

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Identification and Prioritization of Environmentally Beneficial Intelligent Transportation Technologies: Modeling Effort

Troy Young, Daniel Sperling, Susan Shaheen
University of California, Davis

**California PATH Working Paper
UCB-ITS-PWP-99-20**

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Report for MOU 337

December 1999

ISSN 1055-1417

Identification and Prioritization of Environmentally Beneficial Intelligent Transportation Technologies

Modeling Effort

**Troy Young
Daniel Sperling
Susan Shaheen**

Institute of Transportation Studies
University of California at Davis

prepared for

Partnership for Advanced Transit and Highways
PATH MOU 337

May 1999

TABLE OF CONTENTS

INTRODUCTION	3
THE MODELING APPROACH.....	5
THE DATABASE	6
Verification of the Database	8
Modifications to the Database	10
Master control file	10
Node file	10
Link file	11
Signal file.....	17
Demand file.....	17
Incident file	18
Lane striping file	18
Summary of database modifications	19
MAKING MODEL RUNS.....	20
Modeling Issues	20
CONCLUSIONS	22
Environmentally Beneficial Transportation Technologies.....	22
REFERENCES	25

INTRODUCTION

In 1996, California Partners in Advanced Transit and Highways (PATH) commissioned a project team led by the Institute of Transportation Studies, University of California at Davis with the Claremont Graduate School to undertake a review of the environmental impacts of Intelligent Transportation Systems (ITS).

The objectives of this project were to:

- 1) review previous qualitative and quantitative environmental assessments of ITS, from both field operational tests and modeling studies;
- 2) review the regulatory and policy contexts which encompass ITS;
- 3) develop a modeling framework suitable for assessing the short term (up to 10 years) environmental impacts of ITS;
- 4) identify those ITS technologies that have positive environmental effects; and
- 5) rank those technologies according to their energy and emission benefits.

This evaluation of specific ITS technologies was to be performed within the context of legal and regulatory requirements, transport and environmental policy, State forecasts of vehicle miles of travel (VMT) and air quality, and broad transportation scenarios.

The initial phase of the project involved a general literature review of a wide range of previous studies on the energy and environmental impacts of ITS technologies. Support to the findings of this general review was provided in the form of a more detailed review of qualitative and quantitative assessments of ITS technologies from field operational test (FOT) data and previous modeling studies. Included in the reporting of the literature review was a detailed discussion of a number of ITS evaluation frameworks proposed by several authors. Furthermore, a range of modeling tools available for evaluating ITS technologies and user services were described, with an emphasis on tools capable of energy and emissions assessment. The policy contexts that surround ITS-related issues were also presented.

The second main phase of the project involved the development of four scenarios or possible futures for ITS. These scenarios, formulated as the backdrop for quantitative assessment of specific ITS applications, were described as the:

- 1) status-quo world;
- 2) industry world;
- 3) government world; and
- 4) public/private partnership world.

The scenarios were developed with input from a series of interviews and two day-long focus groups (one in Washington DC and one in Davis, CA).

The final phase of the project was the development of a model that would be capable of quantifying the short-term environmental impacts of ITS applications along a typical transportation corridor. The corridor chosen was a section of the SMART Corridor (Santa Monica Freeway (I-10) between I-405 and I-110). The model was built for the INTEGRATION V2.0 application, developed by Michel Van Aerde at Queen's University in Ontario, Canada (Van Aerde 1985; 1995).

This report sets out the research effort relating to the final phase of this project. In particular, the model database is described with details of the modifications necessary to manipulate it into a form suitable for use with INTEGRATION V2.0. This discussion presents the difficulties and challenges faced, leading to the unfortunate conclusion of this project without obtaining useful quantitative results from the modeling exercise.

THE MODELING APPROACH

The modeling effort was intended to focus on four intelligent transportation technologies with deployment under the status-quo and public-private partnership worlds. These scenario worlds are discussed in detail in Shaheen *et al.* (1998). The four ITS applications chosen for study in this project were:

- Electronic toll collection
- Advanced traffic signal coordination
- Vehicle navigation/Route guidance; and
- En-route driver information.

Deployment of each of these applications (individually) was to be modeled for the status-quo world and then subsequently for the public-private partnership world. Modeling outcomes were to be compared between the two worlds for each ITS application and the revealed impacts of each application were to be compared across applications within each scenario world. Comparisons were to be based on measures of trip-based and system-wide energy use, emissions generation, travel time and VMT. Specifically, the criteria on which the modeled ITS technologies were to be ranked included the following:

- 1) Vehicle Miles Traveled (VMT): To what extent does the technology reduce VMT?
- 2) Travel Time: To what extent does the technology reduce travel time?
- 3) Energy Consumption: To what extent does the technology reduce energy consumption?
- 4) Emissions reduction: To what extent does the technology reduce emissions (i.e., of CO, HC, NO_x, and CO₂)

In the long term, it is possible that some ITS applications will generate induced demand for travel on the road network. The application of a simulation model without links to a travel demand model was deemed appropriate for this project because the modeling horizon was only 10 years. In this time frame it is not expected that the ITS applications being modeled (see list above) would have a significant impact on the generation and distribution of trips.

THE DATABASE

The road network selected for the modeling efforts was the SMART Corridor (Santa Monica Freeway (I-10) Corridor). This corridor had been the focus of a previous modeling study at the University of California at Berkeley (Bacon *et al.* 1995) in which the INTEGRATION model was applied to assess the impacts of various ATIS strategies. This study did not incorporate any environmental measures of effectiveness.

The Santa Monica Freeway Corridor was the location for the Pathfinder in-vehicle information system project conducted in 1990. This freeway is one of the most traveled freeways in the country, with an average daily traffic count of almost 250,000 vehicles.

The SMART Corridor database was developed for a section of the Santa Monica Freeway Corridor from I-405 to I-110. The study area consists of approximately 11 miles of freeway with associated ramps (i.e., 26 on-ramps and 26 off-ramps in each direction), five parallel arterials (i.e., Olympic Boulevard, Pico Boulevard, Venice Boulevard, Washington Boulevard, and Adams Boulevard), and a network of other surface streets. The corridor also includes four connector on-ramps and four connector off-ramps.

The following table shows the characteristics of the INTEGRATION database for the SMART Corridor before modification in the current research effort.

Table 1: Magnitude of Original SMART Corridor Database

Feature	Total (from data file)	Total (from Bacon)
Mainline freeway links	85	85
Arterial links	1235	1060
Expanded intersection links	1657	1672
Zone connector links	309	314
Total links	3286	3286
Origin nodes	111	111
Destination nodes	111	111
Total zones	118	118
Total nodes	1747	1747

Source: Bacon *et al.* (1995).

The primary advantages of the SMART Corridor database were identified as:

- good documentation;
- developed for use with the INTEGRATION model;
- extensively tested and calibrated; and
- only California-based corridor database available.

The main disadvantage of this database is that it was created for use with INTEGRATION version 1.5. The current model available from and supported by Michel Van Aerde (developer of INTEGRATION) is version 2.0, and there have been some significant changes to the internal logic of the model and the format of the input data files required. The following section details many of the changes necessary to update the database obtained from UC Berkeley such that it could be used for model runs with INTEGRATION V2.0.

Modification of the original database was complicated by the fact that UC Berkeley were unable to provide the project team with maps and other information to help with network coding. The project team only had access to the final UC Berkeley report (Bacon *et al.* 1995) and its associated Technical Appendix, and the data files in electronic form. Unfortunately, some inconsistencies were found between the data provided in the Technical Appendix and the data provided in electronic form. Each of these had to be reconciled before proceeding which proved to be a laborious task. Since maps showing links and nodes for the network were not available, manipulation of the data was, by necessity, carried out "blind" - without reference to the physical layout of the network. Of course, generic road maps were referenced at times.

Before modification of the database to make it suitable for INTEGRATION V2.0, verification of the database was carried out. The verification process served two purposes:

1. To allow the project team to become familiar with the database.
2. To check for and correct inconsistencies and errors that would sabotage the quality of modeling results.

The verification of the database was a lengthy but important process, as can be seen by the following description of errors identified and corrected.

Verification of the Database

A number of coding errors were identified in the electronic database provided by UC Berkeley. Some of these are described briefly below. To describe all the errors found, or those mentioned here in detail, would add little value to this report. The remainder of this section is simply provided to give the reader an idea of the extent of work required to verify and correct errors in the supplied database.

A number of signals had more phases coded in the signal file than those coded in the link file (for approach links at that signal). For example, signal 431 has 3 phases (page A-109, Technical Appendix of Bacon *et al.* (1995)) but the link file provided only made use of phases 1 and 3. This would imply that there is a whole phase (in this case, 26 seconds long) where no vehicle movements are permitted (except of course the normal right turn on red movements).

Some apparent errors were found relating to the coding of opposing movements. In some cases, there were inconsistencies between the data in the electronic files provided and the data presented in the Technical Appendix (which were provided as different formats of the same database). For example, in the electronic file no opposing movement was specified for link 1651 (the appended link for the left turn movement from main approach link 359). This makes sense for the data provided in the electronic file because the through movement from the opposite approach is released in a different phase. However, link 1645 (the appended link for the left turn movement from main approach link 285) has an opposing movement specified as link 1650 which is the through movement from the opposite approach, but is released in a different phase to link 1685. So the coding here is inconsistent within the same file. Furthermore, in the version of the link file contained in the Technical Appendix, both link 1645 and link 1650 have opposing links coded and the coding makes sense as the coded phases are different to those in the electronic version of the file.

There were a number of inconsistencies between specified approach types and coded signal phasing for corresponding links. In particular, protected left turns were not coded correctly in many cases.

Approach types for each leg of the 167 key intersections and junctions (of 312 total signalized intersections/junctions) were specified in a file, EXPLODE.DAT. This information was accessed by the program INTGEN created by the UC Berkeley team (Bacon *et al.* 1995; pp. 73-75) to automate the process of expanding intersections to include a separate link for each turning movement. This process, and the reason for it, are described in more detail in a later section that presents the modifications to the model link file.

The EXPLODE.DAT file contains a code for each approach that defines the appropriate approach type as given in another file, APPROACH.DAT. APPROACH.DAT gives details of each of 67 different approach types including:

- Number of lanes
- Length of the through, right and left turn links to represent each movement
- Number of effective through, right and left turn lanes
- Capacities of the through, right and left links
- Free flow speeds of the through, right and left links
- Flag to indicate the existence of protected and/or permitted left turn phases

The last of these parameters stored a value of 0, 1 or 2 as follows:

- 0 indicates no protected left turn;
- 1 indicates a protected leading or lagging left, with no left turn allowed in the through phase; and
- 2 indicates a protected/permitted left, with a protected movement on the first phase and a permitted movement on the second phase.

For a number of approaches, the coding of phases for the corresponding appended links (representing various movements) was not consistent with the protected/permitted phasing as indicated by the flag in APPROACH.DAT.

Further, when the key intersections/junctions were being re-coded (see description below), a number of inconsistencies/errors were identified relating to the coding of appended links in the original link file. These were mainly inconsistent entries in the link file when compared to the data in the APPROACH.DAT file. In most cases the problem was missing appended links representing left turn movements that were indicated as being possible by the information contained in APPROACH.DAT and EXPLODE.DAT.

For example, signal 79 has four approach legs and four exit legs. The approach leg from the west is link 175, the approach leg from the east is 233 and the approach leg from the south is 535 (according to EXPLODE.DAT). The approach types for these legs are coded as 4, 16 and 4, respectively. Approach type 4 is defined in APPROACH.DAT to have 1 shared through and right turn lane and 1 shared through and left turn lane. Approach type 16 is defined to have 1 shared through and left turn lane, one through lane and one exclusive right turn lane. Thus, there are outbound legs that allow left turns from approach link 175, 233 and 535 **and** the appropriate lanes exist for these turning movements. However, the link file as provided by UC Berkeley (and reported in the Technical Appendix to Bacon *et al.* (1985)) does not have links for any of these left turns. The only left turn link coded is for the approach from the north. There are right turns and through movements coded for all approaches and this would suggest that left turns can also be made from all approaches. This is one example of more than 10 signals where similar inconsistencies were found.

It was necessary to identify and correct all errors such as those mentioned above before attempting to obtain model outputs, in order to ensure the quality of modeling results.

Modifications to the Database

Following the correction of errors in the original database, as described briefly above, most of the required modifications to the database were due to differences between INTEGRATION V2.0 and V1.5.

The INTEGRATION model uses a set of ASCII files to store input data for model runs. These files include the following:

- Master Control file;
- Link file;
- Node file;
- Signal file;
- Demand file; and
- Incident file.

There are three optional input files: 1) a lane striping file; 2) a detector location file; and 3) a screen capture frequency file.

Each file in the bulleted list above and the lane striping file is described briefly below. For further details of the format of these files and the parameters contained in them, the reader is referred to Van Aerde (1995). Following the description of each file is a discussion of the modifications that were made to update the files for use with INTEGRATION V2.0. The majority of this discussion is focused on the link file since most changes necessary were related to modifications to the way links are coded. The presentation here is meant to reflect the extensive effort required performing these updates, without overwhelming the reader with unnecessary detail.

Master control file

This file stores simulation control values, the names of input data files to be used, the location of these files, the location where output files should be written, and the names of optional output data files. This file also allows the user to define characteristics of the five INTEGRATION vehicle types, including the update frequency of information provided to the vehicles/drivers and a measure of the error inherent in the information provided (information quality indicator).

Node file

The node file defines the characteristics of all the zones and nodes in the network, including the X and Y coordinates and whether the zones/nodes are origins, destinations, both, or intermediate nodes.

The node file was modified in response to changes made to the link file. The end points of each link are defined by a node, consequently, the addition, removal, or change in length of a link generates a necessary adjustment to the node file. Modifications to the node file include:

- addition of new nodes in the center of signalized intersections (see next section on modifications to link file for explanation of this); and
- removal of old upstream node numbers of outbound links from signalized intersections (see next section for explanation).

Link file

This file contains the data fields that define the characteristics of each link in the network. These include: The modifications necessary to update the link file required the most substantial effort. The changes were primarily due the differences between the way the two versions of INTEGRATION simulate signalized intersections.

In version 1.5 of the INTEGRATION model there is no distinction between the individual lanes of an intersection approach. Hence, the approach (or inbound) links act as “pipes,” and if one of the movements (through, left, or right) at the intersection is delayed, vehicles making that movement will block the “pipe” and cause all the movements to be delayed. Bacon *et al.* (1995) describe in detail how they used a solution proposed by Van Aerde (1985) to overcome this problem. One-node intersections were expanded to eight-node intersections with twelve *appended* links (i.e., for intersections with four inbound and four outbound links). Figure 1 shows these appended links for a typical intersection. Each appended link represents a turning movement from one of the inbound links (which were made slightly shorter) to one of the outbound links. This *expansion* of intersections was only done to those intersections with high observed traffic flows or those where unrealistic queues were observed during model runs.

Version 2.0 of the INTEGRATION model implemented a feature that enables the user to specify the lane striping configuration of links. This allows the lanes and lane usage to be coded for inbound links at signalized intersections. Hence, the vehicles arriving at the intersection are allocated to the lane(s) appropriate for their particular turning movements. This means that where there is an exclusive left turn lane, vehicles with path trees that make the left turn are moved into the left turn lane and consequently do not block other vehicles (e.g., through traffic) that are released from the signal in a different phase.

To take advantage of this improved model capability, the link file was edited to change the configuration of each *expanded* intersection from that shown in Figure 1 to that shown in Figure 2. This involved removing all the appended links, adding a new center node, connecting the main inbound links to the new center node with new appended links, and extending the upstream end of the outbound links back to the new center node (discarding the original upstream nodes of the outbound links).

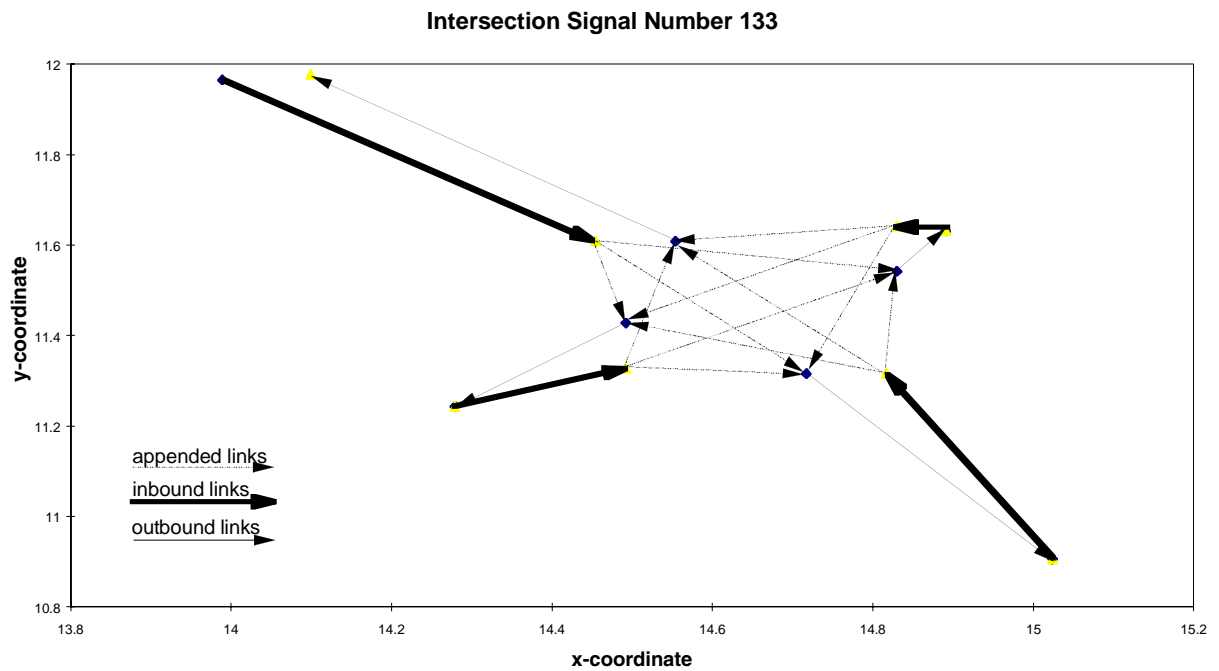
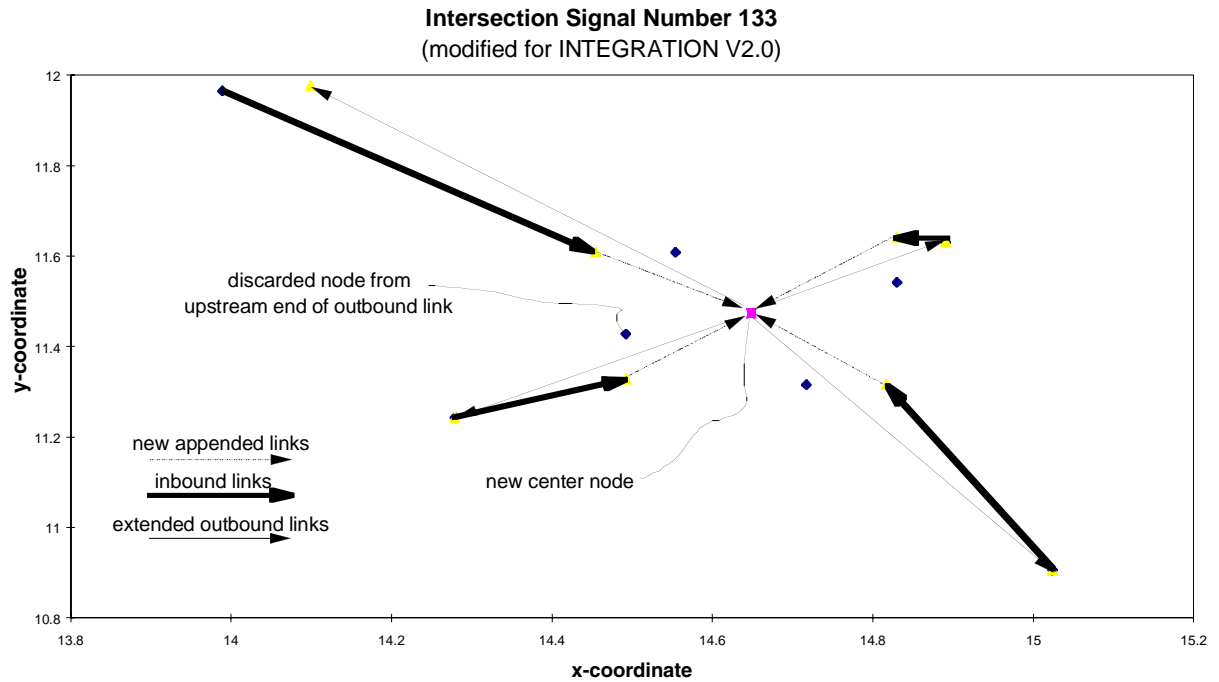


Figure 1: Expanded Intersection (Eight Nodes/Twelve Links) from Original Database

In the original link file, all the data for controlling signal number, first and second phases in which each link discharges, turn prohibition data, and the first and second links opposing the flow of each link were coded in the appropriate fields for the appended links (not the main inbound links), as the appended links represented each turning movement at the signal. Simply removing all the appended links would result in the loss of all this data, so the relevant data were transferred back to the main inbound link. This was a temporary “holding place” since these data were ultimately required to be coded to the new appended links when they were added.



**Figure 2: Modified Intersection (Five Nodes/Four Links)
for INTEGRATION V2.0 Database**

The large number of links (i.e., 3286 in the original database obtained from UC Berkeley) made this exercise a very time consuming effort. Microsoft Excel spreadsheets were used to manipulate the data and a series of Visual Basic macros were written to minimize the amount of time to complete this task. The first macro collected all the relevant data from the appended links and transferred it to the appropriate cells in the record for the corresponding main inbound link. The macro also made changes to the data to reflect new approaches in the model to various characteristics of signalized intersections (e.g., right-turn-on-red (RTOR) permission is coded in V2.0 by assigning a negative value to the signal number; this feature did not exist in earlier versions of the model). It was assumed, based on a conversation with the UC Berkeley team, that all the intersections being considered (i.e., expanded intersections) permitted RTOR movements. The macro did not transfer the two data values representing the discharge phases of each appended link. These were assessed by hand to determine the correct way to code the values from *all turning movement links* for a given inbound link into the appropriate fields on just *one* link (the new appended link).

INTEGRATION V2.0 distinguishes between protected and permitted left turn phases by allowing the user to assign a negative value to the discharge phase number if that phase represents a protected left turn. In earlier versions of the model an algorithm would check if the discharge phase number of the left turn was the same as the discharge phase number as the opposing through movement. If so, it would model the traffic flow as a permitted left turn. Otherwise it would be treated as a protected left turn. The use of the negative value in the INTEGRATION V2.0 model allows more information to be stored

in fewer fields. Hence, it was possible to re-code all the phasing information stored in the two fields of each appended link (i.e., where all three movement types existed) to the two appropriate fields of one link. However, there were many different conditions that had to be checked, so this part of the data transfer from the appended links was carefully performed without the use of a macro. Once the data were transferred to the main inbound links the appended links were deleted before adding the new center nodes and new appended links, to fill the gap created by the removal of the original appended links.

The first step in the process of adding the new center nodes and new appended links was to create a file named MODIFIER.XLS, which contains all the relevant data for each intersection to be modified. A section of this file is presented below in Table 2. MODIFIER.XLS was a working file in which data were gathered from the original link data file and node file, before being used to update those files. These data include:

- signal number,
- inbound link numbers,
- outbound link numbers,
- upstream and downstream node numbers for each inbound and each outbound link, and
- x- and y-coordinates of all nodes.

Table 2: Section of Working File MODIFIER.XLS

	signal #	inbound/ outbound	link #	up node	x up coord	y up coord	dow n node	x dn coord	y dn coord	new node #	new node x coord	new node y coord
1	133	in	587	120	14.279	11.243	697	14.492	11.328	703	14.648	11.474
2	133	in	685	763	13.989	11.965	698	14.454	11.609			
3	133	in	595	122	14.891	11.631	699	14.83	11.642			
4	133	in	693	121	15.024	10.906	700	14.817	11.316			
1	133	out	588	703	14.83	11.542	122	14.891	11.631			
2	133	out	686	704	14.717	11.316	121	15.024	10.906			
3	133	out	596	701	14.492	11.428	120	14.279	11.243			
4	133	out	694	702	14.554	11.609	759	14.099	11.977			
1	153	in	285	125	17.566	11.794	705	17.773	11.88	711	17.906	12.017
2	153	in	744	655	17.745	12.05	706	17.705	12.05			
etc			

The signal number, in- and out-bound links numbers, and link node numbers were obtained from MOD_SUPP.XLS; this is an Excel file that is essentially a copy of the original link data file provided by UC Berkeley (SCF14_2.DAT) with comments and flags. The macro UNEXPANDED was written and saved in the MOD_SUPP.XLS file to collect these data and enter them into the appropriate place in the working file MODIFIER.XLS mentioned above. The upstream node number of the first outbound link at each signal was selected as the number for the 'new' center node. This node number could be re-used since the upstream nodes of each outbound link were to be

moved to the new center node, rendering the original outbound link upstream node numbers obsolete (see “discarded nodes” in Figure 2).

Another macro named GETCOORDINATE was created and saved in MODIFIER.XLS to extract the X- and Y-coordinates from the node file NODE1.DAT for each node listed in MODIFIER.XLS and subsequently entered them into the appropriate place in MODIFIER.XLS. The coordinates of the new center node were calculated by taking the average of the coordinates of all outbound link upstream nodes at the intersection under consideration. This was the most efficient way to place the new node in the approximate center of the intersection configuration.

The macro UNEXPANDED functioned well for “standard” intersections - those with four inbound links to the signal and four outbound links from the signal. T-junctions and/or intersections where one-way links existed, were more complicated. Where no main inbound link existed for a particular leg of the intersection (or potential leg), the nodes and links could not be traced by the macro to identify the corresponding outbound link (on the opposite leg). Hence, the macro would respond as if there was no outbound link on that leg, where in fact one may exist. Such problems could be identified by plotting the coordinates of all nodes at an intersection and connecting them with links to view the configuration of the intersection. This was a very time consuming process and hence an alternative method was sought. Again, a map of the original network, showing node, link and signal numbers would have greatly simplified identification of “non-standard” intersections. To deal with the cases of T-junctions and one-way links another macro named TSECCASE was written and stored in MODIFIER.XLS. The way this macro functions is difficult to explain without the aid of detailed diagrams, but we made an attempt to do this here. This macro obtains the downstream node number of all left and right turn appended links and compares them with the downstream node number of all through movement appended links. Where a downstream node associated with a left or right turn link could not be matched with the downstream node of a through movement link (from a different approach leg), this node was flagged as the upstream node of an outbound link that was not previously identified by the UNEXPANDED macro.

Once all the necessary data were collected for each of the 167 intersections that needed to be modified, the following steps were taken to update the link data file, LINK2.DAT:

1. *New* appended links were added to connect the downstream end of each inbound link to the new center node (these links were later given lane striping data where known).
2. The relevant data (i.e., controlling signal number, first and second phases in which each link discharges, turn prohibition data, and the first and second links opposing the flow of each link) that were temporarily coded to the main inbound links were transferred to the corresponding new appended links (removing it from the main inbound links as these terminated prior to the signal).
3. The opposing link numbers (which at this point referred to main inbound links) were changed to the appropriate numbers for the corresponding new appended links.

- Information was retrieved from the APPROACH.DAT and EXPLODE.DAT files contained in the Technical Appendix of Bacon *et al.* (1995) to update some of the characteristics of the appended links that were different to those of the corresponding main inbound links (e.g., number of lanes and free flow speed).

The first three steps were carried out with the help of the macro ADDNL stored in MODIFIER.XLS. The macro assigned a new link number to each new appended link, assigned the downstream node number of the main inbound link as the value of the new link's upstream node, and the new center node number as the value of the new link's downstream node. The node number of all outbound links was also changed to the new center node number to complete the network connectivity. To correct the opposing link numbers, the associations between main inbound links and appended links were stored so that the values in the opposing link fields could be updated from the numbers of main inbound links to their corresponding appended links.

Before the fourth step was carried out, the data from APPROACH.DAT and EXPLODE.DAT (in the Technical Appendix of Bacon *et al.* (1995)) were entered into two Excel data files, APPROACH.XLS and EXPLODE.XLS. The electronic versions of these files were not obtained from the UC Berkeley team. The EXPLODE.DAT/XLS file listed the characteristics of each intersection by the INTEGRATION node number of the intersection (i.e., the node number when the intersections were represented by only one node, before they were expanded by the UC Berkeley team). The information stored in these records had to be matched to the link numbers and node numbers after the intersections were expanded. The problem is that the node numbers in this list did not exist after the intersections were expanded. However, a comment column in the node file contained the original node number around which each set of new nodes (i.e., eight in the case of the standard intersection shown in Figure 1) had been built. A macro named GETSIGNALNO (stored in EXPLODE.XLS) was created to obtain the first of the new node numbers and search for that node in the file MODIFIER.XLS. Once the node was found, the number of the signal at which that node existed could be determined. The signal number was then entered in the EXPLODE.XLS file alongside the corresponding record.

The fourth step above was then carried out by the macro UPDATENL, which is also stored in EXPLODE.XLS. As described earlier, the EXPLODE.DAT/XLS file contains fields that store the number of a predefined approach type, for each approach link. The APPROACH.DAT/XLS file contains data that defines each of these approach types with parameters including the number of lanes, basic saturation flow rate, free flow speed, and lane configuration (e.g., number of exclusive left turn lanes, shared left/through lanes, etc.).

Another modification made to the link file was the coding of opposing links for all right turn on red movements. For each approach of the 167 key intersection/junctions that had a right turn movement, the appropriate through movement that would conflict with right turn on red movements was identified and entered into an available field for opposing movements (field 14 or 15 of the link file).

Since the release of INTEGRATION V2.0, Van Aerde has developed an alternative way of coding signal phasing. The new method is more flexible and allows for more precise specification of phasing arrangements, particularly with regard to permitted and protected leading or lagging left turns. Up to four phases can be coded for each link and for each coded phase the allowed movements can be specified by a binary code. An attempt was made to modify the link file using the new method of coding signal phasing. However, it was found that insufficient information had been provided for the signals other than those at the 167 key intersection/junctions, making it impossible to code these using the new approach. Since all signals had to be coded in the same way, the attempt to apply the new method was abandoned.

As mentioned earlier, during this re-coding process for the link data file, a number of errors and inconsistencies were identified in the link data. The resolution of these inconsistencies took substantial resources and was made more difficult since the UC Berkeley team was unable to provide a detailed map of the network region or drawings of specific intersections. Some of the problems were resolved by phone calls to members of the UC Berkeley team or other individuals familiar with the corridor. Others were resolved by close analysis of the database and interrelated data files.

Signal file

The signal file stores the signal timing plans for each signal in the network for the period of the simulation. The signal timing plans are specified by initial, minimum, and maximum cycle length; and the offset of the start of the first phase, number of phases, effective green time, effective lost time, and the optimizer frequency for each phase.

No changes were necessary to update the signal file, since the format of this file was unaltered between the two versions of INTEGRATION. However, modifications were made to the signal file to create different inputs for the various scenarios in which ATSC was to be simulated.

Demand file

The demand file contains the O-D demand matrix for the network. The O-D matrix provided by the UC Berkeley team is for the morning period 6:00am - 10:00am. Bacon *et al.* (1995) details the difficulty encountered during attempts to calibrate the full morning period and a midday period (10:00am - 2:00pm). Calibration of the morning peak period from 8:00am - 10:00am was attempted by both the UC Berkeley team and the model developers, but it was unsuccessful after attempts for eight months. The four half hour time slices between 6:00am and 8:00am were calibrated successfully, and the demand pattern for this period was mirrored for the remaining two hours from 8:00am - 10:00am; (i.e., the demand pattern was symmetric about 8:00am).

The format of this file did not change between V1.5 and V2.0 of INTEGRATION, hence, no updates were necessary for that reason. However, different versions of this file were created for the various modeling scenarios to reflect the market penetration rates of the route guidance and en-route traveler information systems.

Incident file

The incident file allows the user to introduce incidents into the simulation by specifying the number of the link on which an incident occurs, the effective number of lanes blocked by the incident, and the simulation start and end time of the incident.

The format of this file for INTEGRATION V2.0 is the same as for V1.5. Modifications to this file can be made to represent the incidents introduced into various modeling scenarios, particularly scenarios involving en-route traveler information.

Lane striping file

The lane striping file is a feature added to INTEGRATION V2.0 that allows the user to specify the lane configuration and lane use on any given link. This is particularly useful at intersections (i.e., exclusive left turn lanes, shared left turn and through movement lanes, etc. can be specified). Additionally, each of the five vehicle types that can be defined in the INTEGRATION master control file can be allowed or prohibited access to any or all of the lanes. The following information is included in the lane striping file: link number, number of lanes, permitted turning movements for each lane, and vehicle type prohibition for each lane. A portion of the lane striping file created is shown below in Table 3.

Table 3: Portion of Lane Striping File for Appended Links at Intersections

SMART Lane Striping File									
488									
1631	3	100	010	011		00000	00000	00000	
1632	3	100	010	011		00000	00000	00000	
1633	3	100	010	011		00000	00000	00000	
1634	2	100	011			00000	00000		
1635	4	100	010	010	011	00000	00000	00000	00000
1636	3	110	010	001		00000	00000	00000	

Since this file is a new feature of the INTEGRATION V2.0 model, it did not exist as part of the database obtained from the team at UC Berkeley. It was important to create this file to specify lane configurations for the *new* appended links that had been added, as described in the above section for the link file. Records in the lane striping file were only created for the appended links since this is where lane assignment is critical. Additionally, information about lane assignment was only available for the approach legs of each of the 167 key intersections and junctions.

Detailed information about the lane configurations for each approach type is contained in the comment column of the APPROACH.DAT file in the Technical Appendix of Bacon *et al.* (1995). Another macro, LANESTRP, was written to extract this information and insert it in the appropriate fields of the lane striping file. A three integer code is used to represent the turning movement permissions of each lane. The integer one represents permission and zero represents prohibition for left, through, and right turning movements respectively. For example, the code 100 for a given lane would represent and exclusive

left turn lane, whereas 110 would represent a lane with shared left and through movements.

Vehicle type prohibition for each lane is defined by a five integer code in which the integer 1 represents prohibition of a certain vehicle type and the integer 0 represents permission. Hence, the code 01000 would represent prohibition to vehicle type two for a given lane with permission for all other vehicle types. No prohibitions were assigned to the lanes of any of the appended links.

Summary of database modifications

The SMART Corridor INTEGRATION database was obtained from the team that created it at UC Berkeley. A comprehensive and critical validation of the data received identified a number of errors and inconsistencies in the data provided. Before further work, these problems were rectified.

Additionally, this database was developed for version 1.5 of the INTEGRATION model. Version 2.0 of the INTEGRATION model incorporated some substantial changes to the model functionality, some of which required a different format for various input data files. INTEGRATION V2.0 was the model available for the current study, and therefore it was necessary to update many of the fields in some input data files.

The major effort required to modify the database was directed toward the link file. The update process has been a very detailed and time consuming process, requiring substantial care and cross-checking to avoid mistakes when working with such a database with tens of thousands of data fields.

MAKING MODEL RUNS

Many attempts to run the model simulation were made. Early runs failed during INTEGRATION's setup of the simulation (reading input files, creating path trees, etc.). Each time the simulation failed, INTEGRATION created a RUNERR.OUT file. This file shows the steps that were completed and provides a comment that indicates the apparent error in the database. In most cases the description of the error is suitably clear and the problem is easily identified. However, there were a few situations where the error description was vague and a process of trial and error was required to identify and correct the problem(s) in the data.

Errors discovered and corrected included:

- hanging links (links with no connecting link at one node);
- signal phase numbers in the link file not defined in the signal file; and
- node numbers in the link file not defined in the node file.

Most of these errors were made during the process of re-coding the 167 key intersection/junctions. The re-coding that was performed by purpose-written macros was consistent and accurate; however, there were some tasks that were carried out by hand (e.g. coding of phases) and a few random mistakes were made. This is not unreasonable when working with data files such as the link file with over 44,000 data fields.

Modeling Issues

Some of the critical modeling issues have been presented in the above section (e.g. the substantial change to the coding of signalized intersections). This section adds to those issues already addressed.

Even with today's personal computing power, performing simulation modeling with the INTEGRATION model is very time consuming. The computer used for the modeling during the latter part of this project was a Dell Pentium II 233MHz machine with 64Mb of RAM and a fast graphics card with 8Mb RAM onboard. Even with such computer power, it took about 18 hours of real world time to simulate a 4 hour period. This is a substantial improvement on the simulation speed achieved by Bacon *et al.* (1995) where runs for the first two time slices of the simulation (6:00-7:00am) had to be run overnight and the base run (4 hour period or 8 time slices) took approximately 36 hours to simulate. The computer used for this work was a 486SX 50MHz machine with 64Mb RAM.

The focus of attention in the latter stages of this project was toward coding the network in a way that would remove the apparent bottlenecks at several locations on the network. These bottlenecks were causing widespread congestion such that not all vehicles loaded onto network were able to reach their destinations prior to end of simulation period. This is not a desirable situation as runs under different scenarios would have different numbers

of vehicles successfully complete their trips and therefore accurate comparisons of trip and system performance could not be made.

One of the reasons for these bottlenecks is that the lane changing and/or routing logic in the INTEGRATION V2.0 model does not appear to be correct in all situations. Closely watching the vehicle behavior at some of these bottleneck locations revealed that the model allows vehicles to get to a point on the network where they should take the off ramp, without being in the correct lane. Then these vehicles stop in the inside lane (or other lanes to the left of the outside lane - the one they should have been in) and obstruct other vehicles from continuing on their chosen paths. No feedback was obtained from the model developers regarding the reason(s) for this behavior and no "solution" was achieved by changing the characteristics of the network.

In the final model run attempted, the number of vehicles being loaded onto the network was much greater than those that were reaching their destination, resulting in an overloaded network beyond the array sizes of the INTEGRATION model. The model failed and INTEGRATION presented the following error in the RUNERR.OUT file:

```
Error in routine SET VEHICLE ID
- Max. concurrent veh on network = 70000
- Value exceeds maximum of limit = 70000
- Requires larger version of INTEGRATION
```

For this run, the model failed when the simulation clock time was 11441 seconds (for a total simulation horizon 14400 seconds) and the real world time that had elapsed was 60807 seconds (16 hours and 53 minutes).

For modeling of ITS applications it is important to consider the impact of each ITS application on trip making. Some ITS applications are expected to have an impact on trip generation and attraction by encouraging land use changes in the long term. Such applications would also be expected to influence trip distribution (the allocation of trips between each origin-destination pair) by making it more desirable to travel to certain locations than it was before ITS deployment. Additionally, ITS applications can influence mode choice by providing travelers with better information about travel options or improving the efficiency and reliability of public transport modes. For the purposes of this project, it was assumed that the 10-year planning horizon was short term and, as such, that it would not be necessary to consider long term land use impacts. It should be noted that studies intending to simulate the impacts of ITS applications over a period of greater than 10 years should establish appropriate feedback loops between a simulation model and a travel demand model, as well as feedback loops within the travel demand model itself. Some guidance with regard to this issue can be found in USEPA (1998). Further, when modeling ITS applications that provide travelers with information, the modeling suite should explicitly account for the impact of information on travel choices, such as mode choice and the question of latent demand.

CONCLUSIONS

The original database provided for this research effort was difficult to work with and contained a significant number of inconsistencies and errors. A substantial validation effort was required to identify and correct these problems before proceeding with the current modeling exercise. The project team has recognized the advantages of create a database from the start over working with one created by someone else. Using an existing database appears to be beneficial in the first instance, but when one is not familiar with the assumptions behind the development of a database it can cause untold difficulties in later stages. This was found to be true in this study even though the UC Berkeley database was very well documented. Attempting to use a database without similar documentation would strongly reinforce this determination.

Though INTEGRATION is perhaps still the most advanced model for simulating ITS scenarios, it does still have problems and needs further refinement. Future research efforts that choose to apply the INTEGRATION model should be careful to not underestimate the resources necessary to set up a network, particularly one of similar magnitude to the SMART Corridor network. Further, it is recommended that researchers who undertake to apply the INTEGRATION model develop a modeling framework and scenarios for a small and simple network that has the primary characteristics of the full network they intend to simulate. This will enable researchers to become familiar with the INTEGRATION tool and the specifics of applying it to model their desired scenarios in a manageable piece. The skills and lessons acquired through this process can then be extended to obtain useful modeling results from simulation of the full network and associated scenarios.

Environmentally Beneficial Transportation Technologies

Despite the modeling effort not being successful, this project has no doubt provided some useful input to the building of knowledge regarding the environmental impact of Intelligent Transportation Systems.

The review of work from a wide range of sources and the brain-storming behind the attempts to quantify environmental impacts of ITS has provided the project team with an improved understanding of both:

- the issues surrounding ITS deployment and the likely impact on the environment; and
- the technologies/applications that have the greatest potential to provide environmental benefits.

After all, the outputs of a modeling exercise are only as accurate as the inputs to the model, the model accuracy and the assumptions behind the modeling scenarios. Further, it is unclear whether modeling results obtained from a study of one location (e.g. the SMART Corridor) are reasonably transferable to another location (say in a different State) or to a wider region encompassing the original location. It is well known the scale

of an analysis is critical to the outcome and results can not necessarily be overlaid on an analysis of different scale.

With this in mind, and the knowledge gained throughout this research effort, the following ITS applications are presented as those expected to provide real, measurable environmental benefits in the short term:

- Environment Protection Management Systems (EPMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Traffic Management Systems (ATMS)
- Electronic Payment Systems (EPS)

EPMS or Emission Control Enabling Technologies (ECET) are unique within the suite of ITS applications with regard to environmental benefits. Unlike other technologies whose primary goal is to reduce travel time or delays, increase safety, or improve efficiency, EPMS/ECET have the environment at the center of their intent. Their singular objective is to reduce the impact of transportation on the environment. No other technology or application can claim this as the primary goal for its implementation.

This, and other features of EPMS/ECET make them more likely to provide substantial environmental benefits than any other ITS application. While other applications may have positive impacts for some pollutants, many do not guarantee environmental benefits for all pollutants and the likely benefits are expected to decrease over time. However, EPMS/ECET can be designed and operated to achieve emission reductions for all pollutants and to build on initial benefits in a way that makes the long term benefits of deployment even greater than the short term gains.

There is no doubt that environmental benefits can be realized through the application of ATIS, particularly through the provision information related to travel options and real time information about traffic conditions. The magnitude of these benefits will depend on factors such as market acceptance of the available technologies used to deliver information, user-perceived accuracy of the information provided, level of tailoring of information for individual user needs and user application of improved information for travel decisions. The impacts of ATIS also depend on the timing of delivery of traveler information. Potential benefits are the greatest for pre-trip traveler information. The provision of such information allows a traveler to make informed decisions not only about choice of route, but also choice of mode and time of travel. The greatest travel time benefits and resulting energy and emission benefits will come from either traveler information persuading a user to take some form of public transport or to postpone their trip until congestion is cleared. Of course, the single greatest benefit will be the result of a user's decision to cancel their trip.

Some ATMS already have a proven track record for environmental benefits. In particular, traffic signal control systems can provide substantial benefits at least in the short term by responding to prevailing traffic conditions and even anticipating future

traffic conditions. Clearly, coordination of traffic signals along an arterial route can reduce fluctuations in vehicle speed profiles and therefore reduce the generation of emissions. ATMS incorporate other technological applications that have expected environmental benefits. These include Incident Management Systems (IMS) that can have considerable impacts on delays, queues and resulting pollution caused by both recurring and non-recurring congestion. In particular, by identification and verification of accidents or vehicle breakdown, an IMS can coordinate a rapid response to clear the incident in a much more timely manner than would otherwise be possible, thereby returning traffic flow to normal conditions where the environmental impact is reduced.

EPS, and in particular electronic toll collection systems have also demonstrated environmental benefits. The important thing to note here is that although electronic toll collection (ETC) can reduce emissions by as much as 80%, the impact is highly localized and the system-wide benefits may be negligible. However, where high volumes of traffic are passing through toll plazas that have been converted to ETC facilities, the reduced exposure of that part of the population to potentially harmful emission concentrations (in the absence of the ETC) is a benefit that cannot be viewed as insignificant.

Previous reports from this project have provided a useful collation of information from other studies and field operational tests regarding the environmental impacts of various ITS applications (Shaheen *et al.* 1998). The actual magnitude of environmental impact for a particular ITS application depends on a number of factors relating to the conditions under which it is deployed and the specific features of its design and operation.

Perhaps the most important work that needs to continue is the development of suitable frameworks, tools and measuring equipment to ensure that the environmental consequences of all transportation planning decisions are given due consideration. This attention is critical to provide a safeguard that the transport systems we maintain and operate today and the systems we propose for tomorrow are sustainable for an indefinite future. Maybe those transport systems that aim to achieve this goal are really the only ones worthy of being called Intelligent.

REFERENCES

Bacon, Vinton W., John R. Windover, and Adolf D. May (1995). "Investigating Intelligent Transportation Systems Strategies on the Santa Monica Freeway Corridor," *California PATH Research Report, UCB-ITS-PRR-95-38*, University of California, Berkeley, November 1995.

Shaheen, Susan A., Troy M. Young, Daniel Sperling, Daniel Jordan and Thomas Horan (1998). Identification and Prioritization of Environmentally Beneficial Intelligent Transportation Technologies. *Research Report UCD-ITS-RR-98-1*, Institute of Transportation Studies, University of California, Davis, February 1998.

United States Environmental Protection Agency (US EPA) (1998). Assessing the Emissions and Fuel Consumption Impacts of Intelligent Transportation Systems (ITS). *EPA 231-R-98-007*, Prepared by Hagler Bailly Services, Inc., December 1998.

Van Aerde, M. (1985). Modeling of Traffic Flows, Assignment and Queuing in Integrated Freeway/Traffic Signal Networks. *Ph.D. Dissertation*, University of Waterloo.

Van Aerde, M. (1995). *INTEGRATION Release 2: User's Guide - Volume 1, 2 and 3*, Transportation Systems Research Group, Queen's University, Kingston, Ontario, Canada, December.