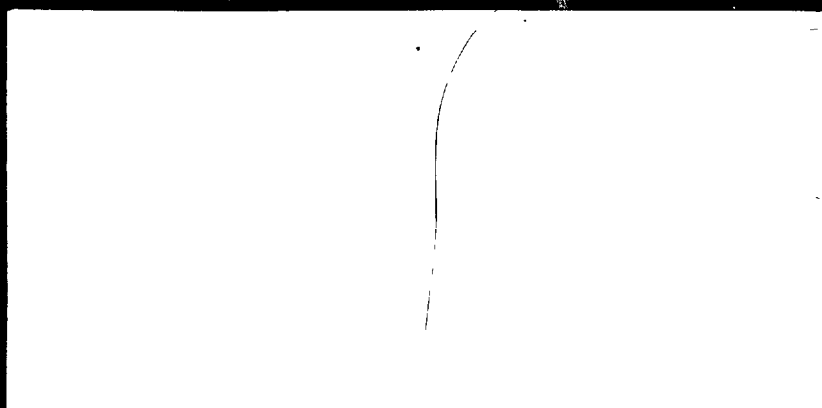


TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

IDEA *Innovations Deserving
Exploratory Analysis Program*
INTELLIGENT TRANSPORTATION SYSTEMS



Report of Investigation

DOT/FHWA

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IDEA PROJECT FINAL REPORT

Contract ITS-3

IDEA Program
Transportation Research Board
National Research Council

January 20, 1995

**AN IMPROVED
METROPOLITAN AREA
TRANSPORTATION SYSTEM (IMATS)**

Prepared by:
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**INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE
TRANSPORTATION RESEARCH BOARD (TRB)**

This investigation was completed as part of the ITS-IDEA Program, which is one of three IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in surface transportation. It focuses on products and results for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan. The other two IDEA programs areas are TRANSIT-IDEA, which focuses on products and results for transit practice in support of the Transit Cooperative Research Program (TCRP), and NCHRP-IDEA, which focuses on products and results for highway construction, operation, and maintenance in support of the National Cooperative Highway Research Program (NCHRP). The three IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods, and technologies, including conversion technologies from the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems.

The publication of this report does not necessarily indicate approval or endorsement of the findings, technical opinions, conclusions, or recommendations, either inferred or specifically expressed therein, by the National Academy of Sciences or the sponsors of the IDEA program from the United States Government or from the American Association of State Highway and Transportation Officials or its member states.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
PROBLEM STATEMENT	3
RESEARCH APPROACH	3
RESULTS	3
INTRODUCTION	3
IRAC TECHNOLOGY	4
<i>Vehicle Rental Procedures</i>	4
<i>IRAC Vehicle Electronic</i>	5
<i>IRA C User Interface</i>	7
MOCT TECHNOLOGY	10
<i>The ChP Algorithm</i>	10
<i>Software in DOS to Exercise the ChP Algorithm</i>	11
<i>GPD Software</i>	12
<i>Software in Windows to Exercise the ChP Algorithm</i>	14
IMATS CONSIDERATIONS LEADING TO PILOT PROGRAM	15
<i>Working with Local Taxi Organization</i>	15
<i>Utilizing UNR Vehicles</i>	16
IMATS IDEA PROJECT ORGANIZATION.....	17
<i>UNR and Lemelson Foundation initial Participation in IMATS</i>	17
<i>Ongoing UNR Participation</i>	18
SUMMARY	18
ACKNOWLEDGEMENTS	19
REFERENCES	19

EXECUTIVE SUMMARY

During the period from 1980 to 1990, single-occupant vehicle (SOV) use increased from 65 percent to 74 percent, carpool use declined from 20 percent to 13 percent, and transit use declined from 8.4 percent to 5 percent. The Improved Metropolitan Area Transportation System (IMATS) has the objective of reversing this trend by providing a multiple-occupant-vehicle (MOV) transportation system that is equivalent or superior to SOV use in terms of convenience, flexibility, and cost.

The successful development of IMATS requires that attention be focused on technology, operational procedures, and cost. Technology, or rather the integration of currently available and low-cost vehicle location, mobile communication, and processing systems, is the basis for providing transportation that is as convenient and flexible as SOV use. The Transportation Research Board (TRB) funded an Ideas Deserving Exploratory Analysis (IDEA) project to evaluate this technology. The evaluation results show that there is good potential for bringing the IMATS concept to market.

IMATS employs, in the most general case, the continuum of vehicles shown in Figure ES-1. Vehicle use is integrated or scheduled by means of a central processor. It is envisioned that IMATS will evolve by sequentially implementing new user services.

The IDEA project focused on a technology demonstration of the instant rent-a-car (IRAC) and

multiple-occupant commuter taxi (MOCT) elements of Figure ES-2. IRAC is a compact automobile that can be conveniently rented using a credit card. IRAC provides local transportation for arriving carpool and transit passengers and local residents. IRAC can be viewed as a personal taxi, with a passenger serving as the driver. MOCT can be viewed as a centrally dispatched carpool system, akin to the use of a conventional taxi carrying multiple passengers during the morning and evening commutes. A basic difference is that the driver is also a commuter.

The project demonstrated integrated IRAC and MOCT operation at the TRB ITS-IDEA Advisory Committee meeting on September 25-26, 1994, in Woods Hole, Massachusetts. The vehicle used for IRAC demonstration of credit card access and use was an electric vehicle (Figure ES-3), provided by the electric vehicle program of the commonwealth of Massachusetts. Although initial IRAC operations will employ internal combustion engines, an electric vehicle was used in this project because of the potential for the IRAC rental program to be a cost-effective way of satisfying the mandate that requires 2 percent of the vehicles sold in California, New York, and Massachusetts in 1998 be of the zero-emission type. Currently, only electric vehicles appear to be viable candidates for zero-emission vehicles. The current high cost and limited range tend to be impediments to individual purchase, but not to IRAC use.

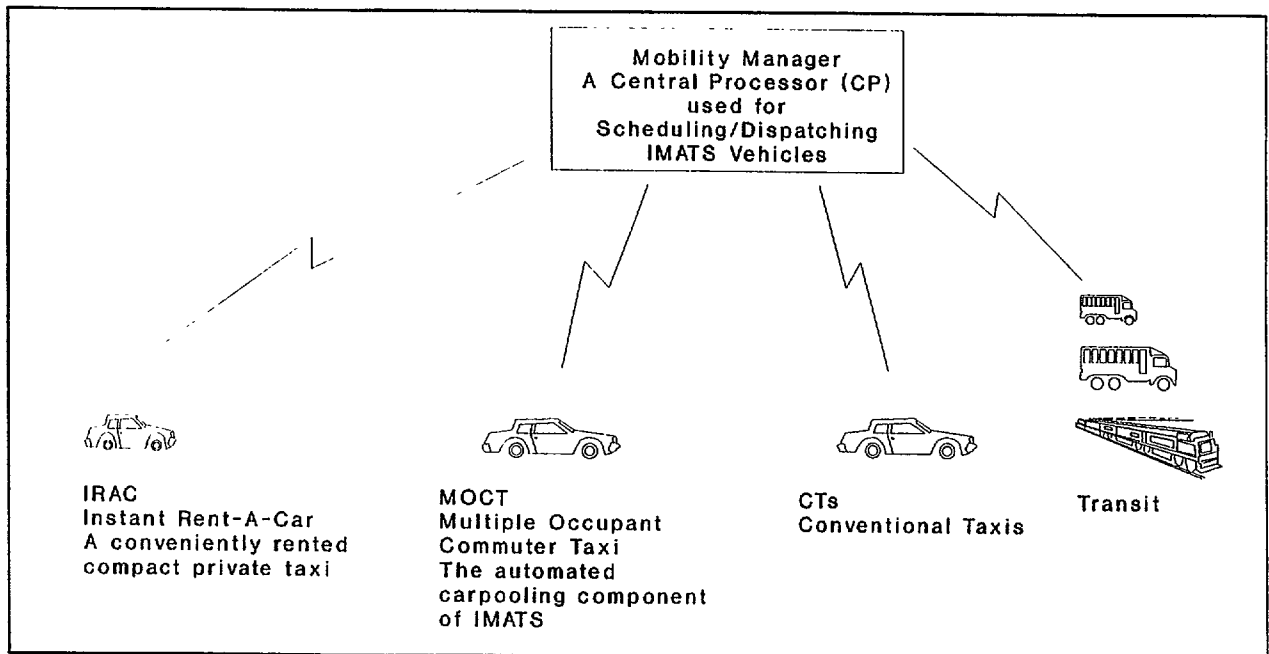


FIGURE ES-1 Continuum of vehicles used in IMATS.

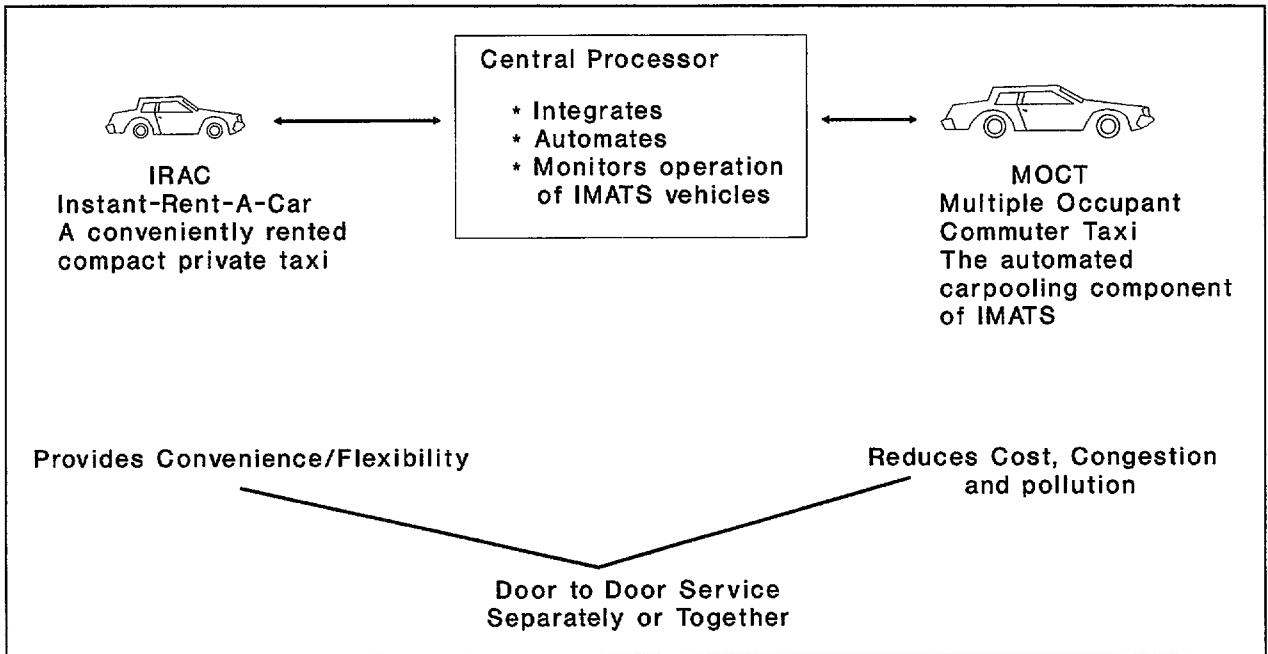


FIGURE ES-2 Vehicles from Figure ES-1 used in the initial stage of IMATS.



FIGURE ES-3 Solectria Force (Geo Metro conversion) provided by the Electric Vehicle Program of the commonwealth of Massachusetts.

PROBLEM STATEMENT

The trend depicted in Figure 1 toward increasing use of single-occupant vehicles (SOVs) and decreasing use of multiple-occupant vehicles (MOVs) (i.e., carpools and transit) is resulting in ever-increasing urban congestion and pollution. The objective of the Improved Metropolitan Area Transportation System (IMATS) is to reverse this trend by introducing a transportation system that is as convenient and flexible as SOV use, but less costly.

RESEARCH APPROACH

IMATS proposes to provide the convenience and flexibility of SOV service by employing vehicles as shown in Figure ES-1. Vehicle use is integrated and scheduled or dispatched by means of a central processor.

The first IMATS vehicle on the continuum is the instant rent-a-car (IRAC). IRAC is a compact automobile that can be conveniently rented with a credit card. IRAC provides local transportation for carpool and transit passengers and for local residents. IRAC can be viewed as a personal taxi, with a passenger serving as the driver. IRAC vehicles can be powered by electric motors or by internal combustion engines; the technology can be applied to virtually any vehicle with an electrical system.

The IRAC element of IMATS could play a significant role as a cost-effective way of introducing electric vehicles in order to satisfy the California 1998 zero-emission vehicle (ZEV) mandate, that is, that 30,000 of the automobiles sold in California in 1998 must be zero-emission vehicles. The IRAC element of IMATS is also of potential significance with respect to emerging station car programs, which make electric vehicles an adjunct to rail or express bus service or both.

The second IMATS vehicle is the multiple-occupant commuting taxi (MOCT). MOCTs can be viewed as centrally dispatched carpool vehicles, akin to the use of a conventional taxi carrying multiple passengers during the morning and evening commutes. A basic difference is that the driver is also a commuter.

A third vehicle is the conventional taxi. Taxis continue to play their current role of providing convenient door-to-door transportation for one or more passengers. In addition, taxis ensure the flexibility and convenience of the overall IMATS system by providing multiple-occupant transportation for commuters when required or most cost-effective. Taxis can also provide an assured ride home at IMATS rates for a commuter who has to work late.

Conventional transit services continue to operate, although they may be augmented by flexible transit, such as paratransit and dial-a-ride. Transit use is made more attractive by the availability of IRAC vehicles for local transportation, and by intelligent transportation system (ITS) technology that better informs users of transit schedules and that provides "smart cards" for fare collection.

The evaluation of the IMATS concept, funded by the IDEA program, is essentially complete. The project has proven the feasibility of a technology demonstration effort involving only the IRAC and MOCT elements of IMATS as detailed in the Results section of this report. A follow-up IDEA project to perform a pilot operational project involving IRAC vehicles is under negotiation. Further work will then be required for commercial realization of the IMATS concept. It is envisioned that IMATS services will become available to the general public by enlisting existing public and private transportation organizations to become IMATS providers.

RESULTS

INTRODUCTION

The three key elements involved in the development and implementation of IMATS are technology, operations, and user cost. Although this project has focused primarily on demonstrating technology, consideration has also been given to operations. The discussion that follows includes the technology aspects of the IRAC and MOCT components of IMATS.

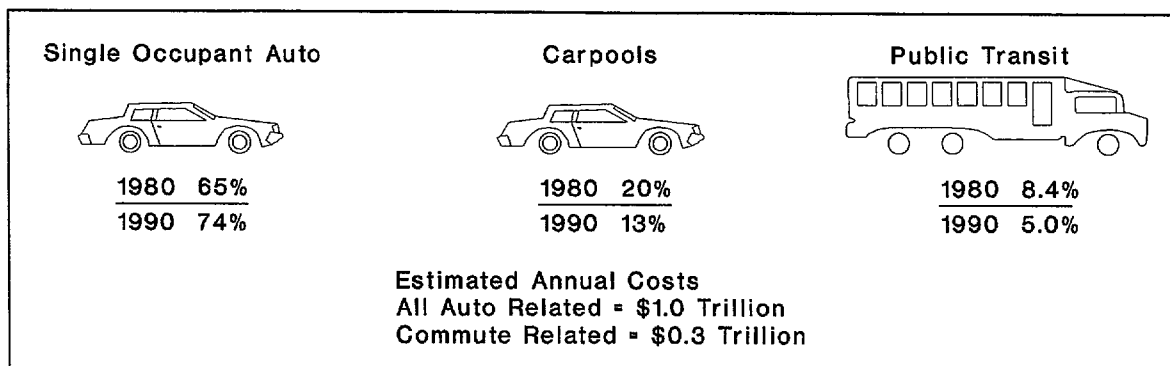


FIGURE 1 Comparison of vehicle use, 1980-1990.

The IMATS IDEA technology-focused effort is structured as in Figure ES-2, where a central processor is being used for both IRAC and the computerized dispatching of carpools. The IRAC demonstration employed both hardware and software; that is, a vehicle was conveniently rented and used, and a bill was generated. The carpool-dispatching demonstration employed simulated random trips using the known geographical distribution of population in the Reno, Nevada, area. Of significance was that ride matching was achieved by the central processor in real time (i.e., within minutes or seconds).

IRAC TECHNOLOGY

Vehicle Rental Procedures

Figures 2 and 3 indicate how a user can employ a personal computer (PC) to request MOCT and IRAC service in the initial technology demonstration effort. Figure 2 shows the high-level program structure. Figure 3 depicts the user interface and the two types of IRAC rental procedures—reserved and unreserved.

In the unreserved mode, a user determines if a vehicle is available via the status of its dome light; if the vehicle is available, the user inserts a credit card into the credit card reader mounted in the car. If the credit card is validated, the door unlocks, the dome light status changes, and the vehicle can be used. When the user is through

with the vehicle, he or she removes the credit card and leaves the vehicle. At this time the dome light status changes to indicate availability and a message is sent to the central processor to indicate that vehicle is available and its location.

A user desiring to reserve an IRAC proceeds as indicated in Figure 3. Using a PC and modem to address the central processor, the user can request the location of the nearest available IRAC. He or she then reserves a specific IRAC with a credit card. At that time, the central processor sends a message to the IRAC that changes the dome light status to indicate that the vehicle is reserved. In addition, data are stored in the central processor (or vehicle processor) so that only a specific credit card can access that vehicle. The user who has reserved the vehicle then uses the credit card to access that vehicle. At the cessation of all trips the credit card is billed for use (and reservation) time.

An alternative IRAC reservation procedure might be used when a transit rider wants to reserve an IRAC for the specific time that he or she will arrive at a transit terminal. The user could in this instance use a home or office PC to connect to the central processor. At a future date the transit rider will probably be able to reserve an IRAC by using one of the "smart kiosks" that are being installed at transit terminals to provide schedule and fare data.

The central processor sorts all available data, including weather and traffic delays, and provides each passenger and driver with several options.

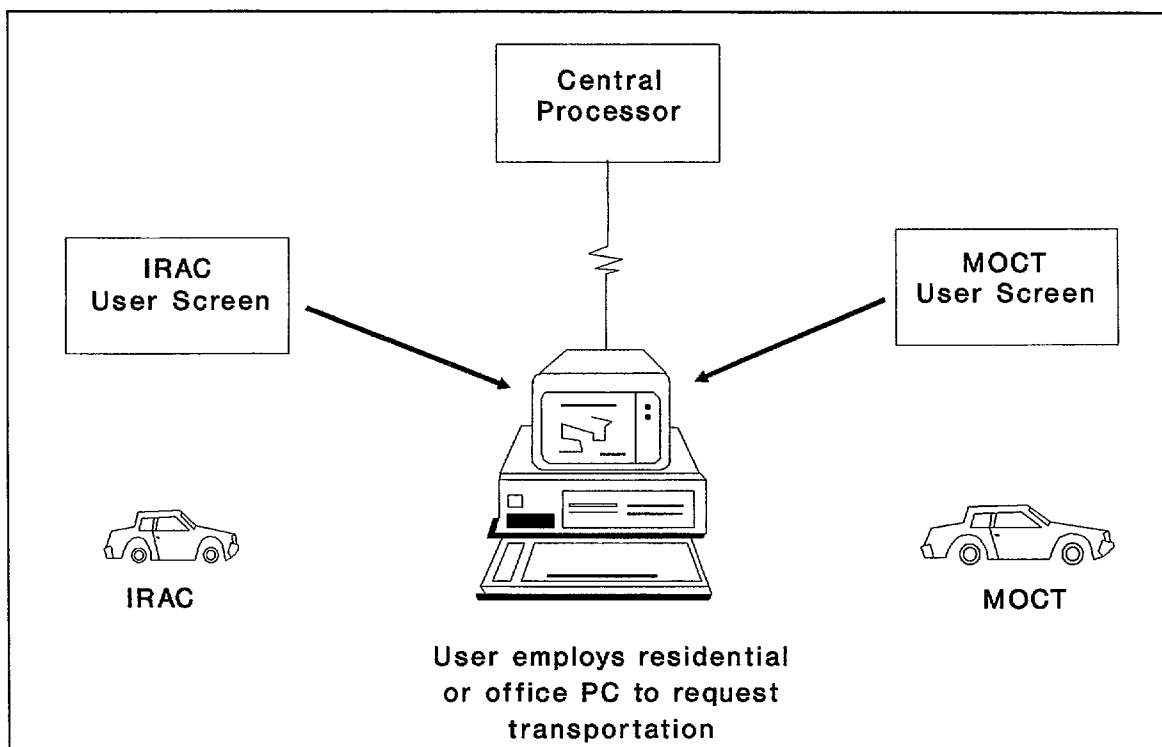


FIGURE 2 IMATS program structure.

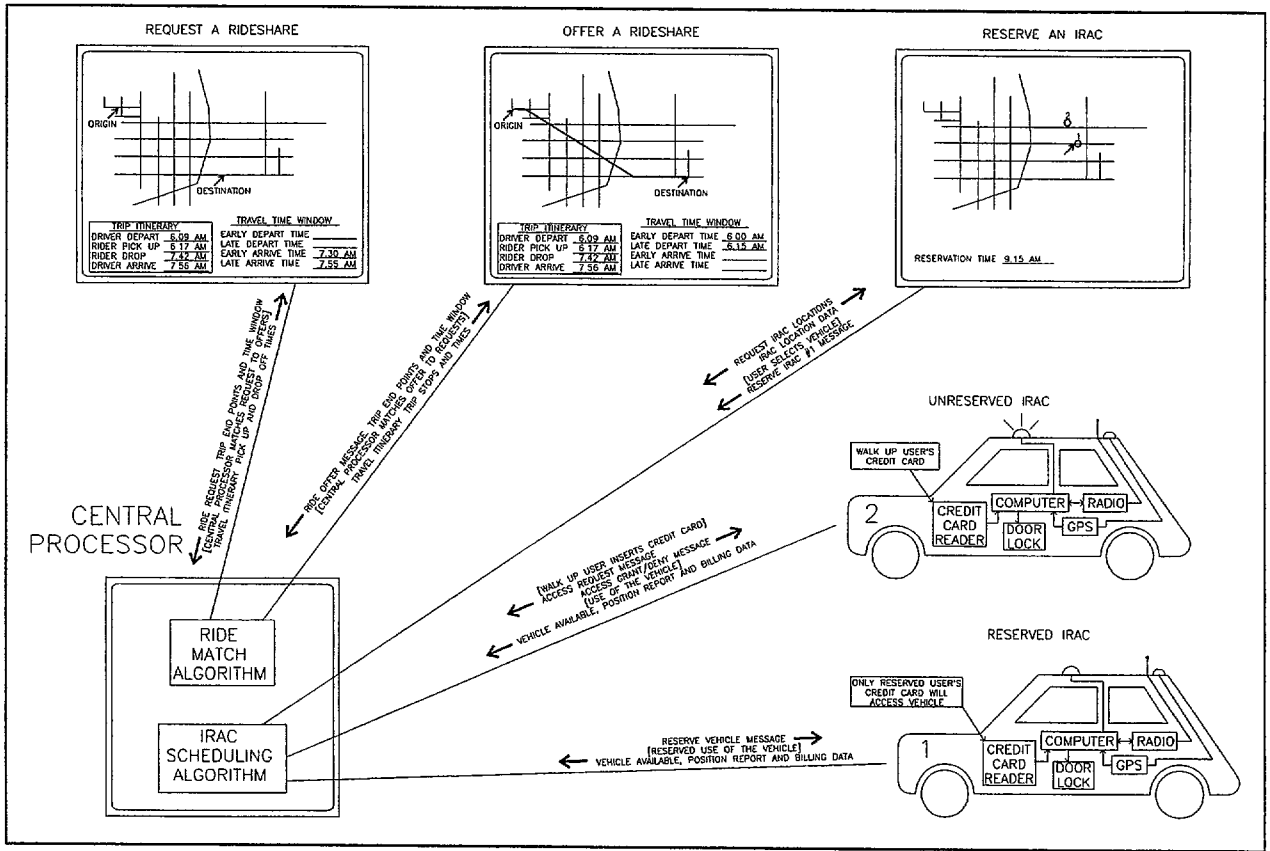


FIGURE 3 IMATS user interface.

Passenger Options

Pickup time, drop-off time, and cost are the passenger options. The passenger selects an option or elects SOV or transit use. If MOCT use is elected, the passenger receives a printout as depicted, and his or her credit card is charged.

Example of Typical Passenger Printout:

Passenger Name:	John Doe
Residence Location:	462 Maple St.
Pickup Time:	7:15-7:30 a.m.
Destination:	7th and Main
Estimated time of arrival:	7:45 a.m.
Cost (14.5 mi @ \$0.25/mi):	\$3.62

Driver Options

Driver options include locations and pickup times of passengers, estimated time of arrival at driver's destination, and compensation. The driver selects an option or elects SOV or transit. If MOCT use is elected, the driver receives a printout as depicted, with compensation credited to his credit card.

Example of Typical Driver Printout:

Driver Identity:	Jim Smith
Residence Location:	862 Vine St.
Passenger Pickup:	
(1) John Doe, 426 Maple St., 7:30-7:45 a.m.	
(2) Sally Brown, 974 Green, 7:30-7:45 a.m.	
Passenger Drop-off:	
(1) John Doe, 675 South Center	
(2) Sally Brown, 972 South Center	
Compensation (15 mi @ \$0.40/mile):	\$6.00

IRAC Vehicle Electronics

Figure 3 also shows a block diagram of the IRAC vehicle electronics package. The heart of the package is a processor that interfaces with a credit card reader, a Global Positioning System (GPS) vehicle location system, a two-way radio link to the central processor, a door-opening mechanism, and a dome light.

The credit card reader has gone through three stages of evolution. Before the submission of the IDEA proposal, IMATS personnel conducted a proof-of-concept test to

satisfy themselves that no major problems would be encountered. This test utilized a Dallas semiconductor "button" that digitally stored user identification (ID) and other information. The button, when inserted into a receptacle that was connected to a laptop PC, caused the ID to be transmitted via a cellular telephone to the central processor. The central processor in turn verified user ID and sent a door-opening (relay closure) message back to the laptop PC.

University of Nevada-Reno (UNR) students used a different credit card reader technique in their IRAC vehicle demonstration. The students elected to use the Texas Instruments Radio Interface Standard (TIRIS) card recognition technique. This TIRIS system employs a vehicle-mounted radio transponder. When a TIRIS card is placed in the vicinity of the vehicle's antenna, it uses energy received from the vehicle transponder's interrogation to send a signal containing user ID back to the vehicle. The transponder is interfaced with the vehicle PC.

IMATS personnel who had used the Dallas button in the initial proof-of-concept effort noted above would have preferred to continue using it throughout the project. However, they accepted the students' decision to change to TIRIS for two reasons. First, it was a student endeavor and hence was their decision. Second, the TIRIS technique is currently used for automated toll collection and is being proposed for congestion pricing. Use of TIRIS would thus expose IMATS personnel to such technology. It should be noted that when the TIRIS system is used for toll collection, the radio transmitter and receiver are installed at the toll booth and the ID card is installed on the vehicle.

The students' use of the TIRIS system was successfully employed in the first demonstration of IRAC on the UNR campus in April 1994, which was seen by more than 150 faculty, students, and visitors. Subsequent IRAC demonstrations have used the Dallas button because of its simplicity.

The Geo Metro electric vehicle currently in use by the IMATS project was equipped with a mechanism that automatically locks the vehicle doors when the vehicle is in motion. The UNR students added a pair of processor-activated relays that enable the processor to both lock and unlock the vehicle doors while retaining the original automatic lock-on-motion feature.

The processor used in the proof-of-concept test was a conventional laptop computer. Subsequent vehicle configurations used a PC 104, which is a PC that is configured from individual modules (provided by over 50 suppliers). The modules are selected to provide the desired performance and are packaged vertically in a standard physical configuration. Modules are available for a variety of central processor units (from 8080 to 486) and

peripheral functions (telephone modems, GPS units, analog and digital input/output modules, and so forth).

Vehicle location is provided by a GPS system. In the proof-of-concept test, a Trimble 10X, costing \$7,500 and previously used in a naval unmanned vehicle program, was employed. The UNR students used a Trimble PACER unit in their demonstration. This unit, which cost \$5,700, included a dead-reckoning capability that augments the GPS data when the GPS signal is lost in metropolitan high-rise canyons. The dead-reckoning capability is achieved by processing data from a vehicle-installed heading rate gyro (provided by Trimble as part of their package) and the vehicle odometer. More recent demonstrations have used a Trimble PC104 GPS module that costs \$600.

None of the above-discussed demonstrations utilized differential GPS (DGPS) to improve positional accuracy since conventional GPS accuracy was deemed adequate for initial demonstrations (and probably also for further work). Of interest, however, in connection with DGPS is that a Reno FM radio station, KNEV (95.5 MHz), is broadcasting DGPS corrections on a subcarrier for use in this area. It is envisioned that incorporating DGPS into an IRAC vehicle will become a future student project.

The central processor and the IRAC vehicles must communicate to exchange vehicle status and control information. The communications are short (generally less than 100 characters) and infrequent (two communications per rental event). The cellular telephone was selected as the communication medium because it is widely available, economical, and easy to use. Each IRAC vehicle is equipped with its own cellular telephone and identified by its cellular telephone number.

The capital cost per vehicle is about \$500 for a modem, cellular telephone, and cellular data access device. Operational cost per vehicle (with the current service arrangement) is \$35 per month, plus about \$0.70 per rental event. Because the supporting technology for cellular communications is advancing rapidly, cost reductions are expected.

Cellular telephone communication appears adequate for near-term use. Ultimately, some communication technology that is evolving from or is compatible with the overall ITS program will probably be utilized.

Cellular telephone data communication is more difficult than land-line communication because of its noisy environment. Calls may be switched between cell sites, causing data glitches at uncontrollable times; cell sites may be completely occupied and temporarily refuse to accept a call; and radiowave propagation varies with physical location.

Initial system testing was at a site outside of Reno, where there was little cellular traffic and good RF coverage. Nearly 100 percent reliable communication was

experienced at that site. Later testing in downtown Reno experienced nearly 100 percent unreliable communication. In fact, it was not possible to communicate data with a vehicle in motion until after the communication reliability problem was addressed. The local Cellular One office in Reno confirmed that communication problems were to be expected because the cell site in Reno, at the Hilton Hotel, is the busiest in the West.

The first approach at reliable communication via cellular telephone was to use MNP type error-correcting modems. Difficulties were experienced with this approach in controlling how the MNP protocol reacted to an initially noisy environment. Time constraints prevented the testing of the MNP 10 protocol designed specifically for cellular service.

The second approach was to reduce the communication baud rate to 300 baud and drop the MNP protocol. The reduced baud rate was sufficient to get communications up and working and provided adequate data transfer given the small size of the data messages. To ensure data validity, messages were check summed and an acknowledgment protocol was implemented. Messages were simply retransmitted when the check sum failed.

When the IRAC vehicle was used in Reno, the check-sum-and-acknowledgment scheme was found to be inadequate. Three types of communication problems were identified: cell site completely occupied and refusing to accept a call, noise hits in every data message, and dropped calls. The first problem was dealt with by simply redialing until a connection was made. The second was dealt with by saving failing messages in a buffer and implementing a character-by-character majority vote scheme. The majority vote process works by first detecting if a message is good or bad. If good, the message is acknowledged and communication continues. If bad, the message is saved in a buffer and marked "not acknowledged." The sender detects either the no-acknowledgment response or failure to receive an acknowledgment within a period of time and resends the message. When at least three failing tries are in the buffer, for example, the messages are compared character by character in an attempt to build a message that passes the check sum test. Consider the message "HELLO" received in error three times, as "HEyLO," "H\$LLz," and "qEL%O." Note that there are more H's in the first position, so H is assumed to be the valid first character. The process continues with each character, and the check sum is tested when the voting process is complete. This scheme has been tested with error rates greater than 50 percent, and it was determined that communication always succeeds within about a dozen attempts.

The call dropping problem required addressing the common disconnect problem: who calls back? The solution here is to have the talker call back. This means

that both communicators must know the other's telephone number so they can redial if the call is dropped in the middle of a message.

The final exam, so to speak, for the communication method improvements was to drive the vehicle around Reno while calling in to the central processor on a regular schedule and reporting vehicle position. The vehicle sends the time the communication was initiated, as well as the position. The central processor records the time difference between when the call was initiated and when it was received as a measure of difficulty in getting the communication through.

Figure 4 shows a typical 3-hour trip to Reno in which the vehicle called in and reported its position every 5 minutes. The trip originated and terminated at an IMATS facility northwest of Reno; circles mark the call-in points. Two sections of the Reno city map are shown to provide geographic orientation. There was one difficult communication, which required about 140 seconds to complete; all of the remaining sequences took about 30 seconds. There were no missing calls.

The central processor used a 386 class PC interfaced with either a telephone landline or directly with a cellular telephone, depending on the test facility. At some locations where an IRAC demonstration was conducted, it was difficult to obtain an "outside" direct line, that is, one that did not have to utilize a switchboard for either incoming or outgoing calls. Such switchboard use tended to complicate the transfer of IRAC data. This problem was overcome by having a spare cellular telephone to connect with the central processor in such instances.

IRAC User Interface

Users and maintenance personnel can locate IRAC vehicles by either searching for them on the street or checking a map of IRAC locations on a PC. Because it is anticipated that system operating personnel will need to be able to visualize IRAC distributions graphically, a computer program has been written to do so. The program is incorporated into the IMATS central processor, and a subset of it will be provided to IMATS participants so that they can locate and conveniently reserve IRAC vehicles from their PCs.

The IRACs are integrated into the rideshare matching algorithm in that they appear to be a specialized type of trip endpoint. During this project only limited experimentation has been done in search of effective means to combine IRAC and MOCT operations. Additional effort is planned to discover methods that will enhance MOCT and IRAC operations by combining them. The IRACs will be integrated into the rideshare matching algorithm when and if the benefit of doing so becomes apparent.

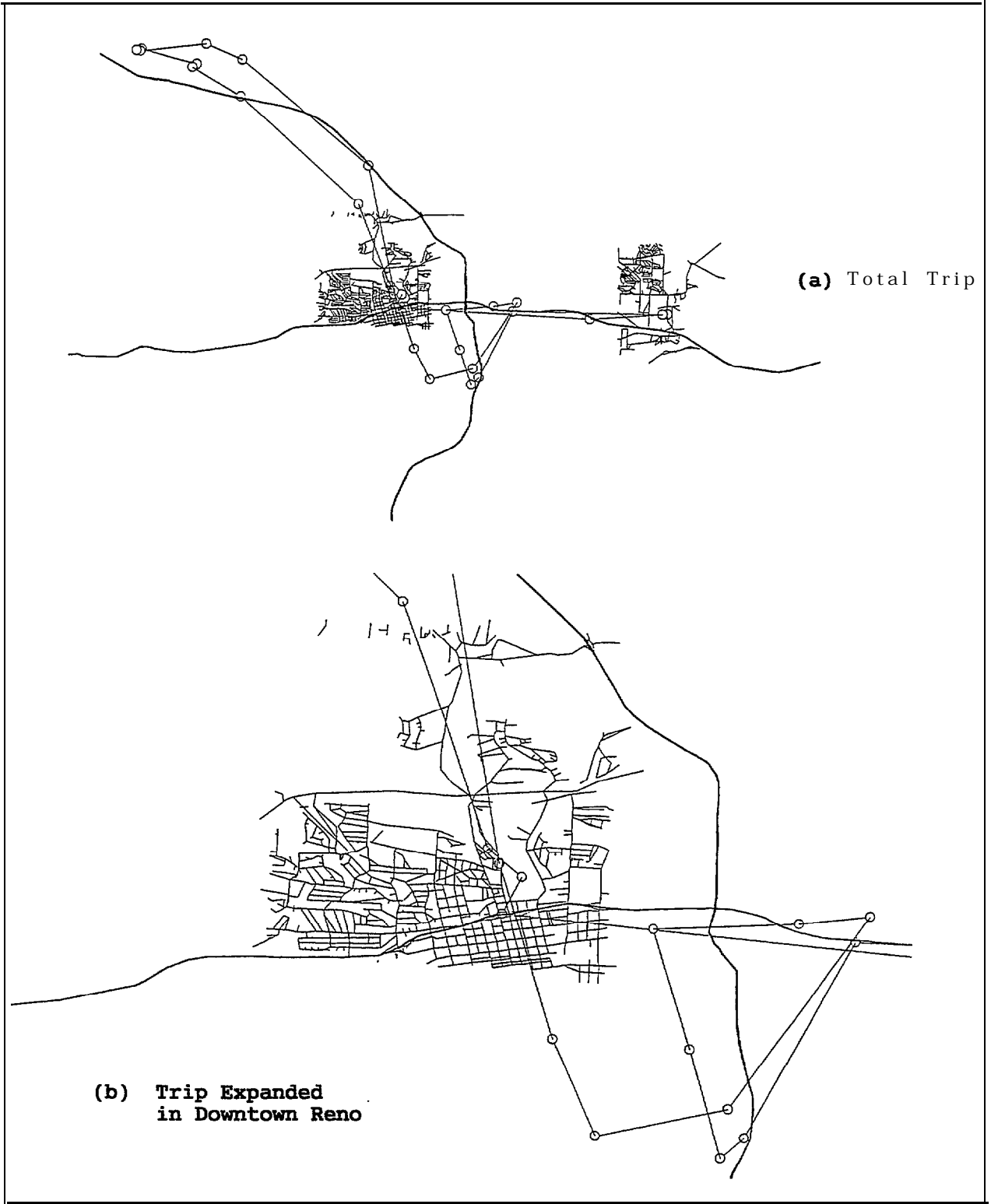


FIGURE 4 Plot of a trip in which a vehicle called in and reported its position every 5 minutes.

The following series of illustrations shows how users may interact with the IRAC element of the central processor (or their PC) to locate and reserve IRAC vehicles. Figure 5 shows a portion of the Reno city map and the locations of several IRAC vehicles. Keep in mind that IRAC locations are updated at the central processor only when their status changes. The “location” of a vehicle that is currently in use will be the point where the user entered the vehicle unless the system operator specifically queries the vehicle to report its current location. IRAC locations are shown as small color-coded circles on the screen. A legend at the upper left of the screen associates colors with IRAC status. (Because the illustrations in this report are printed in black and white, the circles are somewhat hard to see; arrows have thus been added to make IRAC locations easier to spot.) The user can zoom in on the map so that the overall IRAC distribution can be seen as well as an IRAC location on a street. A user can click the mouse near a location and a data block providing further status information on the

IRAC will appear. In Figure 6 the user has clicked near the rightmost IRAC, causing the data box to appear and report the IRAC ID (7715327) and type (Geo Metro). The user knows that the vehicle is available for rental because its circle color is green. In Figure 7 the user has clicked on the “Reserve” button (not shown in the figure) causing the IRAC Reserve Information box to appear. When the user supplies the necessary information and clicks on “OK,” the central processor calls the IRAC vehicle and informs it that it has been reserved by a particular user. The vehicle will then allow access by no other user until the “Pick Up By Time.” When the vehicle acknowledges that it is reserved, the screen changes to that shown in Figure 8, where the circle has changed to yellow to show that the vehicle is reserved and the data box shows the vehicle ID, user number, and reservation void time. Figure 9 shows that the IRAC is in use and the time the user accessed the vehicle. The position indicator circle changes to blue when vehicles are in use.



FIGURE 5 IRAC vehicle locations.

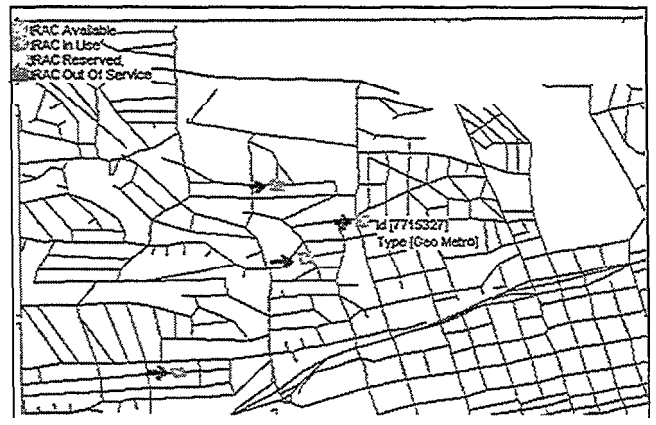


FIGURE 7 IRAC Reserve Information box.

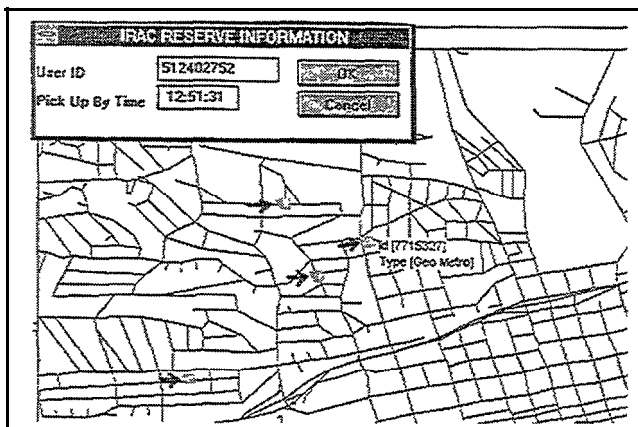


FIGURE 6 Selected IRAC data block.

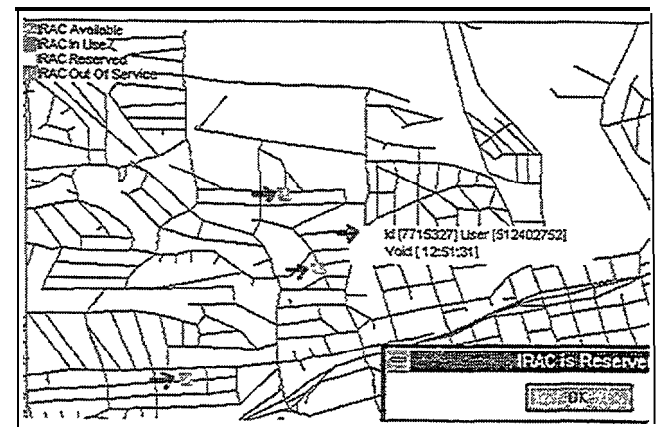


FIGURE 8 Reserved IRAC data block.

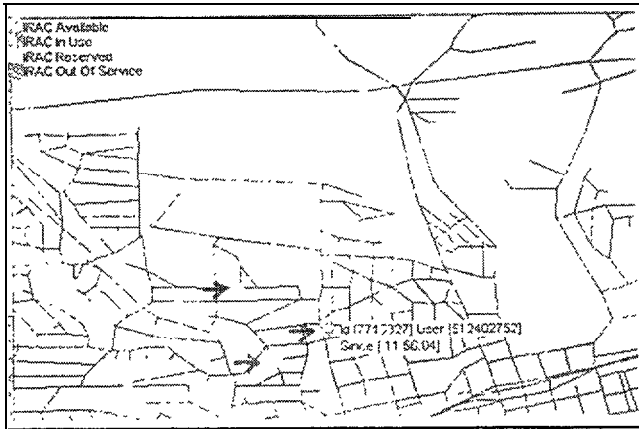


FIGURE 9 IRAC In-Use information block.

All IRAC transactions are recorded in a disk file in the central processor for billing and system research purposes. Figure 10 shows the portion of that file where the above-described reservation and use transactions are recorded.

MOCT TECHNOLOGY

An MOCT dispatch application called the Cherry Picker (ChP) has been developed and tested in a simulation environment. The MOCT dispatch software consists of four basic components:

- 1) The ChP dispatch algorithm code.
- 2) Software to exercise the ChP algorithm under DOS (or UNIX) as might be expected when the ride match function is embedded in a larger transportation management environment.
- 3) Software to generate participant distributions and hypothetical trip requests for testing the algorithm. This code runs under Windows and creates a data file

that contains a collection of trip requests that the ChP can then process in a batch mode. This software can also generate a continuous series of hypothetical trip requests as might be expected in a ride-matching operation.

- 4) Software to exercise the ChP under Windows for convenient graphical display of ride-matching results.

The following is a discussion of how each component functions and performs.

The ChP Algorithm

It is anticipated that MOCT users will request dispatch services at random times with unspecified travel lead times. To accommodate the dynamic nature of the dispatch problem, the ChP algorithm is designed to quickly locate compatible travel partners by what is called “cherry picking.” The ChP algorithm works to find the best driver-rider matches without attempting to optimize an entire population of travel requests.

MOCT travel requests, consisting of a departure location; destination location; optional early and late departure and arrival times; a drive, ride, or don’t care designator; and number of seats available by drivers and “don’t cares,” are placed into a request pool. The algorithm looks at the first request in the pool and then, one by one, hypothetically matches all requests of the opposite “sex” to find the best travel match. “Don’t cares” are matched as opposite to whatever they are tested with. When two “don’t cares” are tested together, the one with the longer trip is assigned to be a driver. A figure of merit, called the travel ratio, is used to determine if the match is beneficial. The travel ratio is the sum of the SOV travel distances required to accomplish the requested travel

Vehicle	7715327	11:50:59	Reserve, 39.5380, -119.9253
User	5 12402752	11:50:59	Reserve IRAC
Vehicle	77 15327	11:56:04	Reserved Entry, 365
User	5 12402752	11:56:04	Reserved IRAC Rental, 365
Vehicle	7715327	13:22:35	Release, 5191, 39.6382, -119.9260
User	5 12402752	13:22:35	IRAC Release, 5191

FIGURE 10 Transactions data file.

divided by the travel distance of an MOCT. For example, two commuters must each travel 20 km to arrive at work or a MOCT can carry both to work while traveling 25 km to do so.

$$\text{Travel ratio} = \frac{20 + 20}{25} = 1.6$$

The travel ratio is related to the number of miles saved by the following relationship:

$$\text{Miles saved} = \text{total SOV miles} \left[\frac{\text{travel ratio} - 1}{\text{travel ratio}} \right]$$

After the first search, the algorithm knows the best match (potential mate) for the first request in the pool. If the travel ratio is less than 1 (or some other number determined to be optimum), then there is no good match for this request, so the algorithm will proceed to the next request in the pool, and so on. When the travel ratio is greater than 1, the algorithm then finds the best match for the potential mate found above. It does so by hypothetically matching the potential mate with all requests of the opposite "sex" in the pool just as above. If the match is not mutually best for both candidates, the algorithm will proceed to the next request in the pool just as if the travel ratio was inadequate, and so on. When the match is mutually best, the rider is placed with the driver and then removed from the request pool. The driver is not removed until all of the seats in the vehicle are filled. When a driver is matched with a first rider, the MOCT travel distance is computed as the distance required to travel from the driver's origin to the rider's origin, to the rider's destination, and on to the driver's destination. When the driver already has a rider and is looking for others, the MOCT distance is computed as the optimum trip for the driver and collection of riders. This is not a problem for a small number of riders (up to 10 have been used) but approaches an n -factorial problem and so would be difficult for a large collection of riders in a single vehicle such as a bus.

In addition to finding suitable travel mates on the basis of saving miles, the algorithm must accommodate the travel time needs of users. To do so, the user may specify travel time windows. For example, the user may wish to arrive at his or her destination no earlier than 7:45 a.m. and no later than 8:00 a.m. The ChP provides four travel time parameters of which the user may specify any or none. The parameters are early departure time, late departure time, early arrival time, and late arrival time. When only an early or late time is specified, the ChP defaults the other to a 30-minute travel window. For example, a user who specifies only an early departure time of 5:00 p.m. will be assigned a window of 5:00 to 5:30. When no travel time parameters are specified, the user is stating that he or she will travel whenever a

suitable match is found. The ChP assigns traveler departure and arrival times that best fit travelers to the center of their travel window requests.

In summary, the ChP algorithm finds mutual best matches for travel requests based upon minimization of vehicle miles traveled and satisfaction of user travel time requests.

Software in DOS to Exercise the ChP Algorithm

The ChP algorithm, along with supporting code, may be compiled to run as a DOS application. Operation under DOS is convenient to analyze algorithm running time and various operational scenarios. When operated under DOS, the ChP, at this writing, runs in the batch mode and processes a preexisting pool of travel requests. The capability for the ChP to run in the real-time mode (processing a continuous stream of requests) is present, but untested. It has been determined that the running time of the ChP is approximately a 2.8 power function of the number of participants in the pool. It requires about 1 minute to process a pool of 200 travel requests when using a 33 MHz 386DX computer. To process a pool of 2,000 requests would take approximately 10.5 hours. A surprising, and fortunate, property of the ChP algorithm is that once it has "organized" a pool of travel requests, it can process incremental requests very rapidly, as will be discussed below. The ChP requires about 45 percent more time to run in the Windows environment as compared with the DOS environment.

Numerous tests have been run to help gain an understanding of how MOCT travel parameters may influence travel ratio given the Washoe County population distribution assumption. One of the most important questions that arises is "How many participants are necessary to make MOCT viable?" The answer, according to our testing, is "surprisingly few." Collections of trip requests of varying sizes have been processed and summarized in Figures 11 and 12. Figure 11 shows that when Washoe County participation reaches 100 individuals traveling during a time window, 60 percent of drivers and 85 percent of riders have been matched. Figure 12 shows that travel ratio increases up to about 200 participants and then levels out at about 1.6.

An experiment to examine the effect of vehicle size (number of seats) on algorithm performance has been conducted. Figures 13 and 14 present the results for collections of 1,000 trip requests. Figure 13 shows how the number of seats a driver offers affects the travel ratio. Figure 14 shows that more drivers are unmatched and must travel alone as the number of seats offered increases. The conclusion drawn (but not tested) from these two graphs is that incentives should be focused to encourage riding over driving.

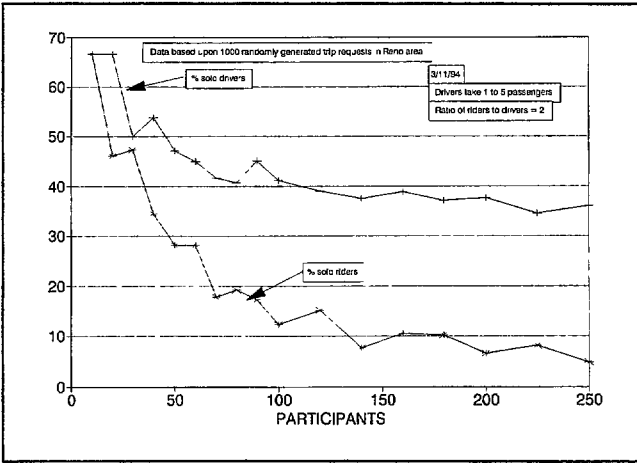


FIGURE 11 Unmatched trips as a function of number of participants.

Figure 15 depicts a typical “trip ticket” showing identification numbers of the driver and riders, geographic terminal locations, stop times, requested travel window times, and statistics about this one particular trip. Here the driver (ID number 101) is scheduled to depart at 12:17, and he had requested to depart between 11:50 and 12:50. Rider 37 is scheduled to depart at 12:29 and, as may be seen by lack of a time window, has indicated no departure time preference. Rider 35 is scheduled to arrive at his destination at 12:49 and requested an arrival time between 12:46 and 13:16. Some additional useful analytic information is presented at the bottom of the “ticket.”

Note that travel time is computed on a sliding scale with distance. Every stop costs 1 minute. For trip stage distances of less than 3 km, speed is computed at 40 km/h. For stage distances of greater than 15 km, speed is computed as 90 km/h with a 3-minute “freeway access” penalty. For distances between 3 and 15 km, speed is scaled between 40 and 90 km/h.

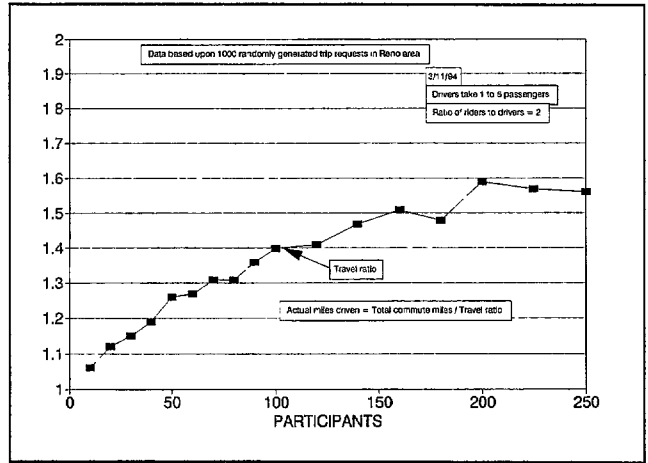


FIGURE 12 Travel ratio as a function of number of participants.

GPD Software

It is beneficial to evaluate the performance of MOCT dispatch algorithms under varying population density and ridership assumptions. To provide a realistic simulation environment, GPD software based on Washoe County, Nevada (Reno and vicinity), has been developed. The total population of Washoe County (based on the 1990 U.S. census) is about 250,000. Most of the population lives within the Truckee Meadows, which includes the adjacent cities of Reno and Sparks. The majority of the remaining population lives in smaller communities within 30 miles of the Reno/Sparks metropolitan area. Census-determined population distribution is used as a basis for potential trip end points. Thus, a locale with a dense population will have more potential trip origins and destinations than a sparsely populated area.

Washoe County is divided into about 50 geographic tracts for purposes of the 1990 census. The latitude and

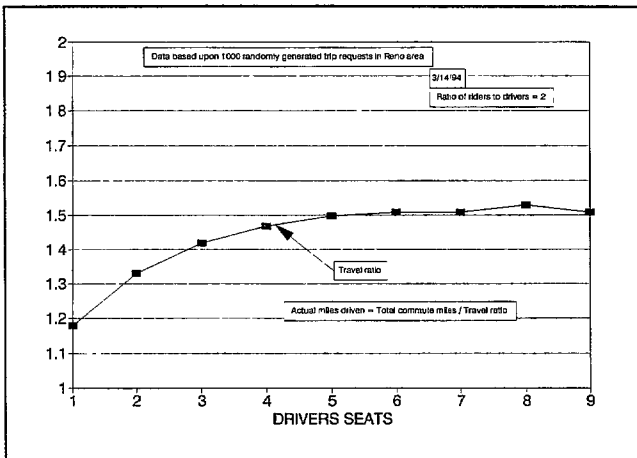


FIGURE 13 Travel ratio as a function of seats offered in each MOCT vehicle.

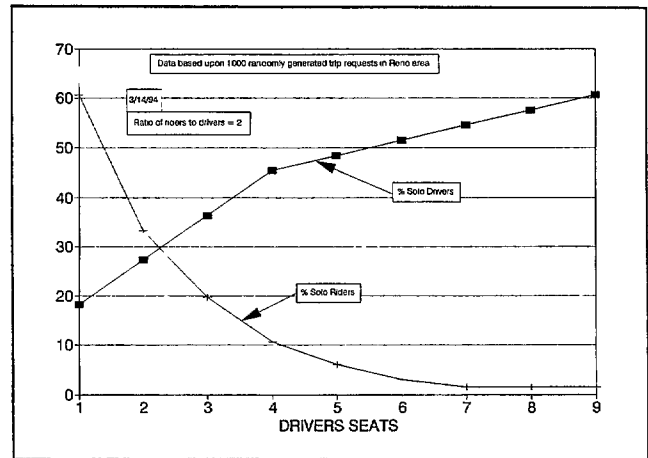


FIGURE 14 Unmatched trips as a function of seats offered in each MOCT vehicle.

Driver 101 departs (39.4251 - 119.9104)	12:17	1 1:50	12:50
Rider 037 departs (39.4892 - 199.8585)	12:29		
Rider 035 departs (39.4783 - 119.8327)	12:37		
Rider 035 arrives (39.5385 - 119.7625)	12:49	12:46	13:16
Rider 037 arrives (39.5568 - 119.7803)	12:57	12:34	13:04
Driver 101 arrives (39.6205 - 119.7762)	13:05		
Useful distance 59.4 Trip Distance 38.2 Ratio 1.55			
Driver's solo trip distance 32.8			

FIGURE 15 Typical “trip ticket.”

longitude of the approximate center of each tract, along with the area and population of each, have been extracted from the census data. The geographic area of each tract is represented as a circle, with a radius that results in a tract area approximately equal to that extracted from the census maps. Note that representing a tract as a circle results in tracts that overrun each other. The actual census tracts have irregular boundaries and do not overrun. This results in about 50 population centers, which represent a realistic population distribution for a real geographic area.

To locate each member of the population (a potential trip endpoint) within each tract, the following equations have been implemented:

Angle = random number between 0 and 360

P = random number between .01 and 1.0

Disp = $e^{(P-1)/P}$ * tract radius in feet

D_y = $\sin(\text{Angle}) * \text{Disp}$

D_x = $\cos(\text{Angle}) * \text{Disp}$

$$\text{PMC}_{\text{latitude}} = \text{TC}_{\text{latitude}} + \frac{D_y}{360,000}$$

$$\text{PMC}_{\text{longitude}} = \text{TC}_{\text{longitude}} + \frac{D_x}{360,000 \cos(\text{TC}_{\text{latitude}})}$$

TC are the tract center coordinates, and PMC,) are the coordinates where the population member (trip origin or destination) is assumed to reside. The tract radius and center latitude and longitude are the data extracted from the census maps. The constant 360,000 converts from feet (the units of tract radius) to degrees of latitude and longitude.

The previous equation set favors concentration of population members (trip terminals) at the center of the

tract. For example, consider a tract with a radius of 10,000 feet: 25 percent of the trip terminals are placed within 500 feet of the center of the tract by these equations. Terminal density declines from high at the center of the tract to 0 at the outer limit. This scheme was chosen because trip terminals tend to cluster at apartment buildings, factories, mass transit facilities, and other locations. Trip endpoint clustering by tract is believed to be a viable method to account for population clustering without undue software complexity. Figure 16 shows the population distribution used.

To generate hypothetical trip requests, two terminal locations are randomly selected from the above-generated distribution. If the second terminal is less than 10 km (or other minimum distance) from the first, it is discarded and another one chosen until two terminals greater than 10 km units apart are at hand. The directional nature of the daily commute is accounted for by assignment of trip destination as the terminal closest to the junction of highways I-80 and US-395 in Reno in order to simulate the morning commute. Next the “sex” of the trip is randomly chosen as driver, rider, or “don’t care.” The proportion of drivers, riders, and “don’t cares” is selectable and is currently 40 percent, 50 percent, and 10 percent, respectively. Next the number of seats provided by drivers and “don’t cares” is randomly chosen as 1, 2, or 3 with equal probability. Finally, the time of requested travel is randomly selected as a departure or arrival time with a Gaussian distribution centered on 12:00 noon. The Gaussian half-width currently in use is 1 hour. This means that half of all requests are for travel within a 2-hour period centered at 12:00 noon, with the remaining requests limited to within plus or minus 6 hours of the center time. The same logic is used to generate both a pool of trips for batch processing and a continuous pool for real-time processing.

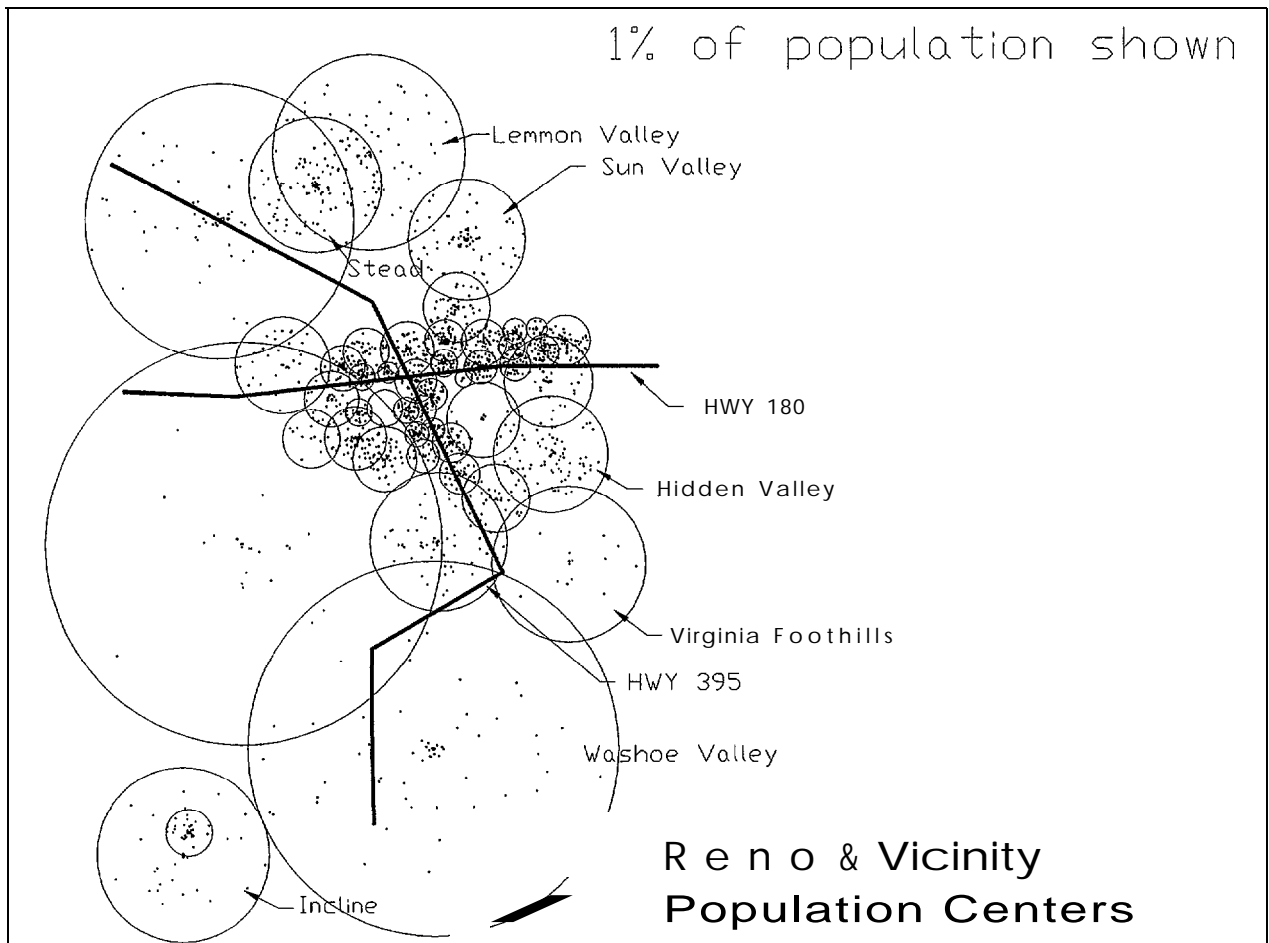


FIGURE 16 Population distribution, Reno and vicinity.

Software in Windows to Exercise the ChP Algorithm

The Windows environment provides a convenient means to graphically interact with the ChP algorithm. Matched trips can be displayed as lines on a plot, and trip requests can be made by movement of a mouse on the computer screen. It is under Windows that the ChP has been tested in the real-time mode. A real-time test typically begins by processing a preexisting pool of participants and then generating a continuous series of travel requests for some period of time (typically several hours). In a representative test, the ChP was given a pool of 100 “don’t cares” and then a continuous stream of requests for a period of 4 hours.

It was completely arbitrary that the test was started with a pool of “don’t cares.” It could have been started with any pool, or none at all. The ChP algorithm pauses to accept new requests each time it has matched a rider with a driver or passed completely through the pool without finding any suitable match. In this test, a single new participant, generated as per the discussion above (40 percent drivers, 50 percent riders, and 10 percent “don’t cares”), was placed in the pool every time the ChP

paused. During the 4-hour test, 2,030 participants, or about 66 percent of the total generated (3,087), were served and would have been issued travel itineraries. About 20 percent (610) of the participants were partly matched and would have been issued travel itineraries when their vehicle became full or shortly before their departure time. Fourteen percent (447) of the participants in the pool were unmatched when the test was terminated. Some undetermined number of those would have become matched with new participants as they came into the pool. Those who were not matched at their departure time would have been issued SOV travel itineraries. The test was arbitrarily terminated after 4 hours, before participants began being removed from the pool because their departure time was at hand. In other words, this was a test of system dynamics during a prescheduling period. A more representative test will need to be run for some arbitrary prescheduling period, plus completely through the 12-hour travel window, in order to make an accurate statement about miles saved and reduction of the number of vehicles on the street. A summary of results for the above preliminary test of 3,087 user requests follows:

- Users matched up and removed from pool:
 - 540** drivers
 - 1,160 riders
 - 330 “don’t cares”
- Users with seats still available in MOCTs:
 - 250** drivers
 - 360 riders
- Users with no suitable MOCT (travel ratio less than 1) or unmatched users:
 - 440** drivers
 - 5 riders
 - 2 “don’t cares”
- SOVs and MOCTs that would have traveled if pool was terminated at end of test: 1,308
- SOVs that would have traveled without MOCTs: 3,087
- Total useful distance traveled: 46,000 km
- MOCT travel distance: 26,000 km
- Distance saved: 20,000 km
- Overall travel ratio: 1.77
- MOCTs dispatched: 611
- Travel requests processed per hour: 770
- Time to process a travel request at the end of test: **5.4 sec**

Travel requests may be entered with a mouse and matched trips plotted under Windows. Figure 17 plots the trip described in Figure 15. The circles of varying sizes are census tracts provided to give some geographic feel for where the travel is occurring. The small circles at the end of the trip lines show travelers’ origins, and the dashed lines connect individual travelers’ origins and destinations. Figure 18 shows a poorly matched trip in that the travel ratio is low; the travel ratio would have been excellent if both occupants had been “don’t cares.” Figure 19 shows a well-matched trip.

IMATS CONSIDERATIONS LEADING TO PILOT PROGRAM

As discussed previously, the primary IDEA project focus was on demonstrating IRAC and MOCT technology. There were no “operational” problems other than ensuring that the equipment functioned properly during demonstrations. The primary efforts during this IDEA project were studies aimed at considering how a technology demonstration effort could transition to an operational pilot program with its attendant problems of multiple vehicles and users, vehicle insurance, maintenance, cash flow, etc. Two approaches were considered, as discussed below.

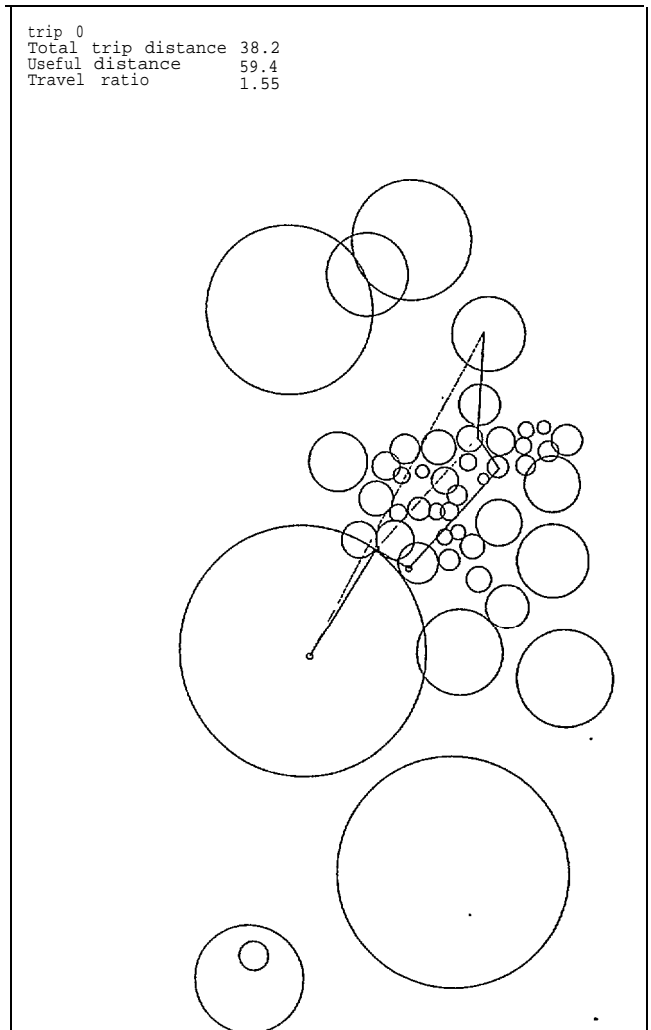


FIGURE 17 Plot of trip described in Figure 15.

Working with Local Taxi Organization

Consideration was initially given to working with a Reno area taxi company that would operate, maintain, insure, and rent the vehicles. Two local taxi corporations were considered in this regard.

Attention was initially focused on Baker and Drake (B&D), a local Yellow Cab franchise with about 150 cabs. The IMATS project was attracted to that organization because a Federal Transit Administration report cited their progressive use of computerized vehicle dispatching (1). Limited conversations were initiated with B&D, and Figure 20 was prepared to indicate a potential working relationship between IMATS and a taxi company (2). B&D was interested in IMATS because of their belief that GPS would be of significant benefit to cab dispatching operations. B&D also provided the interface device that was used to provide odometer data to the Trimble PACER integrated GPS/dead reckoning vehicle location equipment.

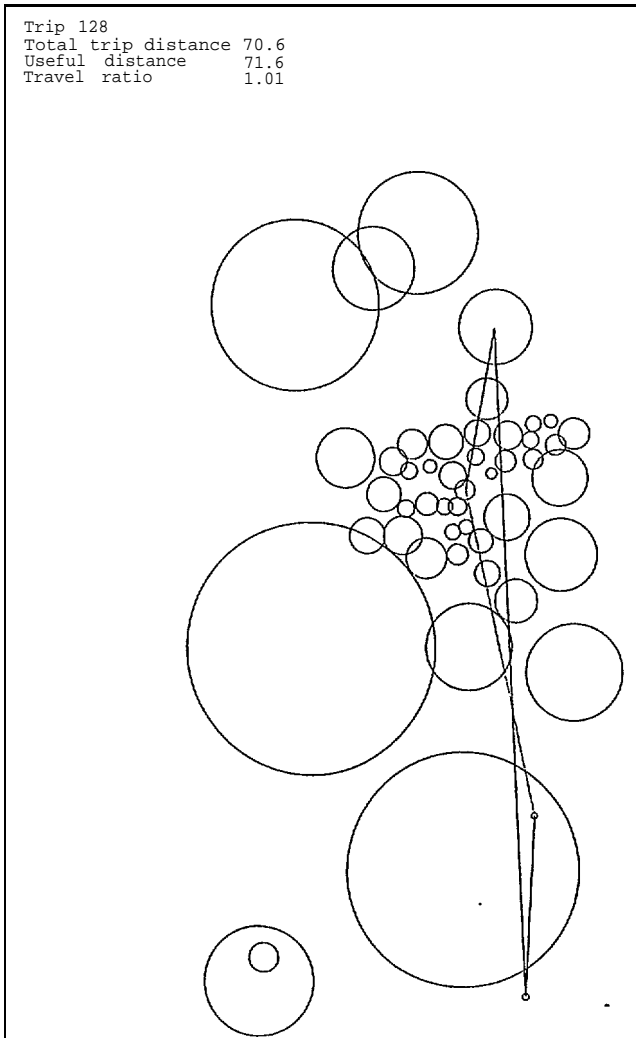


FIGURE 18 A poorly matched trip.

Another local taxi organization, the Reno-Sparks Cab Co., was identified as a possible candidate when an article in the *Reno Gazette-Journal* described their plans to implement GPS-based computerized dispatching. However, although integrating IMATS into a local taxi organization might have been a viable way to proceed, the alternative operational test approach discussed below was finally selected.

Utilizing UNR Vehicles

The IMATS program has worked closely with UNR, producing the following working relationship.

UNR has a pool of vehicles that are used for a variety of purposes in connection with the needs of 3,000 faculty and staff members. Included in this pool are numerous automobiles that are rented as per the schedule shown in Table 1. The current rental procedure is for a user to drive his own vehicle to the motor pool location and sign out a vehicle, use it, and be charged accordingly. Upon returning the rental vehicle, the user then drives his own

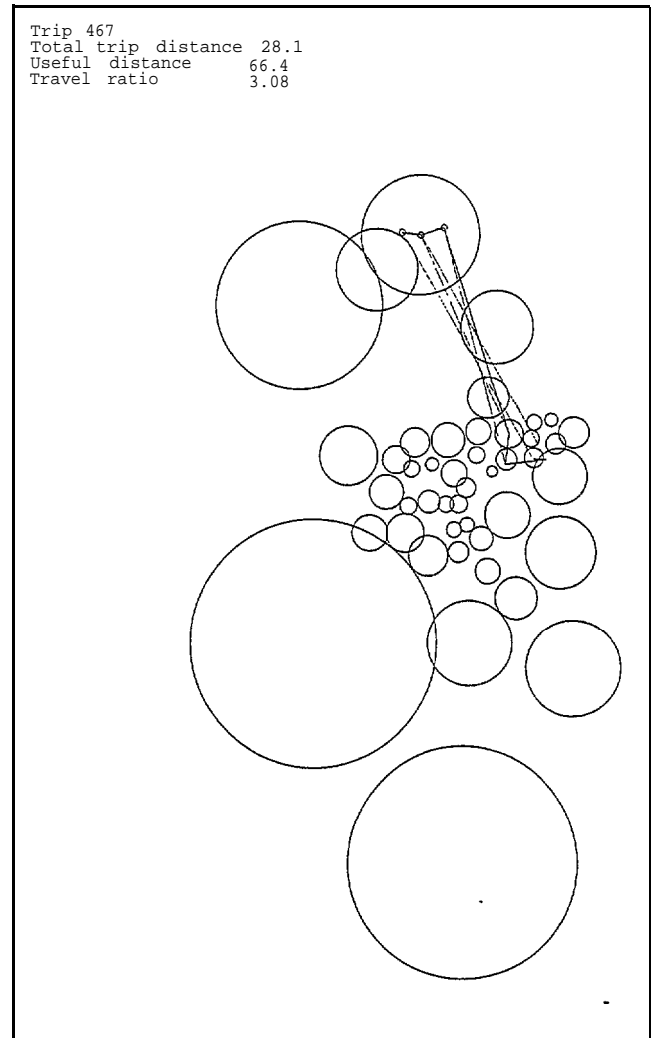


FIGURE 19 A well-matched trip.

vehicle back to his office location, hoping to find a parking spot.

The IMATS project selected UNR vehicles as IRAC vehicles, with users following both the current UNR sign out/sign in rental procedure and the IRAC rental procedure. When the IRAC billings and records adequately correspond with current UNR billings and records, then the IRAC procedures will take over. In addition, the IRAC vehicles will be distributed around campus, eliminating the need to go to the motor pool area.

In effect the IMATS project will be granted a rent-a-car franchise without the necessity of worrying about insurance, vehicle maintenance, and other factors.

In parallel with this operation, the IMATS project will proceed to automate existing UNR-based carpools—that is, employ MOCT dispatching procedures on such carpools. When both IRAC and MOCT procedures have been proven, the intent is to merge the IRAC and MOCT operations with IRAC availability as an incentive to encourage additional UNR-based carpools as indicated in Figure 2 1.

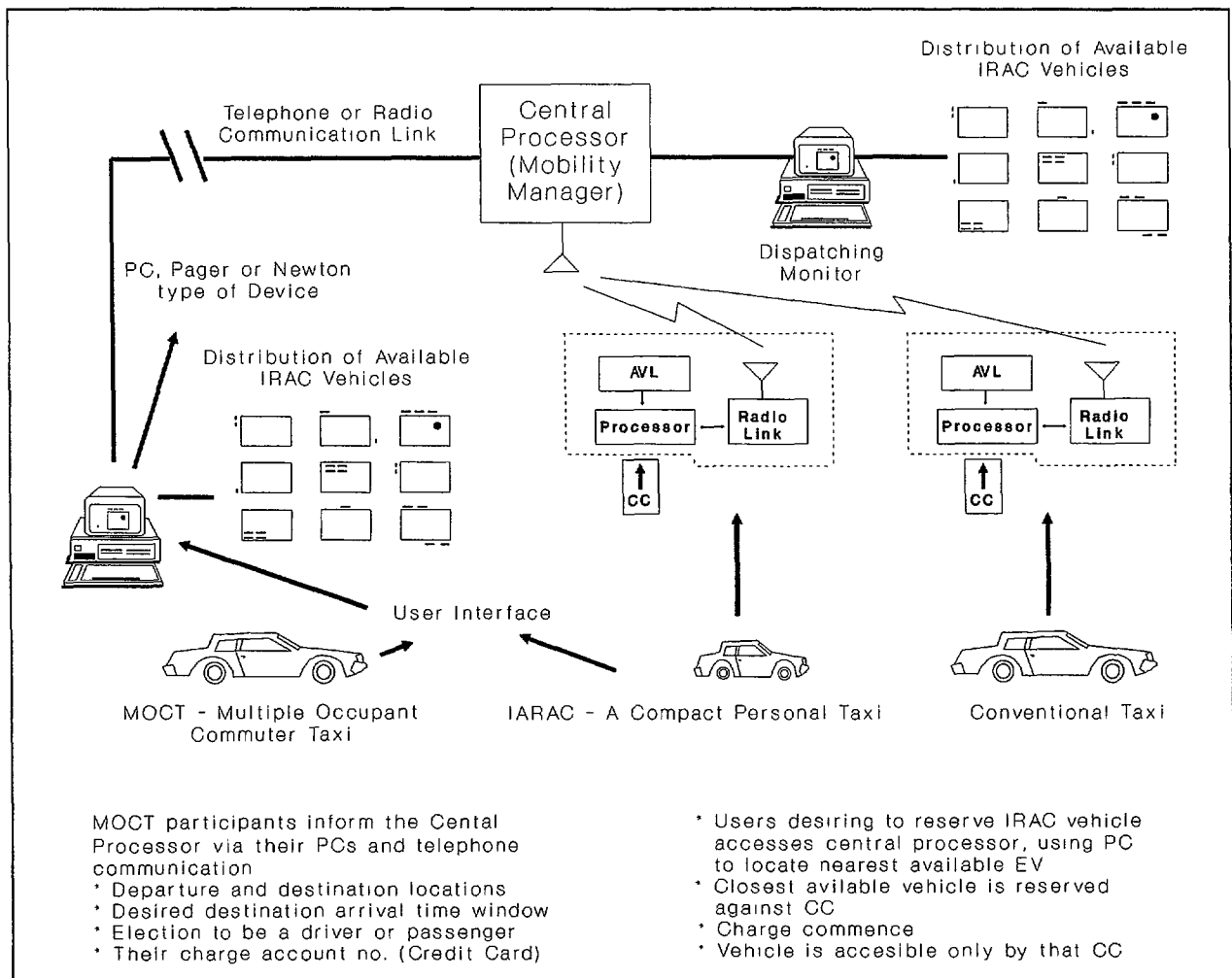


FIGURE 20 MOCT/IRAC system as integrated with a taxi company.

IMATS IDEA PROJECT ORGANIZATION

The three key participants in the IMATS feasibility project are C.F. International, UNR, and the Lemelson Foundation. The relationship among these participants is indicated in Figure 22.

UNR and Lemelson Foundation Initial Participation in IMATS

UNR participation has focused on IRAC. The first in-vehicle IRAC demonstration was provided by students in Dr. Kleppe's 1994 EE 491 class "Innovation and Entrepreneurship." The EE 491 students were organized into multiple student companies, with each company focusing on developing and marketing a particular product. In this case, five of the student companies (comprising 30 students) focused on products related to IRAC, as noted in Figure 22. Four of these student

companies focused on specific elements of IRAC (credit card access, the in-vehicle processor, communications, and the GPS-based vehicle location system). A fifth student company focused on techniques for evaluating electric vehicle performance since there is a scarcity of valid data relating to operational use of electric vehicles.

The main financial support for EE 491 IMATS-related work was provided by the Lemelson Foundation. Additional support was provided in the form of an electric vehicle donated by Sierra Pacific Power Co., a Nevada utility, and other equipment provided by national organizations such as Trimble Navigation (GPS equipment), Cellular One (communication hardware and airtime), and Texas Instruments (TIRIS equipment). The EE 491 students also conducted campus surveys in connection with attitudes toward IMATS, parking problems on campus, and so forth. The student's efforts, including the results of their surveys, are detailed in student company reports.

TABLE 1 UNR Rental Schedule

ASSIGNED VEHICLES		
Vehicle Type	Rate	Mileage (400 Mile Allowance)
Sedans	\$185.00/mo.	.23/mile
Pick-up Trucks and Station Wagons	\$222.00/mo.	.25/mile
Four Wheel Drives, Suburbans and Vans	\$264.00/mo.	.27/mile
DAILY RENTAL		
Vehicle Type	Rate	Mileage (400 Mile Allowance)
Sedans	\$15.00/day	.23/mile
Pick-up Trucks and Station Wagons	\$18.00/day	.25/mile
Four Wheel Drives, Suburbans and Vans	\$20.00/day	.27/mile
Applicable Motor Pool labor charges will be \$29.00 per hour for University of Nevada, Reno, vehicles and \$34.00 per hour for all other UNS vehicles.		

Ongoing UNR Participation

During the summer term the project staff focused on developing an IRAC demonstration for the TRB ITS-IDEA Advisory Committee meeting scheduled for September 26, 1994, at Woods Hole, Massachusetts. An IRAC electric vehicle and the MOCT software package were successfully demonstrated at the meeting.

An IMATS presentation was also give to the California Air Resources Board (CARB) on August 5, 1994, outlining how the IRAC short-trip electric vehicle rental program could be a cost-effective way to introduce electric vehicles into California.

The business school summer students focused on continuing the campus market surveys, as well as accumulating data on rental car procedures, required insurance, depreciation, etc. The most interesting, but preliminary, results of their surveys include the following:

- Sixty-seven percent of respondents said they would participate in an IMATS program at UNR;
- On the average, people said they would have to be paid less than \$5 an hour to carpool; and
- Most people really don't know what it costs them to operate their own cars (responses varied from \$0.05 to \$1.50 per mile).

The first bulleted item lends encouragement to the IMATS program. The second has been discussed in the previous section in terms of the financial inducements that are potentially meaningful for encouraging MOCT use. The third is of particular interest in terms of the apparent, and rather pervasive, misunderstanding of the true cost of driving an automobile, even though it is a very significant portion of expenditures or income, as indicated in Tables 2 and 3.

This apparent lack of understanding of the real cost of automobile transportation has a counterpart in the belief that employer-paid parking is "free" to the employee when in reality the employee pays for it in terms of a lower wage. This "free" parking belief is also an inducement for the employee to use SOVs and thus spend more money while further increasing congestion and pollution.

SUMMARY

It is worthwhile at this point to review the objective of the IMATS program.

IMATS proposes to attract SOV users to MOV use by providing urban transportation that is equivalent or superior to SOV use in term of convenience, flexibility and cost.

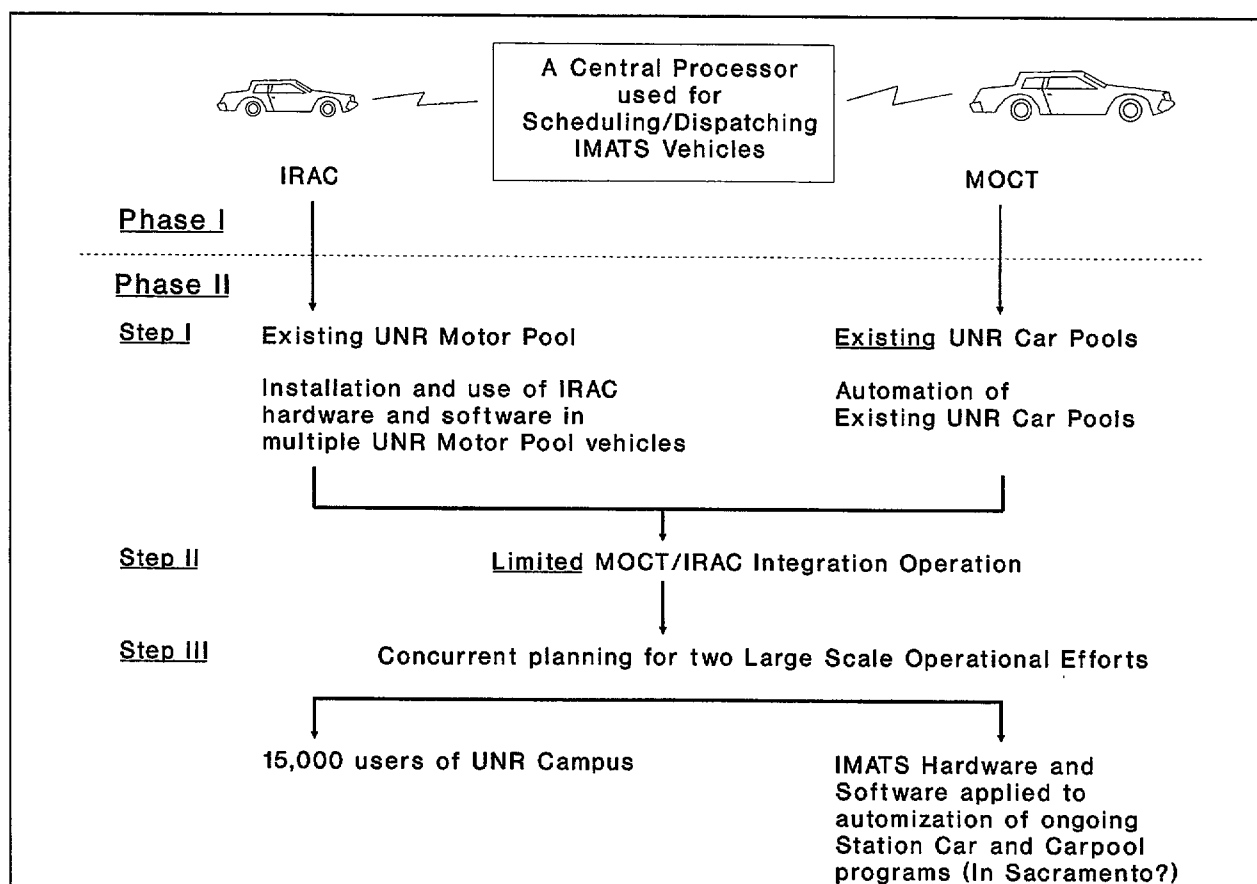


FIGURE 21 Feasibility and operational tests of IMATS.

This IDEA project demonstrated technology that is key to the convenience and flexibility of IMATS—the instant rental of a car and the real-time (within minutes or seconds) dispatching of carpools. It appears that there are no major technical obstacles to providing adequate convenience and flexibility, thus permitting IMATS to successfully compete with SOV use on this score. A follow-up to this IDEA project that will address critical issues for the implementation and marketing of the IMATS concept is planned.

ACKNOWLEDGEMENTS

This project was conducted in conjunction with the University of Nevada, Reno (UNR), with financial assistance from the Lemelson Foundation and equipment provided by the Sierra Pacific Power Company, Trimble Navigation, Texas Instruments, and Cellular One.

The ChP algorithm reported in this IDEA project was developed by Rick Brown of C.F. International. Edwin Berry of Amerivision Corporation in Sacramento, California, previously demonstrated a separate proprietary algorithm, called the “Hill Climbing” solution, at several IMATS presentations.

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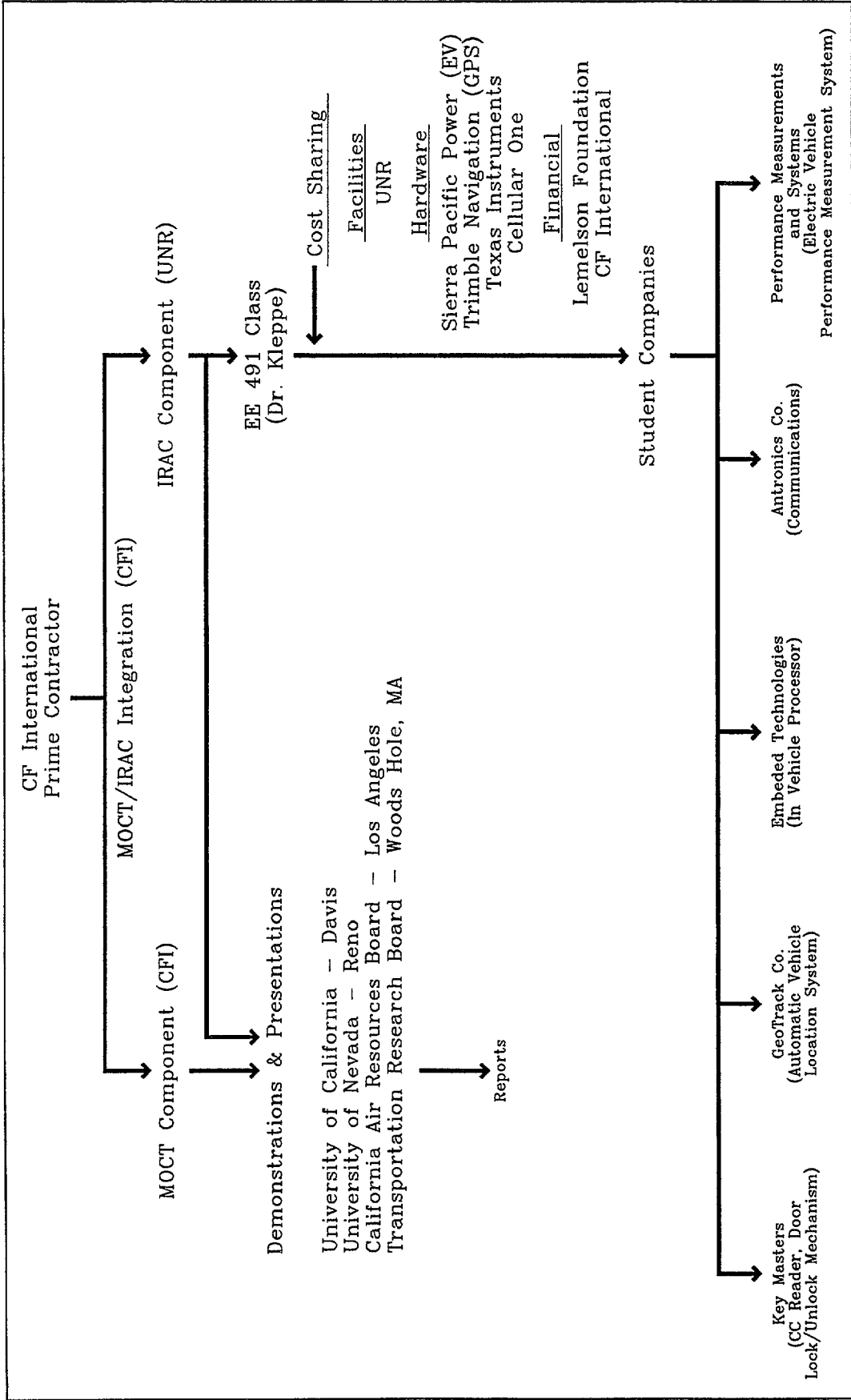


FIGURE 22 IMATS program organization.

TABLE 2 Cost of Automobile-Based Transportation as a Percentage of Household Expenditures

ITEM	1989	1990	1991	1992
Average annual expenditures	100.0	100.0	100.0	100.0
Food	14.9	15.1	14.4	14.3
Food at home	8.6	8.8	9.0	8.9
Food away from home.....	6.3	6.4	5.5	5.5
Housing	30.3	30.6	31.2	31.8
Apparel and services	5.7	5.7	5.9	5.7
Transportation	18.7	18.1	17.4	17.5
Vehicles	8.2	7.5	7.1	7.3
Gasoline and motor oil.....	3.5	3.7	3.4	3.3
Other transportation	6.9	6.9	6.9	6.9
Health care	5.1	5.2	5.2	5.5
Entertainment	5.1	5.0	5.0	5.0
Personal insurance and pensions	8.9	9.1	9.4	9.2
Life and other personal insurance....	1.2	1.2	1.2	1.2
Pensions and Social Security	7.6	7.9	8.2	8.0
Other expenditures	11.3	11.1	11.5	11.0

TABLE 3 Cost of Automobile-Based Transportation as a Percentage of Household Income

	Income Quintile				
	1	2	3	4	5
Per Capita Income	\$4,100	\$7,800	\$11,900	\$18,200	\$38,000
Automobile expenses	12%	19%	18%	18%	13%
Transit fees	1%	0%	0%	0%	0%
Taxes	3%	3%	2%	2%	1%
Air pollution	7%	3%	2%	1%	1%