The people that understood the power of distributed, decentralized processing in the computer and telecommunications fields in the late '70's and early '80's gained significantly by this knowledge. Mainframes (IBM) gave way to minicomputers (DEC) which gave way to PC's (Apple). And now, everyone manufacturers laptops and palmtops. In each case the purveyors of the more complex and costly approach did not understand the subtleties of decentralizing the process of computing, data storage, data sharing, and data manipulation. These were smart people at IBM in the '70's when DEC and their minicomputers stole $10 billion per year from IBM. And, these were smart people at DEC in the '80's that watched Apple and later the workstation/ fileserver providers become the dominant players in computing. In 1974, over 95% of all data processing was centralized. Today, it is less than 40%.

In 1994, Intelligent Vehicle/ Highway Systems, or IVHS, is driving vehicle-borne technology away from dumb tags and towards intelligent (processor-driven) devices, such as smart transponders.

The use of these electronic devices for making the ground transportation infrastructure more efficient is really a new endeavor. It is an endeavor of the '90's, and technology is evolving very fast. The most dynamic aspect of these changes is the move to intelligent vehicles. This requires decentralized processing, manipulation, and storage of data.

Read-only AVI became obsolete nearly as quickly as it appeared on the transportation scene in the late 1980's. Advances in microprocessor and radio (RF) integrated circuits reduced cost and increased performance such that the truly "intelligent vehicle" could practically and cost effectively be deployed. Communication between the **intelligent vehicle** and the **highway system** (IVHS) also made a great leap forward with the introduction of long-range, read-write radio.

Due in part to advances in radio (RF) integrated circuits, two-way radio affords communications not just between the vehicle and the highway but also between the highway and the vehicle. Likewise, due to advances in microprocessor-based transponders, static or dumb vehicle tags have given way to intelligent transponders that can process and store data as well as communicate with the human being at practical prices under $50.00 per unit. And, this cost is likely to decline as computer circuits are reduced to chips or chip-sets.

The emergence of intelligent, vehicle-based communication devices gives true meaning to IVHS where the fundamentals are: an **intelligent vehicle** (microprocessor and memory); combined with sophisticated communications with the **highway system** (read-write radio); and **inclusion of the driver in the information process** (display, audio alarm, keypad, etc.)

It would be very difficult to find anyone in the transportation industry today that doesn't understand or appreciate the performance differences between an AVI tag and a microprocessor-based transponder. That part is obvious. What is less obvious, but will separate the visionaries from the also-rans in the 1990's, is the practical application of decentralized processing (intelligent transponders) for ETTM and IVHS. IVHS after all is the umbrella for ETTM, CVO, Airport Ground Transit Management (GTMS), Weigh-In-Motion processing and Electronic Parking. All these applications become practical and benefit greatly from the network of mobile microprocessors which decentralized ETTM/IVHS promulgates. The intelligent vehicle is the key to IVHS.

To follow is a layman's description of how the intelligent vehicle decentralizes and makes more practical and powerful Electronic Toll and Traffic Management.

The Subtleties are Powerful

Sometimes the most subtle of differences prove to have the greatest impact on cost and performance. The Washington, DC and New York City subway systems utilize a classic decentralized revenue collection methodology. The patron prepays an amount of cash and receives back a "stored-value" card on which a representation of the prepayment value is held in magnetic memory. Each time the patron uses the card, the balance is adjusted on it to reflect the subtraction of the fare for that trip.

Imagine if you can, imposing on that system the requirement that each fare must be pre-validated by a central computer and each transaction routed and recorded to a central computer before adjusting the account balance. Not only would the cost of the system skyrocket, but the shear complexity would add great risk to revenue accountability and add significant time to the transaction process.

Token systems on toll roads are also classic cases of decen-

volatile memory available, a single decentralized transponder can manage multiple accounts for toll agencies, parking applications, airport ground transit and other traffic management applications. This eliminates the need for inter-agency shared-data, and each agency receives a detailed audit for all its accounts with a decentralized system. There is no need for a massive "clearinghouse," as is required with centralized ETTM systems. Is it really necessary for agencies from Maine to Florida to California to have their respective lane controllers constantly updated with "black" or "white" list information on a single motorist? This is what a centralized ETTM clearinghouse requires. The savings provided by decentralized accounting are huge and compatibility made very easy, with no need for third parties to handle agency cash. If toll authorities wish to allow patrons to debit from a single, shared account, the decentralized ETTM system offers a dramatically down-sized and less expensive clearinghouse based on "off-setting" account reconciliation.

- The "Smart" transponder with a microprocessor, display, audio speaker, keypad, large memory and real two-way radio communication (no reflective tags here) provide many enhanced patron features including account balance information at the touch of a button, pre-warning of low funds, anonymous toll receipts and convenient prepayment features. All this for $40.00 per transponder.

Open Road Tolling

Electronic toll technology holds the promise of operating toll roads without the barrier systems used to stop vehicles for payment. And, motorways around the world are actively investigating the use of congestion pricing on open roads. However, none of this can take place without the ability to accurately locate vehicles across multiple lanes for proper account debiting and enforcement purposes.

With a centralized-type ETTM system, accurate processing for vehicle location has not been achieved and demonstrated. Multiple access techniques such as TDMA may provide a means to avoid interference between nearly mobile units, but does nothing for vehicle location. The requirement that individual lanes use up large chunks of bandwidth (1-2 MHz) is not going to be allowed by the FCC, and statistical techniques require too much time for real-time, open road processing. These centralized location techniques lead inevitably to the sad compromise of post-event batch processing. There is only one proven real-time validation and location technology on the market and it is based on intelligent transponders.

With a decentralized ETTM system, account validation is very quick because no central database search needs to be done for account validation. The smart transponder validates the account and debits upon command. Moreover, because the smart transponder, such as AT/Comm's, has a powerful microprocessor, it can actually determine its location on a multi-lane road and determine when it is in the "capture zone" of a specific lane. The return data to the lane antenna includes the lane location so adjacent lane readers ignore any cross-lane signals. This microprocessor-based transponder with read-write capability ensures that proper lane identification can be accomplished automatically for the important purpose of enforcement measures in the case of violations.

The Future Is Here

Virtually every transponder vendor is promising a new generation tag in 1994 or 1995. And, virtually all are promising the features currently available with AT/Comm technology. The final comparison is now between smart transponders and dumb tags with tiny memories. And, if the competitors now promising smart technology in late '94 or '95 are any indication of where the industry is really headed, AT/Comm is way out front on the technical curve.

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Black listing is accomplished at the preprocessing beacon. Interleaved with the toll schedule for warning of insufficient funds is the Black List. Transponders must pass through this radio field prior to a plaza/ramp or they are violators. Thus, all transponders, to work in a lane, will receive the black list. If the device is on this list, it will be disabled and become a violator in the lane. Lost or stolen transponders would obviously be black listed.

At the conclusion of every audit, the balance in each transponder becomes known to the agency, as well as any and all exceptions within the system. These other exceptions include diagnostics and alarm conditions.

The Cost Differences

Decentralized is less expensive, more accurate and provides greater revenue security.

- With the account in the transponder and validation of sufficient funds being done by the transponder itself, there is no need for new or parallel lane controllers, plaza computers or host accounting computers. If validation is going to be done by the lane equipment, as with all centralized ETTM, that equipment must be upgraded or replaced to provide local high-speed memory, processing capacity, new hardware, new software, and a network must be provided to pass account data to the lane. With a decentralized system, the existing lane controllers, plaza computers and headquarter computers need not be replaced. New ETTM audit and control software is provided. The savings here is in hardware costs and integration expense. The AT/Comm system on the Illinois Tollway was designed, installed and integrated using the existing lane controllers for significantly less cost than competing proposals and that included video enforcement and all control and audit software. Indeed, real bids in the last two years from centralized vendors have shown a per lane aggregate cost typically 100% more expensive than decentralized systems.

- In a recent centralized electronic toll contract, the cost bid by one of the vendors to run just the account services was nearly seven million dollars, or an additional $100,000 per lane just to run the "back office" required for centralized billing. At another centralized electronic toll operation, a customer services contract was awarded to a third party to run the agency's back office at a price in excess of $4 million. In addition to the high cost of centralized hardware and software, another agency has a customer service contract pending that will likely add hundreds of thousands of dollars per lane, per year to the cost of ETTM on their bridges. A daily audit of all ETTM transactions based on decentralized accounting and validation, using existing lane, plaza, and host hardware, adds very little to the cost of ETTM while providing superior revenue security. There is absolutely no need to let third parties handle revenues or run a back office accounting system.

- With centralized systems, the process of validation - account recognition, sufficient funds checking, black list checking, determination of lane location - doesn't even begin until the tag is in the lane capture zone. This places tremendous stress on lane processing, requiring sufficient time in the lane capture zone to process the transaction properly.

  In order to eliminate cross-lane reads, reflective centralized tag systems must turn down the radio frequency (RF) power in the lane, thus reducing the size of the capture-zone. Expectations with centralized systems are within the time the vehicle passes through this small capture zone, the tag ID is read, the account validated for sufficient funds, the account checked for black listing, and analysis for lane location be completed. The foolhardy solution to this time problem is batch processing. It's no wonder that after two years of testing centralized read-write tags, no such system can be found collecting tolls by any toll agency.

  On the other hand, by the time a decentralized transponder, such as AT/Comm's, has entered the capture zone, all validation, including black listing and lane location, has been done... 32 bytes at 9600 baud and the transaction is complete, with details forwarded into the lane controller for audit and real time validation. That's less than 27 milliseconds and it's done... toll collected, lane equipment notified, audit trail into system. There is no need for wide bandwidth or high data-rate radio communications.

- With a microprocessor-based transponder and ample non-