83, on M-10.

Ameritech Cell Sites in Downtown Detroit



Cell	Name	Street Address	Latitude	Longitude	Base Elev.	Ant. Height
14	Tigerstm	3860 Vinewood	42 20 13 N	83 05 58 W	601	117
30	River_Pl	300 River Place	42 20 15 N	83 01 11 W	575	132
32	Hamtrack	2950 Council Ave.	42 23 18 N	83 03 04 W	630	117
60	Twig	1430 Marquette St.	42 21 43 N	83 04 58 W	629	117
76	FULTON	9191 Fort St.	42 17 43 N	83 07 45 W	675	117
77	JEFFRIES	12321 Jeffries	42 22 47 N	83 08 49 W	638	117
83	COBO	151 W. Jefferson	42 19 38 N	83 02 45 W	602	126

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Task Statements for Phase One

The first phase of the Cell-Probe project involves the following tasks:

Task 1 - Detailed Planning of the Field Test and Evaluation

Task 2 - Procurement of Equipment

Task 3 - Pilot Field Operation and Tuning of CTL Equipment

Task 4 - Installation of the Complete Basic Cell-Site Network

Task 5 - Development of Surveillance Evaluation Software & Methods

Task 6 - Conduct of the Basic Field Tests

Task 7 - Analysis of Deployment Strategies

Task 8 - Evaluation and Reporting of Results

A brief explanation of each Task is presented below.

Task 1 provides for the detailed plan of a Cell-Probe field test that will yield a comprehensive, yet expeditious, evaluation of a CTL technology. The detailed planning effort will provide (1) an experimental design and associated test plan, given control variables that address topography, traffic conditions, probe-sampling, reference-vehicle deployment, reference detectorization, call-engagement vs. control channel transmissions from the mobile unit, and probe data processing alternatives, (2) an evaluation plan keyed to the test plan and establishing the terms for assessing results, (3) specification of the provisions needed at the MTC to interface with incoming CTL data, including processing, display, and archiving for evaluation, (4) a specification for the protocol and format by which CTL data is to be communicated to the MTC, and the associated RFP for procuring CTL equipment and services, (5) the detailed integration plan for bringing all equipment, software, and methods to the state of readiness needed for executing the test plan.

> Assuming an April 1, 1993 startup, the **milestone** for completion of Task 1 is June 30, 1993.
>
> The **goal** of Task 1 is to produce a Detailed Test Plan.

In **Task 2**, the CTL equipment for four cell-sites will be procured by means of an RFP generated in Task 1. Competing equipment must have been demonstrated in a working prototype operating on mobile cellular phones by the time of the proposal submission. The CTL equipment will include 6-channel receiver/processor packages capable of locating as many as six vehicles simultaneously from each site. In addition, reference-location equipment will be obtained for outfitting six passenger cars for service as RLV's (presumably a full-complement dead-reckoning, map-matching, GPS-enhanced system will be required such as are available in prototype versions from GM, Motorola, Zexel, or others.) Each vehicle is also to be equipped with an available trunked mobile radio data transceiver and a cellular telephone. Finally, communications, processing and display hardware that will be installed at the MTC for development of the Surveillance Evaluation Software will be purchased.

Three **milestones** apply to Task 2. The award for CTL purchase is to be made by October 31, 1993. The delivery of the first two CTL packages is due by January 31, 1994 and all remaining equipment, ready for installation, is scheduled for delivery February 28, 1994.

The **goal** of Task 2 is to obtain the physical packages to be installed at cell-sites and in reference-location vehicles.

Task 3 provides for pilot operation and tuning of CTL equipment which is co-located with cellular transceiver equipment at two cellular towers. This step provides both for protecting Ameritech's service operations to subscribers and assuring full functioning of CTL equipment in the co-located environment. The task is carried out using the first two CTL packages that are built, thus expediting the overall schedule.

The **milestone** for completion of Task 3 is March 31, 1994.

The **goal** of Task 3 is to assure proper tuning of CTL packages in the co-location environment.

Task 4 provides for installation of CTL equipment at each of the four sites comprising the Basic Cell-Site Network. The installation includes hook-up via land line connections from site to site and to the MTC facility and demonstrated satisfaction of the communication protocol and format requirements. At the conclusion of Task 4, each installation has been calibrated so that derived locations are expressed in map-traceable coordinates. An operating network of four CTL sites will be interlinked to deliver individual vehicle location outputs to the MTC. In this task, the RLV packages are installed and their full functionality is demonstrated.

The **milestone** for completion of Task 4 is April 30, 1993.

The **goal** of Task 4 is to complete installation of the CTL and RLV hardware, as confirmed via the proper communication of both CTL and reference location data to the MTC.

Task 5 is to develop and install at the MTC a package of "Surveillance Evaluation Software" (SES) for evaluating CTL data in terms of its utility for traffic surveillance. The SES essentially executes logical tests on the data to qualify a vehicle as a probe, combines time-spaced samples, matches location data with the map database, and obtains comparisons between CTL-derived traffic flow measures and the reference sources. Steps will be taken to incorporate modern methods of artificial intelligence and stochastic modelling to render an effective SES processor. The time-sampling used in the SES process will be guided from the results of a "probe simulation" effort conducted at the beginning of Task 5. This exercise will employ an improved version of the Integration traffic model, implemented to represent individual probes within the traffic stream. In the initial development of SES, it is expected that the package will operate only on a fixed sampling schedule, as guided by the simulation work. Depending upon results from Phase 1 tests, it may be desirable to employ an adaptive mode of sampling for SES by which it solicits repeat CTL samples from individual vehicles that are noted to be on road segments in need of travel speed updates. Task 5 is completed when the SES is installed and operational.

The **milestone** for completion of Task 5 is February 28, 1994.

The **goal** of Task 5 is to implement the SES evaluation tool.

Task 6 provides for the conduct of the Basic Field Tests. A set of six reference location vehicles will be driven on the roads comprising the Basic Cell Site Network, while the instantaneous location of each is transmitted via trunked mobile radio to the MTC. Simultaneously, the vehicles will be tracked via CTL and the resulting location data transmitted by land line to the MTC. The tests will follow the procedures and sequence as defined in the detailed test plan produced through Task 1. Data will be processed at the MTC in order to illustrate the statistical quality of both the CTL location data and the derived traffic flow estimates as obtained on the covered street segments using the RLV units as probes.

In addition, "probes of opportunity" will also be located as their cellular transmission signals are received at the instrumented cell-sites. Upon sanitizing the probe data of any individualizing identities, the location information from vehicles traveling on the detectorized freeways (32 miles of interstate highway in the central portion of the City) will yield information that can be compared to the conventionally-measured traffic flows.

The **milestone** for completion of Task 6 is August 31, 1994.

The **goal** of Task 6 is to obtain an authoritative set of data demonstrating the quality of location data and inferred travel speeds of probe vehicles operating over the test network.

Task 7 provides for identification of the institutional issues raised by the wide-area implementation of a CTL network and the initial development of workable strategies for deployment. The effort must involve all of the stakeholders whose participation is needed in order to implement CTL technology for metro-wide traffic surveillance. Participants in exploring the deployment issue include those who would contribute to financing, jurisdictional approval, installation and physical siting of equipment, and the maintenance and operation of the infrastructure. A rough estimate of the cost to deploy a metro-wide CTL network for collecting data and centrally processing it to determine traffic flow will also be generated. Considering that a privacy issue arises when the identity of a tracked vehicle is known, the participants will seek deployment schemes which satisfactorily protect individual rights, as well.

The **milestone** for completion of Task 7 is September 30, 1994.

The **goal** of Task 7 is to determine feasible strategies for implementing a CTL infrastructure.

Task 8 is to evaluate the test results and to document both the findings and the overall project experience in a final report. The report will address the utility of the CTL approach for conducting traffic surveillance according to road type and nature of the topographical structure of the community, as well as to all other issues which bear upon the feasibility and economy of deployment. The findings will also address basic accuracies seen in the location of individual vehicles in terms of the utility of CTL technology as a means of AVL.

The **milestone** for completion of Task 8 is November 30, 1994.

The **goal** of Task 8 is to produce the Final Report for Phase 1.

Phase Two

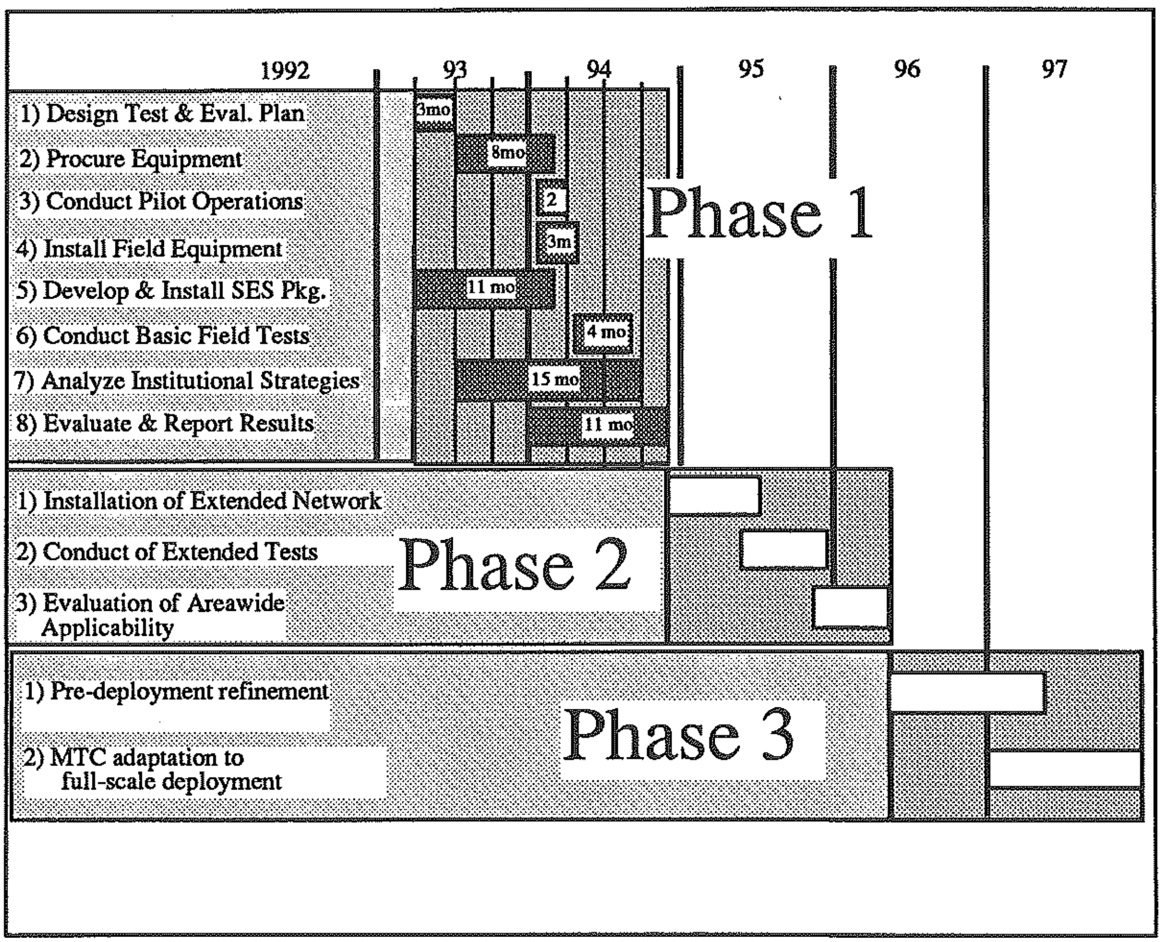
Without elaboration, our general plan is to next conduct a detailed study of areawide application of the location/surveillance technology, including the deployment and testing of a more extensive network of cell-sites. The testing must seek to confirm our expectations on wider area surveillance while also exploring the functions which involve ATIS services offered to individual vehicles whose phone is located via a CTL technology. At the end of Phase Two, the evaluated results must provide the basis for decision making on full-scale deployment.

Phase Three

Again assuming a positive decision on proceeding, Phase Three covers a broad set of "pre-deployment" preparations, especially focused on making the MTC fully ready for areawide surveillance operations. This is not a testing or study phase, per se, but rather provides for development of software, operating protocols, and the long-term relationships, agreements, and provisions that are suited to full scale, areawide operations. Over this period, the cellular industry in Detroit would be engaged in the "roll-out" of Cell-Probe equipment and services, increasingly establishing probe data coverage of the metro area as individual cells come on line.

6.0 Schedule

Shown below, the Cell-Probe project would entail a 20-month Phase 1 effort which leads from an assumed April 1, 1993 start to a report on the basic performance of the location technology by the end of November, 1994. At the end of an encouraging first phase, the providers of cellular switching equipment would go to work on commercially-suitable CTL equipment, given incentive from their customers, the cellular service providers. Phase 2 will require approximately 18 months beyond completion of Phase 1. If the go-ahead for full-scale deployment ensues, Phase 3 is seen as covering a 20-month period.



Cell-Probe Schedule

7.0 Budget

The following budget figures outline project costs.

Tasks	Cost Element ($ / 1000) UM/ERIM	CTL Provider	Task Total
Task 1 - Design Test and Evaluation Plan	60/180	0	240
Task 2 - Procure Equipment	10/100	1,500	1,610
Task 3 - Conduct Pilot Operations	20/25	160	205
Task 4 - Install Field Equipment	5/25	270	300
Task 5 - Develop & Install SES Pkg.	160/560	80	800
Task 6 - Conduct Basic Field Tests	110/580	200	890
Task 7 - Analyze Institutional Strategies	85/0	0	85
Task 8 - Evaluate & Report Results	150/120	30	300
Subtotals	600/1,590	2,240	4,430
Public Education, Supportive Services, & New MTC Equipment			370
Project Total, Phase I			$ 4,800

8.0 Management Plan

The Cell-Probe management plan is presented below in four segments. The *Project Management and Proposed Partnership* introduces each of the partnering organizations and highlights their basic role. The in-kind contributions of partners is shown under the heading, *Cost Sharing*. The section headed,*Management Provisions,* identifies assignments that will be given to those being paid through public funds. Thirdly, *Managing Technology Transfer* identifies the steps by which we propose to manage the sharing of Cell-Probe concepts, methods, and results with the public and the professional IVHS community.

Project Management and Proposed Partnership

The Cell-Probe project has been under development since October, 1991. Over that period, the basic technical issues have been explored, plans for a test deployment in Detroit have been addressed, and industrial partners have been enlisted. With Michigan DOT taking the lead position, the following partnering arrangements have been made.

- The project will be managed by MDOT and will be housed and given support staffing through the new MTC facility in downtown Detroit, at Howard Avenue and the John C. Lodge freeway.

- The University of Michigan, UM, having conceived and developed the concept of a field evaluation of CTL technology, will conduct the test and evaluation effort. As MDOT's continuing partner in a broad program of IVHS research, education, and testing, the UM and a supporting team from the Environmental Research Institute of Michigan (ERIM) will provide complete coverage of the technical, institutional, and evaluation-methodology issues within Cell-Probe.

- Ameritech Mobile Communications, Inc. will provide engineering and technical support, plus access to their cellular transceiver sites, for the installation and operation of CTL equipment in downtown Detroit. An attached letter from the President of Ameritech Mobile further expands upon the company's commitment to the project.

- The Nynex and GTE corporations, both cellular carriers from outside of the Michigan service area, will participate as advisors of the overall project, especially supporting the in-depth consideration of CTL implementation strategies. Letters from both corporations are attached. The participation by cellular carriers will include exploring the synergy between digital packet data services and vehicle location via cellular.

- AT&T, which is the supplier of Ameritech's cellular switching equipment, has been asked to participate as an advisor regarding the future task of integrating CTL functions with the switching and digital modulation equipment that is expected to be deployed in the years just ahead.

- The ETAK Corporation will serve as a project advisor and will supply the digital map data base for metropolitan Detroit. ETAK will also supply map-matching software for augmentation of the processing package needed to evaluate the CTL technology.

- GM, Ford, and Chrysler Corporations will be formally requested to participate as project advisors and to contribute passenger cars from the fleet that has already been committed for use in the DIRECT project, also being managed by MDOT in metro Detroit. The automakers have expressed interest in the impact of vehicle location via cellular as an alternative to other AVL technologies that could be installed in the OEM vehicle.

Cost Sharing

Participation by the various partners can be expressed in terms of the in-kind value of the contributions, as follows:

MTC Concurrent computing equipment - 1.67 years @ 10% of $1M	= 0.17M
MTC space - 15% of $3.5M X 10% for 1.67 years	= 0.09M
MDOT staff - 2 FTE's for 1.67 years @ $0.1 M	= 0.33M
Ameritech - 0.75 FTE for 1.67 year @ $0.2 M	= 0.25M
Ameritech - 4 cell-sites for 9 months @ $4K/mo	= 0.14M
GTE and Nynex - each 0.1 FTE for 1.67 years @ $0.2 M	= 0.06M
others invited and expected, not confirmed (IBM & AT&T)	= 0.06M
ETAK map and software - metro Detroit $25K/yr X 1.67 Yr	= 0.04M
GE trunked mobile radio - 6 veh. X $.5K/veh/mo X 10 months	= 0.03M
GM, Ford, & Chrysler - 6 vehicles @ $20K X 0.4	= 0.05M
SubTotal, in-kind value	$ 1.22M

Management Provisions

- MDOT will appoint a Project Administrator to oversee the Cell-Probe operational field test. The Project Administrator will supervise MDOT staff assigned to the project, monitor the performance of contractors, chair the Advisory Committee meetings, and provide overall project direction.

- The listed commercial partners will be constituted, together with an FHWA representative, as the Cell-Probe Advisory Committee. MDOT's Project Administrator will serve as the Chairperson of this Committee and will arrange for meeting announcement, agenda, and action follow-up.

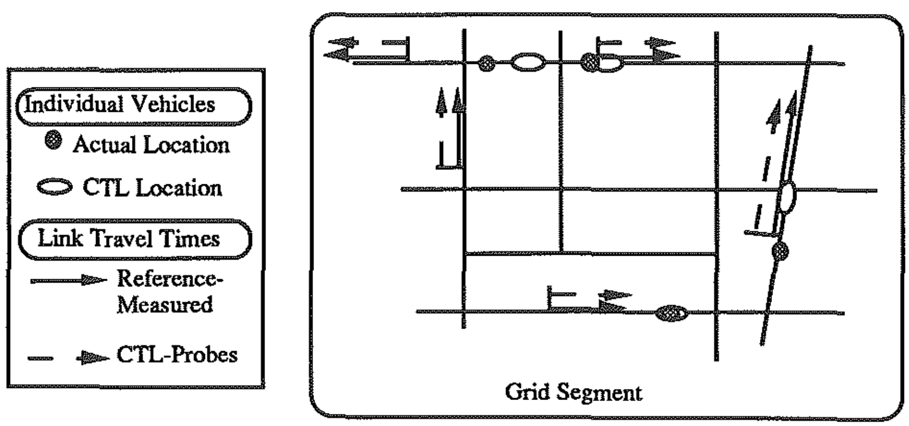
- MDOT will contract with the University of Michigan for the conduct of the Cell-Probe field test and evaluation of results. It has been determined that, since the objective of Cell-Probe is to evaluate a CTL technology supplied by an outside vendor, UM can efficiently serve in the design and conduct of a testing methodology, collection of performance data, and evaluation of results.

- As a first product of the test design task, an RFP will be drafted for procurement of the CTL equipment and the associated services supporting installation and operation of the hardware. MDOT will contract with the selected provider and will monitor performance.

Management of Technology Transfer

Because the Cell-Probe project examines a little-known arena, involving the juncture of cellular telephony, radiolocation, surveillance via probes, and the potential synergies with mobile data communications via cellular, it is expected that many parties would benefit from a sharing of this field test's concepts, measurement methodology, location technology, surveillance processing, implementation strategies, etc. Accordingly, we propose the following:

- augmenting the test data collection and evaluation software system with a large-screen display that will support live demonstrations of the CTL-based location and surveillance system in operation. The display is envisioned to present a limited street grid with simultaneous overlays of CTL and reference-derived locations of individual vehicles and link travel times, as shown below.



Cell-Probe Real-Time Display

The real-time display would be useful especially for visiting groups that wish to gain a sense of the project's purpose and to see samples of data being gathered.

- hosting a workshop for a combined group representing the cellular telephone industry and the traffic management community, near the end of the project. The one-day workshop, in coordination with the ATMS and ATIS Committees of IVHS America, would serve to advise the respective private and public constituencies that would be the primary stakeholders in any joint deployment of a CTL technology. Such a workshop, of course, would proceed only if the results show that traffic surveillance via mobile phones is, indeed, feasible and attractive.

- preparing training materials, in Phase 3 of Cell-Probe if warranted, to communicate the accumulated experience for installing and operating a cellular-based surveillance probe system. Such training materials would go beyond the direct reporting of results from operational testing and would encapsulate the knowledge related to applying the technology in a physical setting.

9.0 References

[1] Ervin, Robert D., "An American Observation of IVHS in Japan"

[2] Boyce, et al, "In-Vehicle Navigation Requirements for Monitoring Link Travel Times in a Dynamic Route Guidance System." 70th Annual Meeting of the Transportation Research Board, Jan., 1991.

[3] Ervin, Robert D., "The Challenge of Securing Public Benefit from IVHS Deployment in the U.S.", Paper Commissioned by the Diebold Institute for Public Policy Studies, Washington, D.C. January 1992.

[4] Radio Communications Report, June, 1992.

[5] On-Line Search of Motor Vehicle Registrations, September 25, 1992, Michigan Office of the Secretary of State, State of Michigan.

[6] Habal, Hadi, " Overview of Cellular Packet Data from an IVHS Perspective," Transportation Research Board Workshop on Communicating with Vehicles, Chicago, July, 1992.

[7] U.S. Patent No. 4,728,959. "Direction Finding Localization System" March, 1988.

[8] "Cellular Geolocation System," A Proprietary Information Document of E-Systems, Incorporated, September, 1992.

[9] "Traffic Monitoring Demonstration," A Synopsis of 12 August, 1992 Proposal to the Michigan Department of Transportation, Hughes Aircraft Company, Ground Systems Group, Fullerton, California.

10.0 Letters From Telecommunications Partners

AMERITECH MOBILE COMMUNICATIONS INC.

JOHN E. ROONEY
President

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Hoffman Estates, Illinois 60195-5000
708/765-5701
Fax: 708/765-3700

October 2, 1992

Dr. Robert Maki
Engineer of Traffic and Safety
Michigan Department of Transportation
State Transportation Building
P.O. Box 30050
Lansing, Michigan 48909

Dear Dr. Maki:

This letter is to confirm the intention of Ameritech Mobile Communications, Inc. to participate in the Operational Field Test in metro Detroit called, Cell-Probe. We heartily endorse the proposition that coalitions of government, private industry, and universities can more readily advance the complex implementations of IVHS and we see Cell-Probe as an attractive example of this notion. The Cell-Probe concept complements our long-term interests. It is especially appropriate in Detroit where cellular penetration is among the highest in the country.

Ameritech realizes the importance of traffic surveillance via probes to support real-time traffic management as well as varied forms of traffic advisory and routing. We also see a host of individual services that are made possible when traffic data and individual vehicle location are combined with a two-way mobile digital communication link. We welcome an opportunity to work closely with the Cell-Probe team in assessing a location technology using conventional cellular phones as the enabler of these key location and surveillance functions.

Ameritech stands ready to participate in the following:

- Establishment of Cell-Probe test objectives
- Critique of test procedures, measures of performance, and data processing
- Selection of cell sites

- Provision of access to sites, where possible, with our oversight on all installations that share sites with Ameritech's cellular telephony equipment

- Review and advice on requirements for integrating the location-finding system with telephony equipment for the conduct of the Cell-Probe experiments and for potential full-scale roll-out if and when deployment is undertaken

- Review of system capacity for supporting integrated functions

- Conduct of other data studies, where appropriate

- Evaluation of full metro-area roll-out, including
  - financial considerations
  - market considerations
  - cross-institutional arrangements
  - technical considerations

As the Cell-Probe project moves through its first task, that of detailed test planning, Ameritech will no doubt be in a position to be more definitive regarding our participation. Nevertheless, it is our intent to participate in depth and to serve as a partner to MDOT throughout the conduct of at least Phase One of the project. Ameritech's participation in later phases would, of course, follow if the initial findings encourage us all to proceed.

Sincerely,

John E. Rooney

Ronald R. Grawert
President

GTE Mobilnet

245 Perimeter Center Parkway
Atlanta, GA 30346
404 391 8497

September 29, 1992

Dr. Robert Maki
Engineer of Traffic and Safety
Michigan Department of Transportation
State Transportation Building
Post Office Box 30050
Lansing, Michigan 48909

Dear Dr. Maki:

This is to confirm the interests of GTE Mobilnet in participating in the Operational Field Test in metro Detroit called Cell-Probe. This project clearly presents an opportunity for us to explore a key implementation of IVHS. The Cell-Probe concept complements our long-term interests since we see broad utility of the cellular infrastructure for supporting mobile information functions.

GTE Mobilnet realizes the importance of traffic surveillance via probes to support real-time traffic management as well as varied forms of traffic advisory and routing. We recognize that the Cell-Probe concept, if proven, could lead to a metro-wide data resource giving travel link times throughout the road system. We also see synergies in combining traffic data, individual vehicle location, and two-way data communications. We welcome an opportunity to work closely with the Cell-Probe team in assessing a location technology using conventional cellular phones as the enabler of these key location and surveillance functions.

GTE Mobilnet is interested in participating in the following contexts:

- definition of Cell-Probe test objectives
- review and comment on system architecture design
- review and comment on test procedures, measures of performance, and data processing
- review and advice on requirements for integrating the location-finding system with the cellular network if full scale deployment is warranted
- review of system capacity for supporting integrated functions
- conduct of other data studies, where appropriate
- evaluation of full metro-area roll-out, including
    - financial considerations
    - market considerations
    - cross-institutional arrangements
    - technical considerations

As the Cell-Probe plan is developed in more detail, GTE Mobilnet will be in a position to more fully define its role as a partner to MDOT in this project. Nevertheless, it is our interest to participate throughout the three phases of this operational test, assuming that it proceeds from initial limited-scale tests toward predeployment testing.

Sincerely,

Ronald R. Grawert

RRG/ss