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The Implementation of State Safety Management Systems

INTRODUCTION

Safety Management Systems

In 1991, the U.S. Government passed legislation which began a new era in transportation in the United States. With the majority of the Federal Highway System completed, the government's focus within transportation shifted toward improving the maintenance and operation of the existing infrastructure. The Federal Government proliferated the shift in emphasis at the state level by mandating the establishment of transportation management systems. These management systems were designed to provide an organized process for guiding decisions regarding a state's transportation infrastructure (*1*). Each state was required by federal regulations to establish and maintain its own management systems, one of which was a Highway Safety Management System (SMS). The SMS had the purpose of improving that state's highway safety in an organized and efficient manner.

Intermodal Surface Transportation Efficiency Act of 1991

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) differed from previous transportation legislation in that it focused on the operation and maintenance of the existing infrastructure. Prior legislation had been directed primarily at enhancing and creating programs for specific purposes such as highway construction projects, safety programs, or commercial vehicle issues. ISTEA was unique because it was the first legislation to focus on the systematic management and cooperation of all existing transportation programs (2). To implement this management approach, ISTEA required each state to create six management systems. These management systems would then coordinate and oversee the state-wide programs related to their areas of emphasis (*3*). The six mandated management systems were: SMS, Pavement Management System, Bridge Management System, Traffic Congestion Management System, Public Transportation Facilities and Equipment Management System, and Intermodal Facilities and Systems Management System (*4*).

Federal Register's Definition

Although ISTEA was enacted in 1991, it was not until 1993 that federal regulations were issued which specifically described the requirements for the six management systems. On December 1, 1993, the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) issued Title 23, Part 500, of the Code of Federal Regulations (CFR) (*4*). In that document a Safety Management System was defined as,

> a systematic process that has the goal of reducing the number and severity of traffic crashes by ensuring that all opportunities to improve highway safety are identified, considered, implemented as appropriate, and evaluated in all phases of highway planning, design, construction, maintenance, and operation and by providing information for selecting and implementing effective highway safety strategies and projects. (*4*)

In addition to providing a definition for an SMS, this document listed requirements, components, and a schedule for compliance for SMSs. The components section included lists of five areas and eight elements which were to be covered by each state's SMS. The FHWA and the FTA were unsure of the severity of burden that was created by some of the requirements, so they issued the regulations as part of an "interim final rule;" meaning they could perform follow-up studies and make any necessary amendments (5).

November 1995 Federal De-regulation

The "SMS compliance" portion of the CFR required each state's SMS to demonstrate full operation and use by October 1, 1996 (*4*). In November of 1995, however, after further review of the progress of all of the management systems, the Federal Government rescinded its mandate for each state to implement the six management systems (*6*). This allowed the states to decide the fates of their own management systems. More specifically, it gave each newly formed SMS the opportunity to reevaluate its own purpose and necessity, and then decide if, and how, it would continue. Because the federal guidelines had been revoked, each state also had the opportunity to reestablish their own goals and objectives for their SMS. All but three states decided to voluntarily continue the operation of their SMSs. However, according to a list obtained from Fred Walker, Chair of the Iowa SMS, the majority of the states which decided to continue their SMS, stated that they would slightly modify the scope of their original, federally approved plans to closer match their own needs (*unpublished data*).

OBJECTIVES STATEMENT

Clarify the Federal Government's Goals for SMSs

The initial objective of this paper will be to clarify the Federal Government's goals for SMSs. Although the federal regulations were somewhat vague, there have been various efforts made to clarify them with regard to the development, establishment, and implementation of an SMS.

This summarization will include outlining areas considered important by the FHWA, and will consider such issues as data management and multi-disciplinary representation.

Identify the Important Components of an SMS

The second objective of this paper will be to identify the important components of a successful SMS. Although it is highly unlikely that there is one ideal SMS which will work best for every state, there are several traits which would be beneficial to the majority of SMSs. This paper will identify those traits which would help states maximize the productivity of their SMSs. The focus will be limited to those traits which can feasibly be developed and sustained in a field which constantly struggles with limited resources. The five important and achievable components of a successful SMS which will be presented and described are: Multi-disciplinary; state-wide oversight; data sharing; task forces; and resource allocation.

RATIONALE FOR OBJECTIVES

Unclear Federal Regulations

Despite the Federal Government's good intentions of establishing an organized and efficient SMS in every state, the federal regulations failed to sufficiently describe procedures for each state to follow. The five areas and eight elements, which will be described later, were meant to be the key components that states considered as they assembled their SMSs. However, they do not follow any logical progression or division. Furthermore, the federal regulations did not clearly indicate guidelines and procedures for SMSs. This was evident from the large demand by states for conferences, publications, and even an FHWA short course (*7*), all aimed at helping states understand and assemble their SMSs.

Another problem is that the five areas and eight elements included items which caused problems for states attempting to comply. One example is the strong emphasis on collecting and managing data, which is very expensive and time consuming. The requirements also contain time and labor intensive demands, such as the "development and implementation of public information and education activities." (*4*) They also contain issue-specific requirements, such as railroad-highway grade crossing safety, which do not belong in the scope of a state-wide management system. Although all of those specific issues are important to highway safety, the amount of emphasis placed on specific issues should be left to the discretion of the individual SMSs. The requirements of an SMS should be defined in terms of its organization and its basic functions, instead of these specific and resource intensive requirements.

Opportunity for Change

Furthermore, with the removal of the federal mandate for management systems, each state now has the opportunity to reevaluate its own SMS. Since SMSs were implemented in December of 1993, the states had been proceeding with relatively little direction from the federal government. This limited direction, coupled with the somewhat ambiguous concept of an SMS, resulted in a wide range of SMS structures across the United States. Now that the states can define their own goals and objectives for their SMS, it is an ideal time for them to compare their own activities to those of other states and identify areas of possible improvement. This paper will describe some of the functions which can be performed by an SMS to make it more productive.

Any forum which combines people from different professional backgrounds who share a common goal (i.e., highway safety), has enormous potential. The challenge is to gain the most benefit from the people of various backgrounds and ultimately, to maximize highway safety through the efficient use of limited resources.

CLARIFICATION OF THE FEDERAL DEFINITION OF AN SMS

On December 1, 1993, the FHWA and FTA issued 23 CFR Part 500 which described the specific requirements for all management systems (*4*). Subpart A described the basic requirements for all management systems and Subparts B through H contained the specific requirements for each of the six individual management systems. Subpart D, which described SMSs, was broken into five parts: "purpose," "SMS definitions," "SMS general requirements," "SMS components," and "SMS compliance schedule." Some of the most significant information in the CFR was found in the "SMS components" section. This was where the actual responsibilities of an SMS were described. The CFR described five major areas, which were to be addressed by each state's SMS:

<u>five areas</u>

(1) Coordinating and integrating broad base safety programs (such as motor carrier, corridor, and community based traffic safety activities) into a comprehensive management approach for highway safety;

(2) Identifying and investigating hazardous or potentially hazardous highway safety problems, roadway locations and features (including railroad-highway grade crossings) and establishing countermeasures and priorities to correct the identified hazards or potential hazards;

(3) Ensuring early consideration of safety in all highway transportation programs and projects;

(4) Identifying safety needs of special user groups (such as older drivers, pedestrians, bicyclists, motorcyclists, commercial motor carriers, and hazardous material carriers) in the planning, design, construction, and operation of the highway system; and

(5) Routinely maintaining and upgrading safety hardware (including highway-rail crossing warning devices), highway elements, and operational features. (*4*)

In addition to these five areas, the CFR also outlined eight elements, which were to be incorporated into the five areas:

eight elements

(1) Establishment of short- and long-term highway safety goals to address both existing and anticipated safety problems as well as substandard highway locations, designs, and features, and to allocate resources;

(2) Establishment of accountability by identifying and defining the safety responsibilities of units and positions;

(3) recognition of institutional and organizational initiatives through identification of disciplines involved in highway safety at the State and local level, assessment of multi-agency responsibilities and accountability, and establishment of coordination, cooperation, and communication, and communication mechanisms;

(4) Collection, maintenance, and dissemination of data necessary for identifying problems and determining improvement needs. Data bases and data sharing shall be integrated as necessary to achieve maximum utilization of existing and new data within and among the agencies responsible for the roadway, human, and vehicle safety elements. These records, as a minimum, shall consist of information pertaining to: crashes, traffic (including number of trains at highway-rail crossings), pedestrians, enforcement activities, vehicles, bicyclists, drivers, highways, and medical services;

(5) Analysis of available data, multi-disciplinary and operational investigations, and comparisons of existing conditions and current standards to asses highway safety needs, select countermeasures and set priorities.

(6) Evaluation of the effectiveness of activities that relate to highway safety performance to guide future decisions;

(7) Development and implementation of public information and education activities to educate and inform the public on safety needs, programs, and countermeasures that affect safety on the nation's highways; and

(8) Identification of skills, resources, and current and future training needs to implement the State's activities and programs affecting highway safety, development of a program to carry out necessary training, and development of methods for monitoring and disseminating new technology and incorporating effective results. (*4*)

The states were then left with the task of interpreting these five areas and eight elements and implementing them into an SMS.

Explanation of Five Areas and Eight Elements

In the five areas and eight elements, the FHWA and FTA outlined some components which they considered important for SMSs. The five areas referred to vital safety program areas selected through FHWA study workshops (*3*). The eight elements were management principles which were to be used to manage the five areas. Almost every one of the five areas and eight elements referred to collecting, organizing, or analyzing some type of data, information, or statistics.

Although the actual regulations were not passed until two years after ISTEA was enacted, several states had already begun to coordinate their safety efforts. A survey conducted by the American Association of State Highway and Transportation Officials (AASHTO) showed that 46 percent of the states had some form of a Safety Management System in place as of January, 1994 (*8*). This means that all but four states had already begun to organize their SMSs prior to receiving the descriptions in the CFR.

EXPLANATION OF 1995 LEGISLATION

When the federal mandates were dropped in November of 1995, an opportunity emerged for an even wider range of definitions and applications of SMSs. Prior to this time, each state's SMS was required to submit work plans and reports to the federal government. This allowed the FHWA to provide some guidance to each SMS and to keep them heading in a common direction. The new legislation made SMSs entirely optional for the states. While it is known that only three states elected to drop their SMSs entirely, it remains to be seen what will actually become of the SMSs in the other 47 states.

IMPORTANT SMS COMPONENTS

Highway safety is a very ubiquitous aspect of transportation. Because of this, it is difficult to establish one vision of a management system which can efficiently oversee all aspects of highway safety for an entire state. There are, however, five beneficial functions which every SMS can perform.

Provide a Multi-disciplinary Forum

The most natural function of an SMS is to provide an avenue for communication among all agencies and organizations interested in improving highway safety in the state. In order to establish any management system, a good communication network must first be established.

Because an SMS is a pervasive concept, it is important to have a multi-disciplinary group of people governing its activities (*9*). By keeping a broad base of members, the focus of the SMS may also be kept broad. The CFR listed several agencies and disciplines which should be represented including: state and local transportation, motor carrier safety, law enforcement, emergency medical services, emergency response, railroads, and education (*4*).

One activity directed toward creating and maintaining a forum for communication could be to assemble and distribute a state-wide directory which lists the contact people and telephone numbers for all agencies, programs, and organizations involved with highway safety in that state.

Regardless of the goals of the SMS, such a directory would be beneficial to anyone concerned with highway safety issues. In addition to providing telephone numbers, the directory would also provide a concentrated view of that state's active participants in highway safety issues.

Another simple and helpful function that an SMS can perform is the holding of regularly scheduled meetings. These meetings would serve as an excellent opportunity for people from various disciplines and backgrounds to exchange ideas. Further, if these meetings can be made open to the public, the exchange of ideas will become that much more broad.

Oversight of All Highway Safety Efforts

By definition, an SMS should take on a management role for the overall highway safety effort in its state. Although this may not include presiding over individual programs, it should involve gaining and maintaining a thorough understanding of all highway safety activities and programs within the state. This could be accomplished in coordination with the collection of information for a highway safety directory. This effort may also lead to the identification and elimination of duplicated efforts by two separate organizations. It should be the duty of the SMS to use the information collected to educate others involved in highway safety in their state.

Multi-agency Data Sharing

Data are a valuable commodity which are expensive to collect and maintain. Therefore, much consideration should be given before collecting data, simply for the sake of collecting data (*10*). An SMS is the ideal organization to inventory the current data being collected, and to evaluate existing and future data needs with respect to highway safety. Utilizing a multi-disciplinary representation and an extensive communication network, an SMS should be able to effectively execute these functions and, at the same time, evaluate their state's current data collection practices. The evaluation should include identifying duplicated efforts, and identifying any agencies which could benefit from data sharing.

Several states have identified geographic information systems (GIS) as a technology with valuable applications in transportation safety (*11*). GISs are spatial databases which appear as computerized maps and can be used as tools for graphically displaying and accessing data. In transportation safety, such maps could be used to graphically display data and statistics for decision makers. Once again, an SMS would have the broad, state-wide view necessary for determining what data should go into the GIS to optimize its usefulness.

Task Specific Task Forces

Another tool which can be used by SMSs is the coordination of special "task forces." Task forces are temporary, multi-disciplinary groups of people assembled to address problems which may not be adequately handled by one, single agency. They can be used to address large issues which involve several backgrounds, such as access management. Or they can be formed to solve immediate problems, such as preparing a report for state legislators to educate them about the expected results of changing maximum speed limits (*12*).

When forming task forces, it is important to carefully select both the problem statement and the task force members. All agencies involved with highway safety value the scarce time of their employees. In order for these agencies to allow their employees to serve on a task force, they must perceive some future benefit. This is done by only selecting problems for task forces which are both timely, and manageable. Also, the topic must be relevant to those who are asked to serve on the task force. If the topic is not of interest to the people serving on the task force, the people can only be expected to put forth a minimal effort.

Example: Iowa SMS's Speed Limit Task Force

One example of the efficient use of a task force was demonstrated by the Iowa SMS in December of 1995. In late November of 1995, the federal government passed The National Highway System Designation Act of 1995, which repealed the national maximum speed limit. This allowed state governments to change maximum speed limits at their own discretion. The Iowa SMS's Coordination Committee recognized that the state legislators were soon going to be faced with decisions which could drastically impact highway safety in Iowa. This prompted the SMS Coordination Committee to form a task force with the goal of educating the Iowa legislators on this important safety issue. In January of 1996, before the Iowa Legislature went into session, the Task Force on Speed Limits had prepared a 52 page report which described the highway safety impacts that could be expected from increasing the maximum speed limit on various roadway types (*12*). On January 30, the report was presented to the Governor of Iowa by the department heads of the Iowa Department of Transportation, the Iowa Department of Public Safety, and the Iowa Department of Public Health (*13*). The next day, the report was distributed to Iowa Legislators to be used as a decision-making tool.

Several key components of a successful task force were present in Iowa's Task Force on Speed Limits. First, the problem being solved was best addressed by personnel from various disciplines and agencies. No single organization or department could have achieved the credibility that was gained by combining people from the fields of law enforcement, engineering, and emergency medicine. Second, it was a timely topic which was relevant and important to the people who were asked to serve on the task force. Because of the importance and urgency of the issue, supervisors were more likely to allow employees the time needed to work on the Task Force, and the employees were more eager to do the work.

Efficient Allocation of Safety Resources

Although most SMSs do not have direct access to the use or distribution of any funding sources, they could serve as a panel for assuring the efficient use of funding designated for highway safety related projects. Again, because of the broad-based, multi-disciplinary involvement, and the knowledge of existing highway safety programs and activities, an SMS is the ideal place for resource allocation decisions to be made.

CONCLUSION

SMS intrinsic benefits

It would be difficult to assemble an SMS comprised of people with professional interests in highway safety, and not realize some benefits. However, in order for an SMS to fully realize its potential, it needs direction and an organized and logical procedure to follow. Furthermore, its goals and objectives should be set at economically attainable targets.

Five important SMS components

When determining objectives for an SMS, there are five important components which should be addressed: a multi-disciplinary communication forum; oversight of all highway safety efforts; multi-agency data sharing; task specific task forces; and, the efficient allocation of safety resources. These are all activities which can significantly affect the management of highway safety, and at the same time, they can be accomplished within the limitations of scarce transportation resources.

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A Comparison Among Computer Packages in Providing the Timing Plans for Iowa Street in Lawrence, Kansas

A Comparison Among Computer Packages in Providing The Timing Plans for IOWA Street in Lawrence, Kansas

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Abstract:

In traffic engineering, three computer packages have been widely used in providing coordinated signal timing plans for arterials. They are Synchro Pro., TRANSYT-7F and PASSER-II. Each package has its own strong and weak points with regard to different traffic situations. This paper explores which of these three packages is the best one in yielding a suitable timing plan for IOWA Street, the main north-south artery in Lawrence, Kansas. The timing plans produced by Synchro, TRANSYT, and PASSER are compared in terms of the delay, stops, speed, fuel consumption and emission as analyzed by NETSIM. The best plan is the one with the most desirable measure of effectiveness (MOE). The timing plan for the off-peak period is also compared on this basis. In addition, advantages and disadvantages of each package are discussed.

Description of the problem

There are three computer packages widely used in providing timing plans for arterials. They are Synchro Professional, TRANSYT-7F and PASSER-II. Synchro Professional is a newly developed software dealing with the timing of a signalized network. Synchro can analyze the capacity for signalized intersections, coordinate networks and arterials and generate time-space diagrams. It is a window-based software. Its main advantage is its easy data entry, quick optimization process and the feature of working automatically with TRANSYT, PASSER and NETSIM.

TRANSYT-7F is an old and sophisticated package developed by TRRL (Transport and Road Research Lab) of England. It is a macroscopic, deterministic simulation and optimization model dealing mainly with the signalized network coordination. It can simulate the existing condition of signalized intersections, select the best cycle length for a signalized network, optimize phase lengths and offsets for a given cycle length.

PASSER, an acronym for Progression Analysis and Signal System Evaluation Routine, is a coordination model for the main arterial. This microcomputer program can analyze both individual signalized intersections and progression operations along an arterial street. Unlike Synchro and TRANSYT, PASSER can't do the network optimization job. It deals with the arterial only and its main objective is to achieve the maximum bandwidth in the arterial progression. Neither TRANSYT nor PASSER are window-based software, but they can work under Synchro environment. This saves a lot of time in data entry.

To provide a timing plan for arterials is the common feature of these three packages. Which is the best in providing a timing plan for a particular arterial with specific traffic characteristics is questionable. There is no saying which is superior to the others in the provision of timing plans for arterials. The question is which package is mostly suitable for the traffic improvement along a particular arterial.

The goal of the study

With regard to this undecided situation, the goal of the study is to determine which package can best provide a timing plan to improve the existing traffic operation along IOWA street. IOWA Street is a main north-south arterial in Lawrence, Kansas. The sector starting from 9th street to 33rd street has been considered a deteriorated segment, causing congestion and delay during the rush hour. On this sector there are nine signalized intersections. The total length of this segment is 16,050 feet. Fig. 1 (see Appendix A-1) shows a sketch map of the IOWA arterial.

The criterion to evaluate the timing plans in our study is based on the average delay, percentage of stops, average speed, fuel consumption and emission. These criteria are commonly used and accepted widely by transportation professionals. We are trying to find a timing plan with the best weighted values in delay, stops, speed, fuel consumption and emission. Theoretically, the technical and future maintenance issues as well as cost should also be taken into

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consideration when a final alternative is to be chosen. But, due to the study orientation and the time limit, what we are looking for comes from the result of the timing plan only. That is to say the final decision is based on the timing outcome with the most desirable MOE's.

As is known, decision-making is a complicated process. For the case we've studied, what we are after is the optimization of the whole system. That means we seek the desirable MOE from the view of the whole system. Improvement or optimization of a specific link or intersection is not our focus. There is no priority assigned to any link or intersection in our study. Fig. 2 (see Appendix A-2) shows the flow chart of the study.

The data collection and analysis

Traffic counts are conducted at nine intersections along IOWA Street. The survey period is from 7:00 to 10:00 am, from 11:00 to 2:00pm and from 3:00 to 6:00 pm respectively. The time interval is 15 minutes. For each intersection, we take only an one-day count. From observation we find the peak hour is within 4:45-- 5:45 in which highest 15-minutes volumes of most intersections fall. The peak hour factor (PHF) is then calculated based on this hour as shown in table 1. The PHF unevenly distributes (from 0.5 to 0.96) showing that the volumes approaching the intersections during the peak hour is in an irregular fashion.

Some assumptions

Before making the analysis, some necessary assumptions have to be made. First, the best alternative comes from the results produced by Synchro, TRANSYT and PASSER only. Second, the criterion used in the evaluation of the alternatives comes from NETSIM only. Third, the geometric design of the system remains unchanged except for the turning pocket length. Fourth, the original left turning treatment of each intersection remains unchanged unless there is an error occurring in the delay calculation under Synchro. The reason to make such an assumption is that if there is an error in the delay calculation, the result of the timing plan in Synchro will be incorrect. Fifth, only a pretimed controller is used in the coordination.

Table 1. The peak hour volume and the peak hour factor (PHF) of each intersection

Intersections		Eastbound			Westbound			Northbound			Southbound		
		L	S	R	L	S	R	L	S	R	L	S	R
9th St.	Vol	120	273	86	248	327	137	87	780	6	156	987	54
	PHF	0.94	0.94	0.90	0.85	0.87	0.88	0.87	0.87	0.50	0.78	0.92	0.79
Harvard	Vol.	45	34	72	40	44	33	31	1123	30	20	1125	21
	PHF	0.75	0.57	0.69	0.83	0.69	0.75	0.78	0.87	0.68	0.83	0.95	0.66
15th St.	Vol.	158	202	282	163	410	114	293	888	141	181	1231	114
	PHF	0.68	0.69	0.78	0.77	0.88	0.77	0.79	0.92	0.90	0.64	0.91	0.89
19th St.	Vol.	41	66	123	263	46	281	49	984	135	313	1344	14
	PHF	0.54	0.69	0.58	0.85	0.82	0.85	0.72	0.94	0.80	0.82	0.96	0.58
23rd St.	Vol.	229	418	142	282	513	287	155	672	304	254	1028	263
	PHF	0.83	0.87	0.87	0.88	0.96	0.88	0.76	0.78	0.89	0.85	0.79	0.82
25th St.	Vol.	155	60	56	47	63	53	49	822	26	56	934	120
	PHF	0.92	0.83	0.88	0.65	0.83	0.83	0.77	0.87	0.65	0.74	0.88	0.91
27th St.	Vol.	165	149	37	81	182	89	39	556	37	110	701	145
	PHF	0.71	0.89	0.77	0.78	0.91	0.86	0.70	0.93	0.77	0.69	0.89	0.79
31st St.	Vol.	88	244	167	108	261	139	133	430	45	171	571	102
	PHF	0.92	0.68	0.79	0.69	0.77	0.91	0.88	0.89	0.59	0.79	0.94	0.85
33rd St.	Vol.	80	45	53	60	46	191	19	418	46	174	690	95
	PHF	0.87	0.75	0.83	0.71	0.61	0.71	0.53	0.93	0.64	0.87	0.94	0.95

L --- left; S --- straight; R --- right;

The steps of the analytical procedures

Evaluation of the existing timing plan of the arterial

After entering all needed data into Synchro, we can use NETSIM to evaluate the existing operation along IOWA street based on the entry information. As we know NETSIM is a microscopic program simulating individual vehicular behavior in response to any or all of the factors such as volume, turning movements, signal operations, intersection configurations etc. Its simulating results are extremely complete and detailed.

It is very easy to run NETSIM under Synchro. The input card file produced by Synchro can be viewed and modified in the NETSIM environment. This modified file *cannot* go back to Synchro, because Synchro cannot figure out the data file made by any other packages. This is the weak point of Synchro. It should be noted that Synchro version 2.0 itself cannot produce cards 43, 44, 45, and 46 which are used for the actuated controllers. The on-going Synchro version 3.0, which is expected to be released soon, overcomes this disability.

Before running NETSIM, it is necessary to specify two additional values: network fill time and simulation time. The fill time is the maximum number of minutes to fill network to reach equilibrium before simulation actually begins. The default is 15 minutes and this value is used in the study. The simulation time represents the time duration in which traffic operation is animated based on the given situation. The default in Synchro is 15 minutes. But, in our study, 30 minutes is used as the simulation time, because from the theory of simulation, the more the time used. the better the result received.

The outputs by NETSIM include: vehicle travel miles, travel time, delay time, percentage of stops, average speed, queue time, vehicle occupancy, number of phase failures, fuel consumption, and emission. As we know that there are correlations among these parameters. In our study, we just consider five of them. They are: delay time in second per vehicle, percentage of stops, average speed in miles per hour, fuel consumption in gallons per hour, and emission in kilogram per mile per hour. NETSIM can estimate the emission produced by car, truck and bus in terms of carbon oxygen, hydrocarbon and nitrogen, expressed by CO, HC and NOX respectively. We choose this parameter because the consideration of the Clean Air Act is very important at present in transportation.

The reason we use NETSIM to evaluate existing operative performance instead of using TRANSYT (even though it is much faster than NETSIM) is that TRANSYT can only simulate the intersections with the same cycle length. It is very inconvenient to get the result, if these nine intersections have nine different cycle lengths. Moreover, the outputs from TRANSYT are not as detailed as NETSIM.

To perform optimization of individual intersections by Synchro

Synchro can optimize a timing plan for individual intersections. The advantage of using Synchro to optimize individual intersections over other software such as EZ-POSIT or SOAP is that you can set up a network to put all intersections to be analyzed together to form just one file, and then solve timing problems one by one. If you want to coordinate it, you can still use it by simply renaming the file. The other advantage of Synchro over EZ-POSIT and SOAP is that the timing results produced by Synchro can be read directly by NETSIM to evaluate.

To use Synchro to optimize timing plans of individual intersections is very easy. Choose the intersection by either clicking the node to make it black or selecting it from the window. The first thing to optimize the intersection is to determine the best cycle length for that intersection based on the geometric configuration, traffic assignment and left turn type. Synchro provides Cycle-length window for users. Just click this window, the best cycle length will be given. The next thing is to optimize the splits for each phase sequence. All phases are assigned a split greater than or equal to their minimum split entered during the data entry. The time is divided proportionately based on each lane group's traffic volume divided by its adjusted saturated flow rate. If a lane group serves two or more movements, such as through-and-left or through-and-right, the sum of their volumes is divided by the sum of their lanes. If there are permitted left turns, the entire process of split-assignment is done repeatedly. At first, splits are assigned by using protected left turn factors. Then permitted left turn factors are calculated based on these splits. Then, splits are recalculated using the permitted left turn factors. Finally, the left turn factors are recalculated using the new splits. If there are permitted+protected left turn phases, the calculations are a bit more complicated. The saturated flow rate for left turns depends on what proportion of the left turn phase is permitted and what proportion is protected. The above calculations are reperformed repeatedly to balance the volume-to-capacity ratios of the permitted and protected portions of the left turns. If there is a shared turning lane plus an exclusive turning lane, the calculations are repeated even further. The traffic is assigned among the various lane groups based on volume-to-capacity ratios. Lane group assignment affects permitted left turn factors and volume-to-saturation flow ratios. These, in turn, change the optimum splits which means that the traffic may need to be reassigned further.

The final work for the individual intersection timing is to optimize offset and phasing by clicking Splits and Phasing. This command tests all possible left turn signal sequences to minimize delays on links. It should be noted here that this function only affects the selected intersection. It does not make any changes to the surrounding intersections. There may be better timing plans available by changing the timings of surrounding intersections, but Optimize-intersection Splits and Phasing will not find them. Actually, this function is only used to guarantee the V/C ratio less than 1.2. From using this command, we find there is no any change when clicking this command where there is no lane group with V/C ratio greater than 1.2.

To perform Synchro to coordinate the whole system

In addition to giving the optimization for a single intersection, Synchro can coordinate the network of streets. Unlike TRANSYT and PASSER, Synchro can do coordination group by group, without requiring that all intersections in the system should use the same cycle length. Before coordinating groups of intersections, Synchro first makes a coordinatability analysis to determine which intersections to coordinate and which to leave independent. Whether or not the neighboring intersections should coordinate is determined by the so-called coordinatability factor (CF). The coordinatability factor is a measure of the desirability of coordinating the intersections. Several criteria are used in an attempt to determine whether coordination is warranted. These criteria are used to determine a CF on a scale from 0 to 100. The rule is as follows: any score above 80 indicates that the intersections must be coordinated to avoid blocking problems, any score below 20 indicates the intersections are too far apart from coordination. In fact, the CF for each link will appear on the map by double-clicking on any link. The report produced by Synchro will also give the CF value in detail. Table 2 gives the CF value of each link.

Table 2. The CF value of each link

Name of links	Coordinatability factor
9th -- Harvard	74
Harvard -- 15th	47
15th -- 19th	77
19th -- 23rd	52
23rd -- 25th	74
25th -- 27th	85
27th -- 31st	78
31st -- 33rd	89

The CF is used to initially determine which intersection should coordinate. It should be noted that the calculations of CF are very empirical and immature. The application of these factors should be used with great caution. In most cases, engineering judgement plays an important role in the decision of whether or not the coordination is to be carried out. Nevertheless, the CF value may help engineers make more sensible decisions. In Synchro, there is not a specific criterion set to decide if coordination can be carried out when CF value falls between 20 and 80. However, any value above 50 means that coordination is recommended. The higher the value the CF, the more likely that this link will benefit from coordination. Based on the result of Table 2 and the practical situation along IOWA Street, we think that all intersections along this arterial should be coordinated.

To do coordination under Synchro, just click the Cycle Lengths and Coordinatability window and then All Offsets and Phasing window. The coordinating result will come out within a minute. As is known, for as few as ten intersections to be analyzed, there are potentially millions of combinations of signal sequences and offsets. To check all possible combinations seems impossible and unnecessary. Synchro uses advanced artificial intelligence logic that helps decide which possibilities will give the optimum solution.

To perform TRANSYT to coordinate a timing plan

The optimization technique used in TRANSYT is referred to as a "hillclimbing" technique which is an iterative, gradient search for the best timing plan. It deals in the equivalent pretimed operations, not good at

Table 3. Cycle length evaluation summary performed by TRANSYT

Cycle length (sec)	Step size (step)	Average delay (sec/veh)	Percent stops (%)	Fuel consumption (gal/hr)	Disutility Index	Number of links saturated	Performance index
60	20	563.38	69	4412.0	4041.5	22	4041.4900
70	23	336.21	69	2879.0	2520.0	16	2520.0160
80	27	234.59	71	2197.0	1997.7	16	1997.6760
90	30	183.08	71	1848.7	1689.1	15	1689.0950
100	33	168.33	71	1752.7	1919.7	17	1919.6910
110	37	166.41	69	1731.7	1513.4	16	1513.3770
120	40	154.07	69	1648.9	1558.1	16	1558.0520
130	43	165.13	68	1720.8	1705.7	14	1705.6730
140	47	188.45	69	1881.5	2001.1	15	2001.1020
150	**50**	**171.52**	**67**	**1760.9**	**1509.6**	**14**	**1509.6080**
160	53	211.96	64	2024.9	1644.6	11	1644.6300
170	57	207.25	65	1998.1	1809.5	13	1809.4900
180	60	217.67	68	2077.4	1830.6	14	1830.6200
190	60	231.50	67	2164.9	1937.5	12	1937.5440
200	60	228.02	67	2142.4	2198.5	13	2198.4900

BEST CYCLE LENGTH = 150 SEC. CYCLE SENSITIVITY = 31.6 %

handling actuated controllers. In the first process of running TRANSYT, the best cycle length will be chosen. The range of cycle length provided by TRANSYT is from 60 to 200 seconds with increments of 10 seconds. The rule in choosing the cycle length is that the cycle length must be long enough to provide sufficient minimum time for all phases, considering both vehicle and pedestrian requirements. The sum of these minimum phase lengths is the absolute lower limit of the cycle length. Also, the cycle length should be sufficiently long to ensure that no movement is oversaturated, but not be so long as to cause unacceptable delays. In TRANSYT, the best cycle length is the one that produces the lowest disutility index (DI, analogous to the original TRANSYT performance index PI) which is defined as the weighted value to measure the delay, stops and queue lengths on links. (see reference [4] on page 4-30 for detail). Table 3 shows the result of selecting the cycle length by TRANSYT.

The best cycle length produced by TRANSYT is 150 seconds for these nine intersections with the lowest value of the DI (=1509.6). The cycle sensitivity is the measure to tell how sensitive the design is in relation to the cycle length. It is the coefficient of variation of the DI, expressed as: $CS = SD(DI)/DI(avg)$. Here, CS is the cycle length sensitivity in percentage, SD(DI) is the standard deviation of the DI's estimated by TRANSYT for each cycle length, and Di(avg) the average value of the DI's estimated by TRANSYT for each cycle length.

The next step, after applying this cycle length to these nine intersections, is to optimize phase lengths and offsets. These two processes are completed within several minutes.

To perform PASSER to optimize a timing plan

PASSER is a tool to coordinate an arterial street. Its goal is to achieve the greatest green band along the main street to discharge the traffic stream more efficiently. The newly released version of PASSER II-90 can analyze up to 20 intersections per arterial. In our study, we have only nine intersections. PASSER uses Webster's method to calculate cycle lengths and green splits. The travel time is used here to help find the optimal coordination offsets that maximize arterial progression bandwidth. PASSER uses heuristic time-space relationships to examine the phase sequences and gives the best combination. The program can provide optimal timing plans for signal operations ranging from a simple two-phase signal sequence to multi phasing arrangements. Selecting the most suitable cycle length is the most important decision to be made during signal coordination analysis. All intersections in the progressive system must operate on the same cycle length.

There are some changes of default values used in the embedded data in PASSER. One is the ideal saturation flow. The value of 1800 is used as the default. In our case, we change it to 1900 to order to be consistent with what we do in Synchro. The second is in the left-turn phasing. Based on the real situation of these nine signalized intersection, the left turn phasing is "ring-based" operation instead of the "approach-based" one defaulted in the PASSER. The running time of PASSER for this case is very short. The cycle length is 110 seconds. The southbound bandwidth is 32 seconds and the northbound bandwidth is 25 seconds. The efficiency used to measure the consequence of progression is 0.27. The attainability, a measure of using green band, is 0.92. Based on the criterion stipulated in PASSER, the progression is good, but it needs to be fine tuned for the phase length in order to achieve the better attainability.

This coordination process is considered the uniform band approach (U-Band) due to the unchanged bandwidth along each direction on the arterial.

As an alternative, the V-Band (variable band) coordination by PASSER is also considered because the distribution of the natural cycle length of the intersections is uneven. The other reason to try the V-Band process comes from the result of research on U-Band versus V-Band coordination. This research demonstrates that the V-Band method is better than U-Band when there is a lot of turn-in and turn-out traffic at the intersections of the arterial (see reference [8] for detail).

Based on the distribution of the natural cycle length of each intersection, we pool the first five intersections as a group and the rest of the four intersections as the other group for the coordination. (In fact, there are many combinations for pooling the intersections; due to the time limit, we only consider this pooling strategy) The cycle length of the first group is 120 seconds. Its southbound bandwidth is 44 seconds and northbound bandwidth is 36 seconds. The efficiency for the first group is 0.34 and its attainability is 0.99. The cycle length of the second group is 65 seconds. The southbound bandwidth is 20 seconds and the northbound bandwidth is 17 seconds. The efficiency for the second segment of coordination is 0.29 and its attainability is 1.00. These results are very good. There is no need to do fine tuning in this case.

The comparison of the results and discussion

All timing plan results produced by Synchro, TRANSYT and PASSER are put into NETSIM to run to see which is the best alternative. As a rule of thumb, Do-nothing also enters as an alternative. As mentioned before, NETSIM is a tool to evaluate these timing plans. Even though each software used above also has the report about MOEs, none of them is as detailed as that presented by NETSIM. Moreover, Synchro, TRANSYT and PASSER can only provide the MOEs associated with the intersection or the whole system; while NETSIM can provide the MOEs in terms of links, intersections and the whole system. NETSIM can also give the operative condition of each movement of the traffic on the links. This functions help traffic engineers analyze problems on a wider scope.

Table 4 gives the measures of effectiveness in terms of the whole system produced by NETSIM. This is based on the peak-hour situation. With regard to the fact that MOE's are usually discussed intersection by intersection, we regroup the data from links and give the MOE's of each intersection as shown in Table 5 (see Appendix A-3). This is to compare the improvement of MOE's among intersections corresponding to the different alternatives.

comparison of delay

From Table 4, we can conclude that the result from PASSER is the best one among these alternatives in delay. Synchro Coordination produces great improvement in delay compared to Do-nothing, but its improvement is not as good as PASSER. TRANSYT is the worst in the improvement in delay. The reason may be its lack of capability to analyze leading or lagging phasing which can be done in PASSER and

Table 4. The system MOE's of different alternatives during the peak hour

	Do-nothing	Synchro Indiv.	Synchro Coord.	TRANSYT	PASSER U-Band	PASSER V-Band
Delay (sec/veh)	26.10	26.37	24.20	27.60	21.55	22.58
Stops (%)	50.61	48.26	43.69	41.09	37.44	41.21
Speed (MPH)	20.90	20.94	21.53	20.75	22.32	22.11
Fuel use (gallon)	490	486.3	470.2	475.9	447.4	450.6
Emission: HC	0.206	0.204	0.200	0.196	0.188	0.188
CO	9.840	9.692	9.552	9.058	8.865	9.196
NOX	0.625	0.620	0.603	0.585	0.564	0.569

Synchro. The other reason is that TRANSYT has a narrow scope in the cycle length selection and its increment in cycle length is 10, missing a lot of chances. In Synchro and PASSER this increment can be as little as 1, even though 5 is the normal value. In addition, the criterion for choosing the best cycle length set in TRANSYT is not the one with minimum delay. This can be seen in Table 3. From the whole system, PASSER U-Band coordination is still better than PASSER V-Band coordination in delay. From Table 5, we can find that Harvard and 25th street intersections have very little improvement in delay, whereas 23rd street intersection has no improvement in delay.

comparison of stops

The improvement of PASSER in stops is more pronounced, especially for the Harvard, 19th and 25th street intersections. TRANSYT has the greatest improvement in stops for Harvard, but no betterment for the 9th and 23rd street intersections. Overall, TRANSYT is better than Synchro in the improvement of stops, but not as good as PASSER. Synchro Individual Timing is the worst in the improvement in stops. From the result made by Synchro Individual Timing shown in Table 5, we can see that five out of nine intersections are even worse in stops than Do-nothing.

comparison of speed

The improvement in speed is not so obvious. From Table 5, we can see that there is no improvement for the 23rd street intersection in speed for all five alternatives. The reason is that the improvement in the main stream is offset by the decrease in speed on the side street because the traffic volume of side street of the 23rd street intersection is relatively high. (Progression is not applicable for the intersection with balanced volume) PASSER is still the best in the improvement of speed. Synchro Individual Timing has no improvement in speed, and TRANSYT has a small decrease in speed.

comparison of fuel consumption

PASSER coordination is still in the leading position in the fuel consumption improvement. Synchro Individual Timing has a small decrease in the fuel consumption, but Synchro Coordination has a considerable improvement, which demonstrates that coordination is conducive to the reduction of the fuel use. From the intersection fuel use (Table 5), we find there is no improvement in the fuel use for the Harvard, 31st, and 33rd street intersections. TRANSYT is worse than Do-nothing in fuel use for the 9th street intersection.

comparison of emission

Compared to Do-nothing, all the five alternatives have some improvement in the gas emission in terms of HC, CO and NOX, but PASSER is in the top. From Table 5, we find that 25th street intersection gets the greatest improvement in HC, CO and NOX.

comprehensive comparison

Overall, the 19th street intersection gets the most improvement, whereas the 23rd street intersection gets the least. This is due to the difference in traffic composition between these two intersections. From Table 1, we can see that during the peak hour the split of volume from East-West bound versus North-South bound for the 23rd street is 1871:2676, while this split for the 19th street is 820:2839. That shows the reason why the improvement of the 19th street intersection is better than the 23rd street intersection because coordination favors the intersection with more unbalanced volume.

The recommended alternative

In our study, there are six alternatives to provide for making the final decision. The traffic on the IOWA arterial during the day is unevenly distributed. The volume during the off-peak hour is much less than the volume during the peak hour so the treatment in timing plans for each period should be different in order not to waste the green time.

Alternative for the peak hour

From a comprehensive analysis of the delay, stops, speed, fuel consumption and emission, we conclude that the timing plan produced by PASSER is the best choice for the given circumstances. The reason that PASSER is chosen as the best timing plan is due to the heavy volume on the IOWA street. It is believed in general by traffic professionals that the heavier the traffic on the arterial, the better it is to use linear progression. The distance between two intersections along this arterial is rather short, which is another reason to achieve good coordination results. From observation, we can see that the commercial activity on both sides of the arterial is not so intense, so it is beneficial for the vehicles to fully use the green belt.

Compared with Do-nothing alternative during the peak hour, the timing plan provided by PASSER gets the best improvement. This can be proved quantitatively by creating an overall evaluation Table as shown in Table 6. In creating this table, it is stipulated that each parameter has an equal weight in the evaluation. No preference is designated. The rating score is measured by the percentage of improvement of each of the alternatives versus Do-nothing. Do-nothing is taken as the base line. Each alternative has a rating score based on a comparison with Do-nothing. If the value of a parameter (e.g delay) is better than Do-nothing, the score is positive, and this score is measured by the percentage of improvement. If the value of a parameter is worse than Do-nothing, the score is negative. If the value of a parameter of the alternatives is the same as Do-nothing, then the score is zero. For example, the value of system delay produced by Synchro Individual Timing and Synchro Coordination is 26.367 and 24.20 seconds respectively as shown in Table 4. Compared to 26.10 seconds, the value of Do-nothing, Synchro Individual Timing is worse than Do-nothing and Synchro Coordination is better than Do-nothing in system delay. The former worsens by 1%, and the latter improves by 7.3% in delay. Therefore, the rating score for system delay is -1 for Synchro Individual Timing and +7.3 for Synchro Coordination. The total rating score is the accumulation of the scores coming from delay, stops, speed, fuel consumption and emission. Table 6 gives the overall rating scores for each alternative.

From Table 6, we can see that PASSER greatly overscores the other options. Based on the result given by PASSER, Table 7 gives the comparison of level of service of the nine intersections before and after the coordination.

From Table 7, we find that all intersections except 23rd street intersection have improvement in average delay, and only Harvard, 15th, 25th, 27th and 31st street intersections have improvement in level of service. The remaining four intersections have no change in level of service. There is no any improvement for 23rd street intersection in delay. The reason is that the improvement of delay in the main stream is offset by the deterioration of its side street in delay.

Alternative for the off-peak hour

All the timing plans we made above are for the peak hours. As we know, the length of peak hours lasts a very short time in a day. There would be a waste of green time or more unnecessary delay of side streets if we use the peak-hour timing plan for the off-peak period because traffic volume during the off-peak is much less than during the peak hour. Here, we still use NETSIM to evaluate the existing operation of these

Table 6. The overall rating scores for different alternatives during the peak hour

Alternatives	Improvement of parameters versus Do-nothing							Overall rating score
	delay	stops	speed	fuel use	HC	CO	NOX	
Synchro Individual	- 1%	+4.6%	+0.2%	+0.7%	+1%	+1.5%	+0.8%	**7.8**
Synchro Coord.	+7.3%	+13.7%	+3%	+4%	+3%	+3%	+3.5%	**37.5**
TRANSYT	-5.7%	+18.8%	-0.7%	+2.9%	+4.8%	+7.9%	+6.4%	**34.4**
PASSER U-Band	+17.4%	+26%	+6.8%	+8.7%	+8.7%	+9.9%	9.7%	**87.2**
PASSER V-Band	+13.5%	+18.6%	+5.8%	+8%	+8.7%	+6.5%	+9%	**70.1**

Table 7. The before-and-after comparison of delay and level of service during the peak hour

Intersections		9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Delay	Before	29.72	16.03	54.54	47.78	34.40	15.65	29.62	27.74	21.05
	After	27.65	13.24	45.61	26.84	34.47	12.54	24.68	23.95	18.13
LOS	Before	D	C	E	E	D	C	D	D	C
	After	D	B	E	D	D	B	C	C	C

Table 8. Delay and LOS of each intersection during the off-peak hour

Intersections	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Delay (sec/veh)	26.67	15.22	41.67	23.23	30.12	14.29	27.18	25.13	20.80
Level of service	D	C	E	C	D	B	D	D	C

Table 9. The system MOE's of different alternatives during the off-peak hour

	Do-nothing	Synchro Indiv.	Synchro Coord.	TRANSYT	PASSER U-Band	PASSER V-Band
Delay (sec/veh)	20.99	14.87	14.77	16.58	14.81	14.65
Stops (%)	45.72	45.14	43.22	41.87	38.12	40.30
Speed (MPH)	22.23	24.52	24.63	24.12	24.65	24.77
Fuel use (gallon)	348.8	340.7	341.9	336.3	329.7	321.0
Emission: HC	0.146	0.145	0.145	0.140	0.138	0.135
CO	7.006	7.159	7.162	6.721	6.678	6.655
NOX	0.445	0.449	0.447	0.429	0.426	0.406

Table 10. The overall rating scores for different alternatives during the off-peak hour

Alternatives	Improvement of parameters versus Do-nothing							Overall rating score
	delay	stops	speed	fuel use	HC	CO	NOX	
Synchro Individual	+29.1%	+1.3%	+10.3%	+2.3%	+0.7%	-2.2%	-0.9%	**40.6**
Synchro Coord.	+29.6%	+5.5%	+10.8%	+2%	+0.7%	+2.2%	-0.4%	**50.1**
TRANSYT Coord.	+21%	+8.4%	+8.5%	+3.6%	+4.1%	+4.1%	+3.6%	**53.3**
PASSER U-Band	+29.5%	+16.6%	+10.9%	+5.5%	+5.5%	+4.7%	+4.3%	77
PASSER V-Band	+30.2%	+11.8%	+11.4%	+8%	+7.5%	+5%	+8.8%	**82.7**

Table 11. The comparison of delay and level of service during the off-peak hour

Intersections		9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Delay	Before	26.67	15.22	41.67	23.23	30.12	14.29	27.18	25.13	20.80
	After	18.52	10.68	26.09	20.93	21.91	9.13	14.36	15.62	13.69
LOS	Before	D	C	E	C	D	B	D	D	C
	After	C	B	D	C	C	B	C	C	C

nine intersections during the period of the off-peak hour, and get the result as shown in Table 8.

From Table 8, we can see that the level of service during the off-peak period is nearly the same as that of the peak-hour period after coordination by PASSER. This is not good, because five out of nine intersections are still operated under or below level D. So, it seems necessary to seek the best timing plan for the off-peak period, following the same procedure, in order to have the IOWA arterial run under optimal status. Similar to the way we do for the peak hour period, we take the six alternatives as the candidates to compare in terms of delay, stops percentage, speed, fuel consumption and emission. The results are shown in Table 9.

From Table 9, we conclude that PASSER still is superior to other alternatives. (The intersection-based comparison for the off-peak period has not been carried out) Moreover, the PASSER V-Band coordination is in the leading position. As we do for the peak hour, we also create an evaluation table to show a comparison among the alternatives based on Table 9. The evaluation result is shown in Table 10.

Table 11 tells about the situation of the nine intersections during the off-perk period before and after the PASSER V-Band Coordination. From this Table we can see that most intersections after coordination are operated under level of service C, which is more acceptable.

Based on the analysis, the conclusion can be drawn that the coordination made by PASSER is appropriate for the IOWA arterial either for the peak period or the off-perk period. The progression result for each situation is very good. The efficiency and attainability are satisfactory.

Conclusion and comment

The timing for the signalized arterial is a complicated process. Which of the timing plans produced by Synchro, TRANSYT and Synchro is most suitable for improving the IOWA arterial has been discussed in the paper. PASSER is the best alternative based on the overall evaluation of delay, stops, speed, fuel consumption and emission. This conclusion is only true for this specific case. For a different traffic situation, we may get different result.

Based on the study, some findings can be made:

1. Synchro is good at entering and transferring data, but can't read the data from other packages. It needs to be updated to tailor the requirement by NETSIM.

2. TRANSYT always gives longer cycle lengths which results in higher delay and fuel consumption, because it attempts to keep disutility index the lowest in the cycle length selection.

3. PASSER seems better to coordinate the intersections with unbalanced volume.

4. Coordination has its limits in the improvement of traffic condition when traffic volume reaches a certain level (see Table 7), but it is always better to use coordination than to go without from the view of whole system.

5. V-Band coordination by PASSER may be a good choice when the natural cycle length of the intersection along the arterial has a big difference, but it is not proved yet from this study.

6. NETSIM is very good at evaluating timing plans, but very hard in data entry and editing, unless you are well trained. Its output needs to be reorganized in order to be useful in practice.

It is recommended that steps be followed when doing the complete signal timing analysis for the arterial. (1) Enter data using Synchro. (2) Develop timing plans by TRANSYT, Synchro or PASSER. (3) Fine tuning the timing plans using Synchro. (4) Evaluate the timing plan by NETSIM. (5) Give the output of the timing plan by Synchro.

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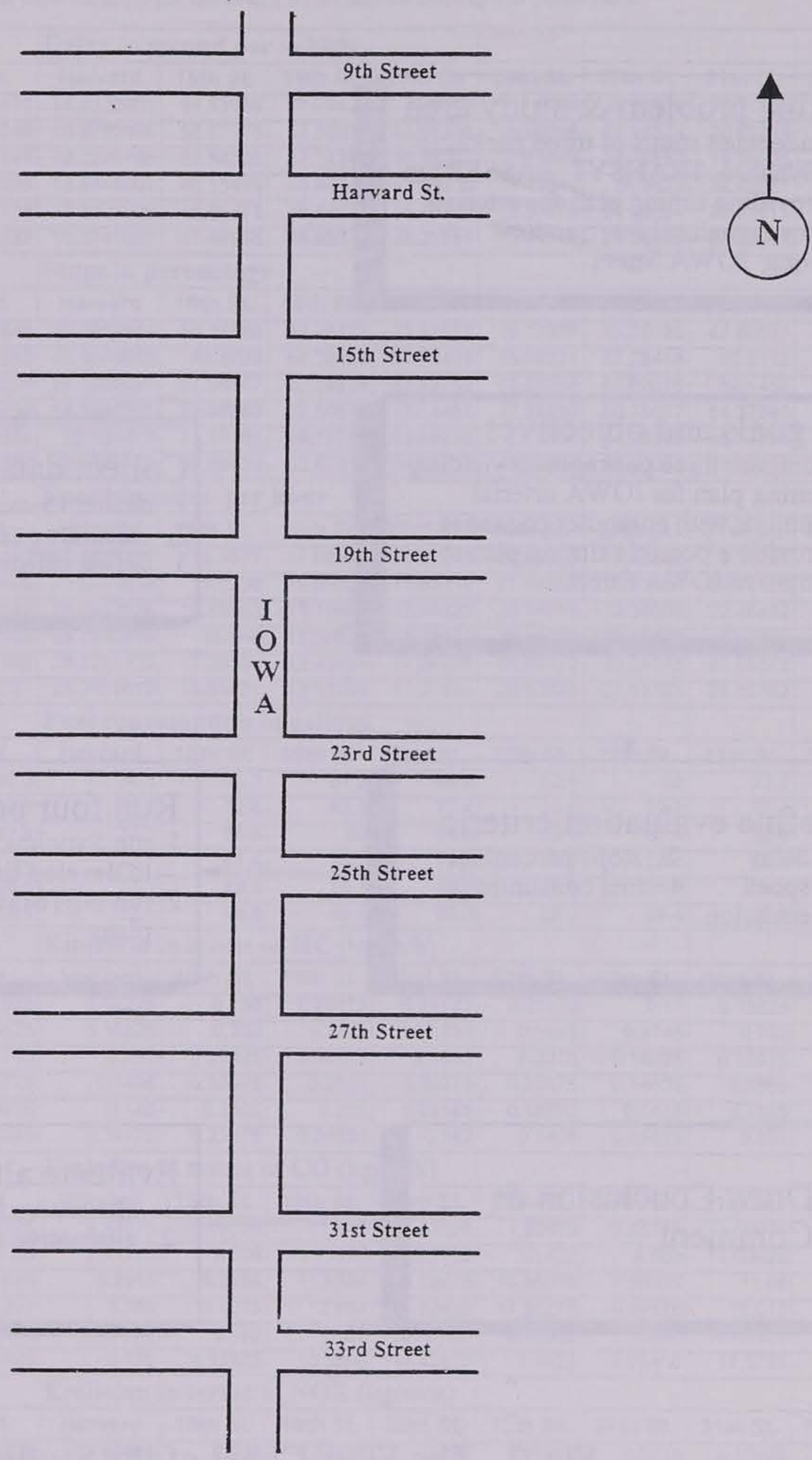

Fig. 1 The Sketch Map of the Study Area

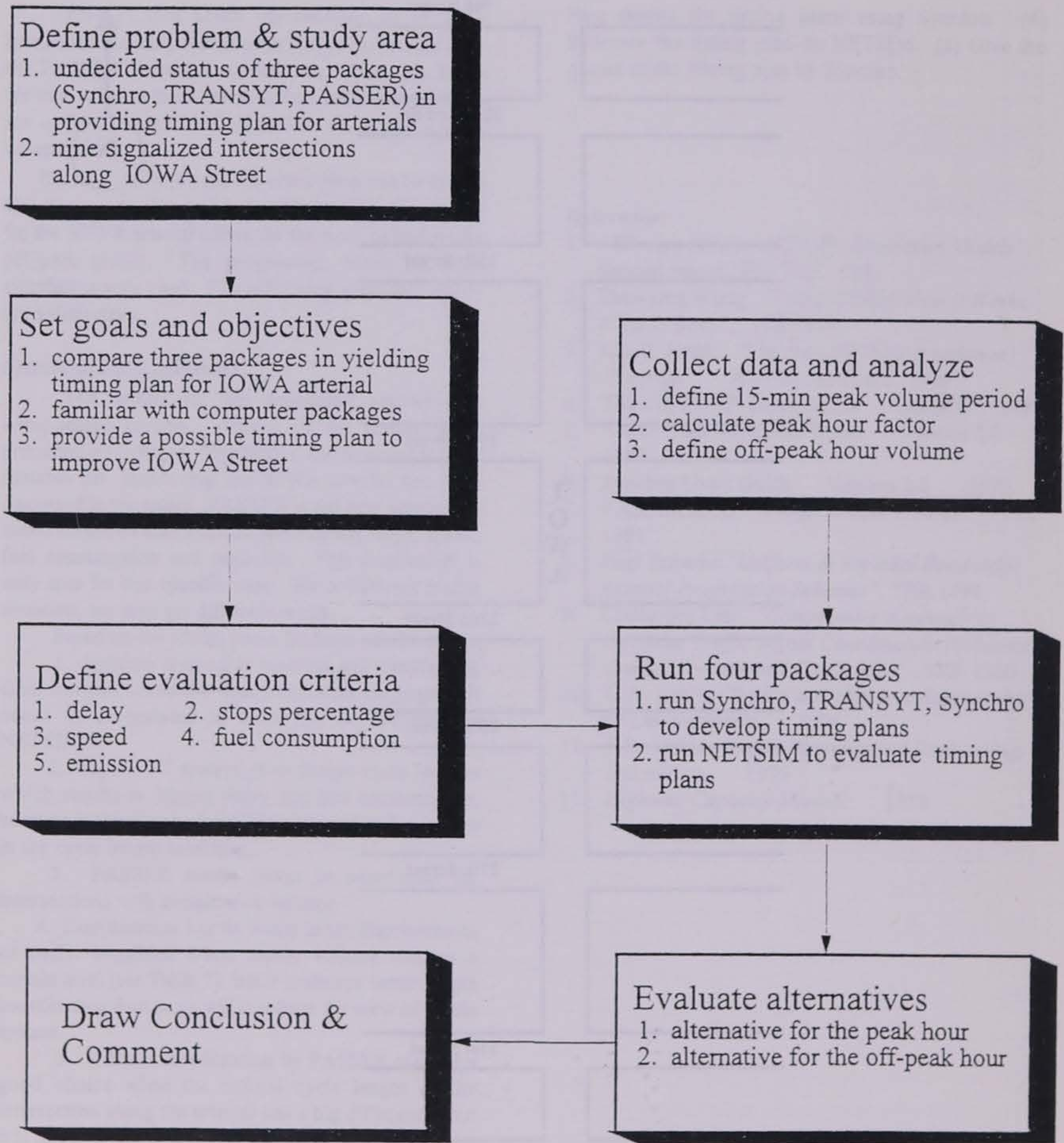

Fig. 2 The Flow Chart of the Study

Table 5. The MOE's of each intersection for different alternatives during the peak hour

	Delay in second per vehicle							
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	29.7176471	16.0332606	54.53938	47.78426	34.4009	15.6526	29.62205	27.74381	21.05087
Synchro individual	25.2700348	15.6760696	58.67978	35.56813	45.99336	18.90046	37.28374	20.62249	17.36527
Synchro coordination	21.8437245	12.2275708	50.54306	37.34949	43.86223	21.61089	28.76652	19.36326	15.88639
TRANSYT-7F	44.916628	13.5445501	46.15419	40.84144	47.89603	14.10311	25.8829	32.49081	25.92037
PASSER U-Band	27.646796	13.2375929	45.61471	26.84511	34.46774	12.53676	24.68124	23.94811	18.13462
PASSER V-Band	26.7201962	13.5141697	47.98968	36.83019	35.23351	13.09214	23.08545	21.92092	15.20834
	Stops in percentage								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	65.9607843	45.7852984	80.33528	82.26223	72.81658	·46.17306	65.39185	67.60831	56.70197
Synchro individual	68.6881533	42.9079043	83.8739	54.36585	64.79436	55.98321	67.78468	66.6112	65.00551
Synchro coordination	62.2942207	28.1892697	67.08877	50.99838	68.63759	52.60264	66.20976	62.1455	56.04752
TRANSYT-7F	65.8928158	14.3445501	72.36355	52.69673	77.4467	22.28939	50.78577	54.77886	49.06681
PASSER U-Band	56.3809524	23.191679	71.21185	49.10749	62.86275	23.3661	44.99049	46.34399	47.32633
PASSER V-Band	55.7749567	26.3188192	69.86839	53.67014	64.26771	45.19064	58.40068	57.09313	48.24492
	Speed in miles per hour								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	17.7319493	23.5898108	15.3577	17.65952	17.81645	23.66576	18.92646	19.11205	20.26168
Synchro individual	19.0165505	23.9478608	15.0235	19.88022	15.65219	21.90107	16.91464	21.81153	21.90529
Synchro coordination	20.4189142	25.8457526	16.55483	19.19681	15.94623	20.74712	19.09033	22.48432	22.854
TRANSYT-7F	14.4944959	25.7640819	16.946	18.33897	15.33297	26.26023	20.18806	17.3461	18.68543
PASSER U-Band	18.6627866	25.2291233	17.33604	22.43958	17.94369	26.66122	20.34045	20.05542	22.43131
PASSER V-Band	19.19221	25.2696679	16.61421	19.31008	17.97184	26.63629	21.13733	21.52762	23.41936
	Fuel consumption in gallons								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	40.3	34.3	72.7	67.2	68.2	32.5	32	33.3	21.2
Synchro individual	39.5	35.5	72.6	62.3	72.4	30.5	32.7	31.4	20.3
Synchro coordination	37.4	32.8	66.6	62	69.6	30.8	30.4	32.9	21.3
TRANSYT-7F	43	33.7	67.4	63.7	71.7	31.6	28.1	32.4	21
PASSER U-Band	38.6	32.3	66.8	58.1	63.9	28.3	26.9	30.8	19.8
PASSER V-Band	38.7	32.1	65.8	60.1	60.6	25.3	29.4	33.9	21
	Emission in terms of HC (kg/m/h)								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	0.1925	0.15225	0.258	0.25175	0.31125	0.21175	0.17	0.19825	0.149
Synchro individual	0.18825	0.15825	0.252	0.2505	0.335	0.1945	0.1745	0.192	0.15
Synchro coordination	0.1795	0.151	0.23825	0.24725	0.3255	0.2015	0.16025	0.19975	0.155
TRANSYT-7F	0.19775	0.1495	0.23875	0.2525	0.32275	0.20875	0.14625	0.1885	0.14475
PASSER U-Band	0.18075	0.145	0.2355	0.235	0.29125	0.18725	0.1415	0.1865	0.1395
PASSER V-Band	0.1855	0.14175	0.23475	0.23525	0.282	0.1405	0.15875	0.201	0.1555
	Emission in terms of CO (kg/m/h)								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	7.8775	6.80775	10.49125	11.848	14.53225	11.93975	8.65775	11.06975	8.63125
Synchro individual	7.86	7.11775	9.705	11.71675	15.2755	10.432	8.666	11.00425	8.82675
Synchro coordination	7.493	6.8995	9.2455	11.6385	14.79475	10.86075	7.98525	11.66	9.3735
TRANSYT-7F	7.261	6.764	9.4375	12.004	13.97625	11.93875	6.94575	10.012	8.10025
PASSER U-Band	7.2575	6.47125	9.483	11.37	13.16625	10.42525	6.888	10.43925	8.077
PASSER V-Band	7.42625	6.173	9.15525	10.9865	12.43575	7.4525	8.23425	11.5795	9.3075
	Emission in terms of NOX (kg/m/h)								
	9th St.	Harvard	15th St.	19th St.	23rd St.	25th St.	27th St.	31st St.	33rd St.
Do-nothing	0.53775	0.46625	0.739	0.75125	0.924	0.66975	0.5215	0.59925	0.45875
Synchro individual	0.52825	0.49775	0.71725	0.749	0.978	0.59875	0.52575	0.58875	0.45825
Synchro coordination	0.50575	0.46375	0.66425	0.72975	0.947	0.61625	0.493	0.61825	0.48525
TRANSYT-7F	0.51625	0.45275	0.677	0.74425	0.93275	0.65425	0.44375	0.56975	0.4365
PASSER U-Band	0.492	0.434	0.678	0.7065	0.844	0.57575	0.426	0.5735	0.43325
PASSER V-Band	0.5095	0.4245	0.66125	0.6985	0.7815	0.39975	0.4855	0.62275	0.476

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A Planning Model for City Maintenance in Lincoln

A Planning Model for City Maintenance in Lincoln

Optimization of Maintenance Services Based on Travel Cost

Yiming Li [1]

Abstract: A special linear programming model, called transportation model, is widely used in solving transportation related planning, engineering, and economical problems. The difficulties in applying such a model to real world problems often stem from identification of model parameters. This paper provides an application of the transportation model to a real world problem, namely, optimization of the operation of a city maintenance division based on minimization of service travel cost.

Introduction

The city of Lincoln has population about 200,000 now and is expanding at a relatively uniform rate of 1-2 percent per year. Associated with this rise of population is an increase of the demand for street maintenance services. Currently, the City Maintenance division performs five major services (street and highway, drainage, snow removal, sanitation, and traffic engineering) from its three facilities. The work loads are evenly distributed among the three facilities. To meet the challenge of growing demands based on current resources, we need to find out a cost-effective allocation of each service among the three facilities. Thus, the main objective of this research is to develop a model to identify the best facility locations for each service and to redeploy the supplies of each service among the three facilities in a cost-effective way.

Model Development

Model Background

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For the five major services provided by the city maintenance division, the cost of each service consists of three parts: salary, supplies, and service. The salary and supplies are generally fixed. The model is aimed at decreasing a major portion in the service cost, specifically the travel cost. Among the five major services, street and highway maintenance is the biggest. It takes one third of the man power and one third of the expenditure of the entire division. The expenditure breakdown for street and highway service is presented in Table 1.

Table 1. Expenditure of Street and Highway in 1994-1995

	Sub-item	subtotal	% of total
Personnel		1,569,315	58
Supplies		175,194	6
Equipment		11,313	1
Transfer to Snow Fund		552,102	20
Services (399,318)	Travel/Mileage	180,573	7
	Rentals	180,480	7
	Others	26,328	1
total		2,707,242	100

Source: 1996-1997 Annual Operating Budget, Mayor's office, City of Lincoln, 1996.

It can be found from Table 1 that the travel cost is about 45% (180,573/399,318) of the total service cost. Thus, to minimize the travel cost is important toward a cost-effective operation of the City maintenance division.

Linear Model Description

The primary goal of the model is to minimize the annual travel related cost of services supplied by the facilities. This problem may be described by a special linear programming model called the transportation model [2] presented as following.

$$Minimize\ z=\sum_{k=1}^{h}\sum_{i=1}^{m}\sum_{j=1}^{n}c_{ij}^{k}x_{ij}$$

where

z = total annual travel cost of all services considered, dollar.

k = a particular service such as sanitation, or street and highway.

i = location of a facility.

j = location of a demand destination.

m = number of facilities.

n = number of destinations.

c_{ij}^{k} = cost of transport of 1 unit of service k from facility i to destination j, dollar.

x_{ij} = amount of supplies for a service k transported from facility i to destination j, number.

Each service k subjects to following constraints

$$\sum_{j=1}^{n}x_{ij}=s_i \quad for \quad i=1,2,...,m$$

$$\sum_{i=1}^{n}x_{ij}=d_j \quad for \quad j=1,2,...,n$$

where

d_j = number of units of a service demanded at destination j.

s_i = number of units of service supplied from facility i.

Assuming the demands can always be met by the service supplied such that

$$\sum_{i=1}^{n} s_i = \sum_{j=1}^{n} d_j \quad for \quad x_{ij} \geq 0$$

Estimation of Model Parameters

1. Cost

The cost, c_{ij}^{k}, is the cost of transport of 1 unit of service k from facility i to destination j in dollar. It is a product of the travel rate of a service and the travel distance between a facility and a destination. The travel distance from a facility i to a destination j can be measured on a map of demands. The travel rate for each service (sanitation, street and highway, drainage, etc.) can be approximated based on the rental rate of equipment used per service. The rental rate is a composite rate (dollar/mile) of gas, parts, wear, and insurance cost for a piece of equipment. Although both concrete and asphalt work belongs to the street and highway service, different equipment is employed to perform the work. So one should study them separately. An example of how the travel rate can be estimated is shown in Table 2.

Table 2. Travel Rate (concrete)

Equipment	unit	Usage Frequency (% per service)	Dollar per mile
1 Ton GP Truck	1	100	0.412
2-1/2 Tone Doal	1	20	0.956
Pickup Truck	1	50	0.3
2-1/2 Dump Truck	1	40	0.992
14 YD Tandem Dump Truck	1	20	0.945
10 YD Tandem Dump Truck	1	20	0.576
Total Travel Cost			1.46

Note: The equipment listed in the table is the travel related equipment.

2. Supplies of a Service

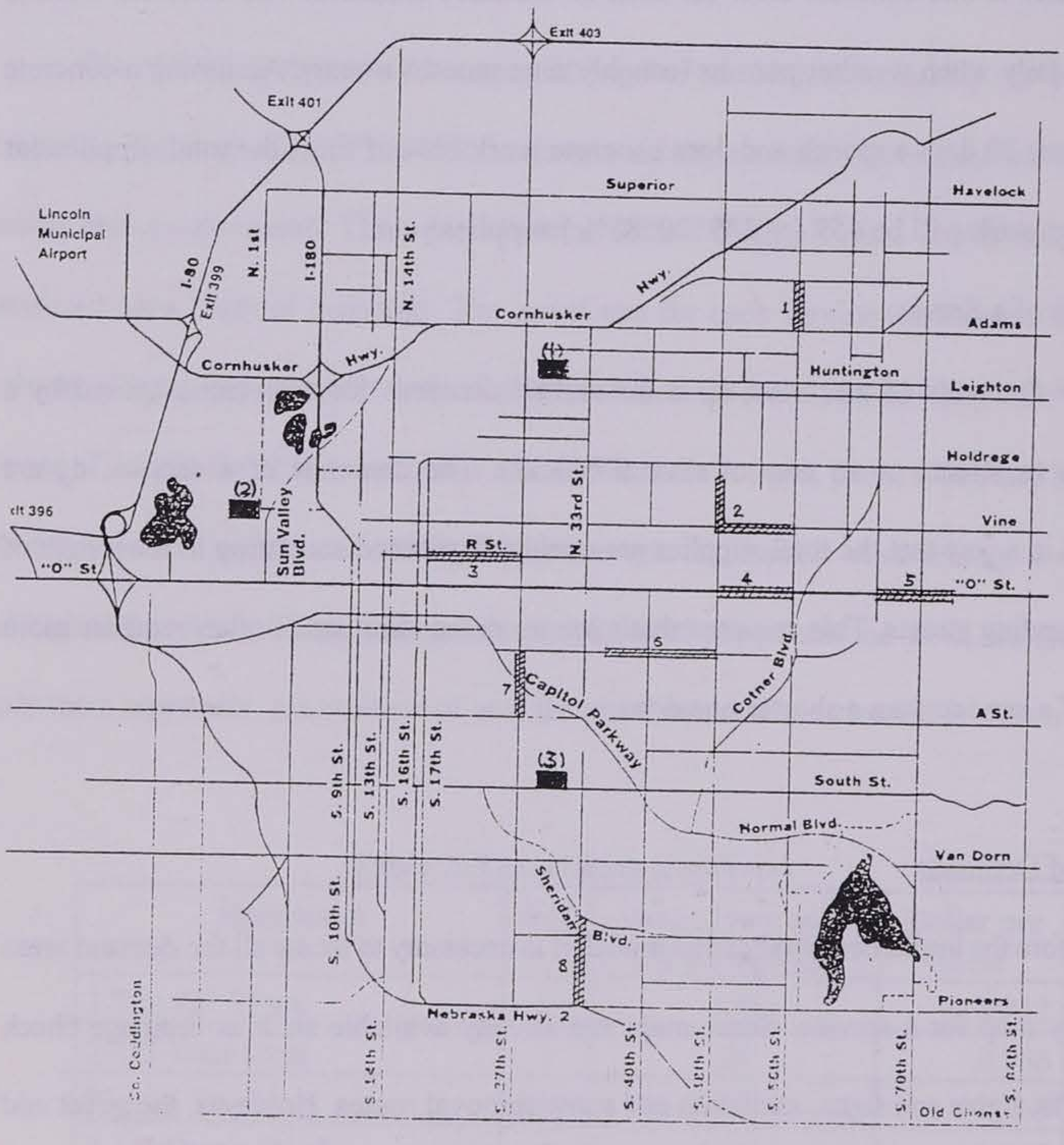
The supplies of service, s_i, are the annual capacity of a service provided by one facility. The total supplies of a service are the annual capacity for a service provided from all facilities. Following is an example of computing the total supplies for the concrete service. There is one concrete crew for each of the three facilities. The concrete work is performed daily when weather permits (roughly nine months a year). Assuming a concrete crew operates 20 days a month and does concrete work 85% of time, the total supplies for the concrete work will be 459 (= 3*9*20*85%) supplies/year.

3. Demands of a Service

The demands of a service, d_j, is the annual demands for a service required by a destination (a street or an area of several blocks). The demands of a service, d_j, are determined in a way that the total supplies are evenly distributed according to the length of those demanding streets. This assumes that a longer demanding street often requires more supplies of a service than a shorter one does.

<u>Mapping of Demands</u>

Before the implementation of this model, it is necessary to locate all the demand areas on the City map for a service. Some maps are already available such as drainage check points, traffic lights and signs, sanitation and snow removal routes. However, the street and highway maintenance map is unavailable. To plot all streets and highway maintenance work such as asphalt and concrete repairing work may not be realistic since the history of the street repairing location is not well documented in the City maintenance division. One approach of the problem is to use the street rating information provided by the street construction department to approximate the most likely street and highway maintenance demands. On the map one can exclude those worst rated streets that maybe beyond the maintenance division's responsibility to repair them. The likely demands of the concrete work are plotted in Figure 1.



Scale: 1" = 7000' facility demands

Figure 1. Demands of Concrete Work Using Street Rating Information

Preliminary Results

The model has been applied to the street and highway service covering asphalt and concrete activities. The round trip costs of the concrete work are presented in Table 3.

Table 3. Round Trip Cost (c_{ij}^k, dollar) of Concrete Service

facility \ demands	1	2	3	4	5	6	7	8	d_j number/year
1	6.0	5.8	7.2	9.0	12.5	8.7	7.5	13.2	153
2	16.2	10.1	5.7	12.8	16.3	12.6	11.5	17.0	153
3	15.9	9.9	7.4	8.6	12.1	5.5	2.6	4.0	153
s_i number/year	43	39	77	51	46	77	53	73	459

The Simplex method [3] has been used to solve the transportation model for all different combinations. The model results shown in Table 4 represent the optimum travel cost for the current situation (three facilities with one crew at each).

Table 4. Model Result for the Concrete Service(three facilities)

facility \ demands	1	2	3	4	5	6	7	8	d_j number/year
1	6.0	5.8	6 7.2	51 9.0	23 12.5	8.7	7.5	73 13.2	153
2	16.2	10.1	5.7	12.8	23 16.3	77 12.6	53 11.5	17.0	153
3	43 15.9	39 9.9	71 7.4	8.6	12.1	5.5	2.6	4.0	153
s_i number/year	43	39	77	51	46	77	53	73	459

In Table 4, data shown in the small font is the cost of travel and the data shown in the large font is the supplies of the concrete service. For instance, in row 1 and column 3 of Table 4, 6 represents supplies of the concrete work provided from the facility 1 to the demand area

3 with a round trip cost of 7.2 dollar per supply.

To find the best facilities, it's necessary to consider all possible combination of facilities and working crews. The model should run for all possible combination of facilities and crews to produce the annual travel cost. Then, the optimum combination of facilities and crews will be identified for the lowest travel cost. The model results for all those combinations are listed in Table 5.

Table 5. Model Results for the Concrete Service

facilities		1,2,3	1	2	3	1,2	1,2	1,3	1,3	2,3	2,3
# of crew at facilities 1,2,3	1 2 3	1 1 1	3 0 0	0 3 0	0 0 3	2 1 0	1 2 0	2 0 1	1 0 2	0 2 1	0 1 2
Annual cost, $		5303	4104	5752	3488	4992	5100	4703	4506	5864	5100

The model has also been applied to another street and highway service, namely, asphalt work. All different combinations of facilities and crews were considered for the asphalt work. The results are presented in Table 6.

Table 6. Model Results for the Asphalt Service

facilities		1,2,3	1	2	3	1,2	1,2	1,3	1,3	2,3	2,3
# of crew at facilities 1,2,3	1 2 3	1 1 1	3 0 0	0 3 0	0 0 3	2 1 0	1 2 0	2 0 1	1 0 2	0 2 1	0 1 2
Annual cost, $		13485	10165	13671	6529	12543	13834	12186	9628	13355	10857

Discussions

It can be found from both Table 5 and 6 that the facility 3 with all three crews will provide the lowest travel cost among all the facility and crew combinations. Comparing with the current three-facility combination, it almost saves travel cost 34% for the concrete service and 52% for the asphalt service. The concrete work and asphalt work are only two major activities within the street and highway service. More studies need to be done on other activities before we can draw a final conclusion. Also, when one studies the overall travel cost for all services, some constraints need to be added to represent the relations among those services since some services may share the same equipment. Although it should be cautious to interpret the model results right now, one can find the transportation model is very effective in providing some optimum solutions for saving travel cost.

The model discussed above may only shed some lights on one aspect of the maintenance problem. Although travel cost is one important part of the whole task, there are many more criteria influencing the best location and use of facilities. Such criteria may include customer satisfaction, management efficiency, the city's future expansion planning, etc. In future studies, the model will be extended to consider a whole set of criteria.

Acknowledgement

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The Use of Geographic Information Systems in the Iowa Department of Transportation's Office of Project Planning

ABSTRACT

Geographic information systems are computer applications which allow for the assembly and display of both spatial and non-spatial data. The Iowa Department of Transportation (DOT) Office of Project Planning (OPP) analyzes corridors for future DOT highway projects. GIS may enhance current OPP efforts through two means: accessing other GIS users' data and GIS spatial analysis methods. The use of GIS in through these two areas is applied to a current OPP project: improvement and widening of U.S. 61 from Burlington, IA to north of Mediapolis, IA. World Wide Web data resources supply data for the project and GIS methods are compared to current OPP practices. It is concluded that GIS serves as a valuable enhancement to current practices, but cannot replace them as a corridor analysis tool.

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INTRODUCTION

The Iowa Department of Transportation (DOT) Office of Project Planning (OPP) analyzes corridors for future DOT highway projects. The use of geographic information systems (GIS) may enhance their current work in two ways: first, through data sharing with other GIS users; and second, through the GIS's spatial analysis capabilities. This project seeks to evaluate the usefulness of GIS to project planning in these two areas using World Wide Web (WWW) resources in a desktop GIS environment.

OBJECTIVE

The objectives of this project are to download data sets from the WWW and to evaluate their usefulness to the duties of the Iowa DOT OPP.

HARDWARE RECOMMENDATIONS

The recommended system for running a desktop GIS is a Pentium P5 or P6 150MHz machine with 16Mb of RAM (32Mb preferred). It should have two gigabytes of disk space, an ethernet connection, WWW access, and run Windows 95 or NT. The cost for this would be approximately $4000.

A scanner or plotter may also be required, depending on the application. A flatbed color scanner (8.5" x 14" or larger) is recommended for applications involving scanning aerial photographs, graphics, or photos from field surveys. Approximate cost is $300. A HP 750C, E-size inkjet plotter with a minimum of 48 Mb of RAM is recommended for applications involving plotting large posters for public meetings. Approximate cost is $8000.

STATE OF THE PRACTICE

Other Transportation Agencies

Other transportation agencies have written papers on their use of GIS for corridor planning, environmental assessment, or preliminary design. These projects involved a significant investment in the creation of data through field surveys as well as the use of data from other sources. West Virginia DOT created basemaps for a project area from 1:1000 scale aerial photos. The thrust of their project was to improve the interaction between engineers and environmental scientists in the alternatives development stage using GIS. They concluded that GIS improved the design process.

> GIS enables a concurrent approach to preliminary alignment development and environmental investigation, that results in a shorter overall time requirement; facilitates alignment adjustments; provides for retrieval and dissemination of information; complies with various regulations, and produces analytical evaluation of impacts. And while many time-saving and cost-cutting techniques often sacrifice quality, the GIS improves quality. (1)

The British Columbia Ministry of Transportation and Highways used GIS with Computer Automated Drafting (CAD) and highway design software in their preliminary design and environmental assessment. They used aerial photos, Global Positioning Systems (GPS), and survey data to create basemaps. These basemaps were given to environmental consultants who marked their findings on the maps. Later, these findings were recorded in the database. They summarized the following.

> GIS has demonstrated its power as a tool in support of corridor selection, environmental impact analysis, public information sessions, notification requirements, and engineering design. (2)

These projects involved an investment of time and money in the collection of data beyond the scope of this project. The maps created by these projects are at a much smaller scale than those available to the public through the WWW. Nevertheless, these projects show the usefulness of GIS to project planning.

Iowa Dot Office Of Project Planning

The responsibility of the Iowa DOT OPP is to develop alignments for highway projects and to assess their impacts on the environment. Currently, once an alignment is developed, the OPP seeks evaluation of the alignment from various government authorities (federal, state, county, and municipal). These evaluations consist of notifying OPP of other conflicts along the alignment, including underground storage tanks, wetlands, flood plains, or possible habitats of endangered species. In some cases, the OPP may need to change the route of the project, while in other cases, the OPP may address the conflict areas by mitigating the damages.

ADVANTAGES OF WWW GIS DATA

Data Sharing

The amount of geospatial data available to the public has increased dramatically in recent years. The U.S. Department of Interior established the Federal Geographic Data Committee (FGDC) in part "to coordinate spatial data activities of federal agencies" which includes "providing wider access to geospatial data." (3) With federal leadership and coordination, the amount and quality of geospatial data available will only improve. The WWW is the medium of choice for distributing geospatial data. According to the Iowa Department of Natural Resources (DNR), "The Web is an exciting new way to deliver GIS information services." (4)

Using other agencies' data available on the WWW can save time, mistakes, and money. Other agencies have labored to collect and maintain data and most are willing to share it to prevent an overlap of effort by other agencies. Most of the data available to download must pass certain standards and must include documentation (metadata). Use of quality data leads to fewer mistakes attributable to errors in the data, while quality metadata leads to fewer mistakes based on a misinterpretation of the data. WWW download sites are free and look to remain so for the near future.

Specifically for the OPP, the use of shared data offers an advantage in the ability to assess a wider database of corridor restraints without leaving the office. This leads to more efficient route planning. Better information obtained in the beginning, will decrease the chance for changing alignments later in the project when corrections are more expensive.

GIS Analysis

A GIS offers several benefits to project planning. One is the simple advantage of spatial display. In the task of locating objects in relation to one another, a map leads to better comprehension than a list of locations. Another benefit of GIS is the ability to overlay multiple layers. This allows the user to see a truer picture of the difficulties present in the field. While a layer of topography may suggest one location for a route, adding the floodplains may lead to a different location. Figure 1 shows an example of spatial display and overlaying with GIS.

A third benefit of GIS is its analytic capabilities. A user can not only visually investigate a data set, but can quantitatively analyze it. One example of a GIS's quantitative analysis is the ability to perform queries like a common database (e.g., finding all of the cities with a population greater than 5,000). Another example of quantitative analysis is a GIS's ability to perform spatial analysis (e.g., finding all of the public wells in Des Moines County). A GIS can also create buffers around objects. Figure 2 contains an example of buffering coupled with spatial analysis to find the underground storage tanks within 100m of a proposed route.

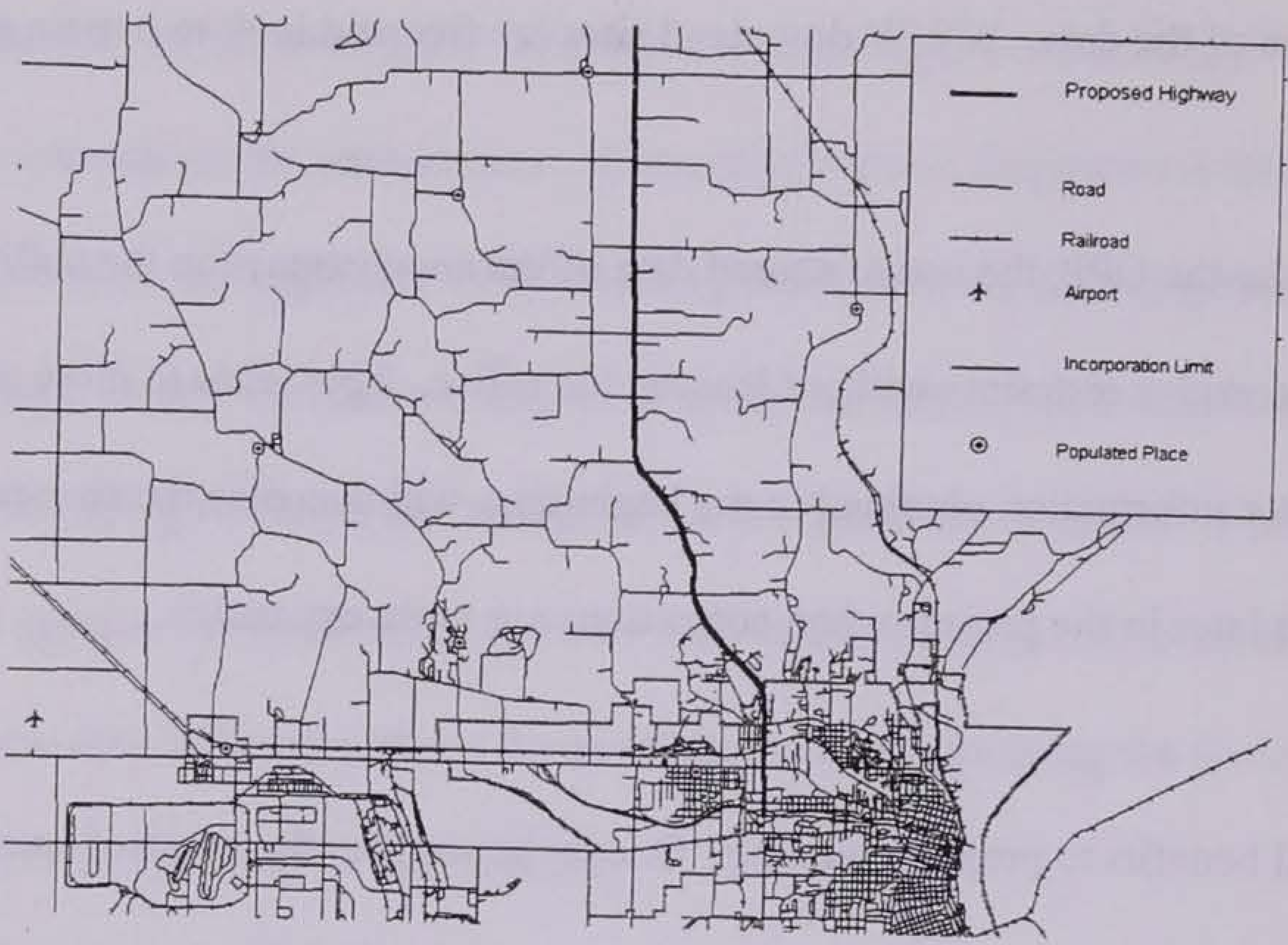

FIGURE 1. Spatial Display and Overlaying of Cultural Features Around a Proposed Route.

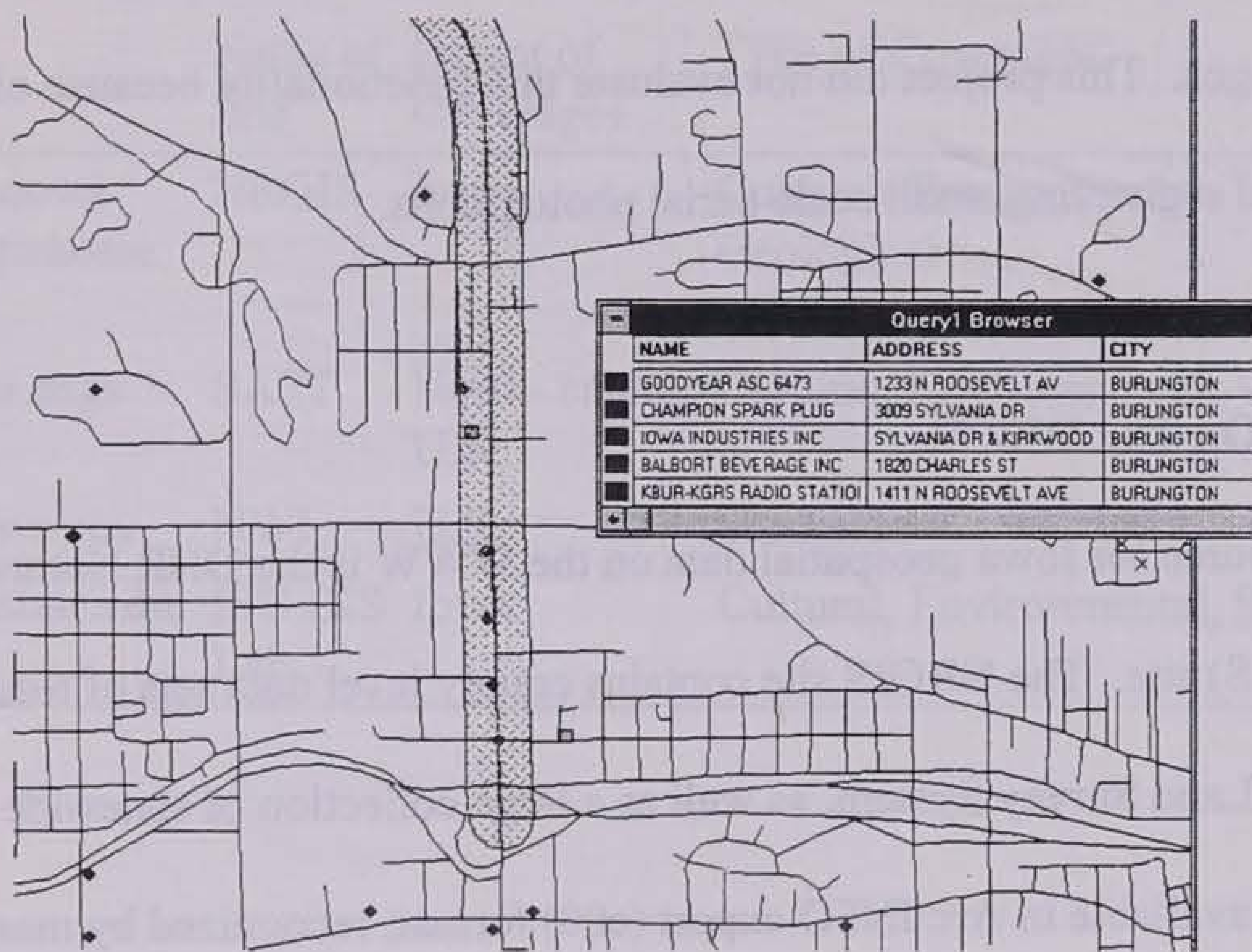

FIGURE 2. Buffering and Spatial Analysis Identifying Underground Storage Tanks within 100m of Proposed Route.

Another capability of GIS is the ability to underlay images. These could be aerial photos or satellite images. This project did not evaluate this functionality because of the time involved in scanning and registering small scale aerial photographs.

FINDINGS

GIS Sources On The WWW

The primary source for Iowa geospatial data on the WWW is the DNR Natural Resources GIS Library (NRGIS) site. The NRGIS site contains county level data sets of roads, rivers, topology, and the Public Land Survey System, as well as a large collection of statewide data sets. The NRGIS data is available in Arc/INFO export (e00) format, recognized by many GIS packages (MapInfo, AtlasGIS, ArcView, and Maptitude all offer utility programs that will import e00 files). Another WWW site offering geospatial data for Iowa is the Scientific Assessment and Strategy Team (SAST) homepage. This site contains a variety of geospatial data for the north central region of the U.S. collected for the scientific community after the floods of 1993. This data is available in Spatial Data Transfer Standard (SDTS) format. SDTS is a standardized geospatial data format supported by the federal government. Many agencies are already using SDTS as their transfer format. Iowa DNR has said that they plan to move to SDTS in the future. Currently, import functions only exist for more sophisticated GIS packages, but that is expected to change as the demand for SDTS translators increases. The National Wetlands Inventory (NWI) is distributed in Digital Line Graph (DLG) format from the NWI homepage. Iowa State University's (ISU) GIS Lab also has a large collection of geospatial data available from its WWW site. These sites have some overlap of data sets, but each also offers a few unique data sets. Table 1 is a summary of these WWW sites. Other WWW sites exist which contain

TABLE 1 Summary of WWW Geospatial Data Sites

WWW Address	Name of Site	Extent of Coverages	Type of Coverages	Data Format
http://www.igsb.uiowa.edu/htmls/nrgis/gishome.html	NRGIS	Iowa	Cultural, Environmental, Geological	e00
http://edswww2.cr.usgs.gov	SAST	North- central U.S.	Cultural, Environmental, Wildlife	SDTS
http://www.nwi.fws.gov	NWI	U.S.	Wetlands	DLG
http://www.gis.iastate.edu	ISU GIS Lab	Iowa	Cultural, Environmental, Soil,	e00

descriptions of geospatial data, but the data is not available for download and must be ordered through the mail. These include the State Soil Survey (STATSGO) and Soil Survey (SSURGO) data bases and the US Forest Service land boundaries.

Two particular issues arise in using shared data. First, as each GIS package has its own data format, the format of data on the WWW varies. This presents complications in translating data to a specific GIS application. The data may need to be imported to one GIS and then exported in a different format which can be read by the second GIS. Second, the scale at which the data was originally collected varies. While some data sets were originally 1:24,000 scale, others were 1:250,000, and still others are of unknown scale. The user needs to understand that the relationship of one dataset to the other on the computer screen may not be exactly the relationship found in the field.

Comparison Of GIS And Traditional Methods: U.S. 61 Planning Study

OPP identified a pilot project area in southeastern Iowa. The project is a realignment and widening of U.S. 61 from Burlington to the junction with Iowa 78 near Mediapolis. The project used MapInfo as the primary GIS. MapInfo is one of the top three GIS in sales and is one which ISU's Center for Transportation Research and Education (CTRE) personnel are familiar with.

Data Collection

The WWW sites utilized in the pilot project were the NRGIS, SAST, and NWI sites. The process of collecting the NRGIS data consisted of downloading, uncompressing, and translating each of 30 data sets into MapInfo. The time involved in processing a single data set varied from 5 to 30 minutes depending upon file size and Internet speed. Table 2 contains a list of the NRGIS data sets used for the pilot.

TABLE 2 NRGIS Data Sets Used in Pilot Project

Data Set Name	Description	Scale / Accuracy
PLSS29, PLSS58	Township, range, and section for each county	24,000 / 22m
Rivers29, Rivers58	Rivers for each county	100,000 / 52m
Roads29, Roads58	Roads for each county	100,000 / 52m
Topo29, Topo58	Topography at 10m intervals for each county	100,000 / 52m
Airports	Airports	NA
IABG	Block Groups	100,000 / 52m
DNRLands	Lands owned or maintained by the Iowa DNR	NA
Highway	Major Highways	100,000 / 52m
Incorp	Boundaries of incorporated Cities and Towns	100,000 / 50-100m
Places	All populated places	NA / 100-150m
Abandond	Pre 1989 registered, plugged wells	NA / 275m
Abwell91	1989-91 registered, plugged wells	NA / 275m
Luse	Land use from 1975-84	NA
Muniwu	Wells and intakes for cities with pop. > 25,000	100,000 / 220m
Privwell	Registered private wells since 1987	NA / 140-570m
Ustsites	Permitted underground storage tanks	NA
Wateru	Wells and intakes with rate > 25,000 gpd	NA / 1140m
Wwtp	Waste water treatment plants	NA / 1100m
Brgeo500	Bedrock geology - 1969	500,000 / 1100m
Brtopo	Bedrock topography	100,000/ 100-3200m
Basin100	Drainage basins	100,000 / 235m
Lakes92	Lakes	24-100,000 / 210m
Landform	Landform regions	1,000,000 / 2000m
River500	Major rivers	500,000 / 570m
Sinkhole	Sinkhole Locations	200,000 / 500m

The process of collecting a single SAST data set involved finding the USGS 100,000 reference quad, downloading, uncompressing, translating into Arc/INFO, exporting in e00 format, and importing the file to MapInfo. Arc/INFO is a more sophisticated GIS package and one for which an SAST translator already exists. Arc/INFO can then export the file in e00 format, which MapInfo can import. The time involved varied from 20-40 minutes per data set, again depending on file size and Internet speed. Table 3 contains a list of the SAST data sets used for the pilot. One drawback to the SAST datasets is that metadata is not available and thus the scale and accuracy are unknown.

The process of collecting the NWI data involved downloading, uncompressing, translating into Arc/INFO, exporting in e00 format, and importing each data set to MapInfo. This process varied from 20-40 minutes. The NWI data is 1:24,000 scale, but the positional accuracy is not available.

Corridor Conflicts Identified with GIS and Downloaded Data Sets

The buffering and spatial querying of the GIS led to the identification of objects from the downloaded data sets within 100m of the project. Identification of the following areas took approximately 3 hours with GIS. It is important to note the accuracy of the data set when analyzing a query. A more thorough analysis might include buffering at different radii to account for varying levels of accuracy. For instance, the sinkhole coverage is accurate within 500m, so a 500m buffer could be used to make sure that no sinkholes are located near the project. The NWI is accurate within 50m, so a 50m buffer would suffice.

TABLE 3 SAST Data Sets Used in Pilot Project

Data Set Name	Description	Scale / Accuracy
Fldpln	Floodplains	NA
NPL	Environmental Protection Agency's (EPA) National Priority List (Superfund) sites	NA
TRI	EPA's Toxic Release Inventory Locations	NA
Rail	Railroads	100,000 / NA
Birds	Bird habitats	NA
Mussel	Mussel locations	NA
Wildlife	Wildlife habitats	NA

Landuse The route passes almost entirely through agricultural land with a small area of forested land a few miles north of Burlington. Starr Cave State Preserve is located near the Beginning of Project (BOP) in Burlington. The route also passes through Newport, an unincorporated town.

Topography The route begins at about 200m. It crosses the Flint Creek valley and rises to 220m. The route is somewhat level the rest of the way aside from crossing the Smith Creek valley. It also crosses three intermittent streams: Paul Creek, Hawkeye Creek, and Yellow Spring Creek.

Sinkholes There are several sinkholes located near the BOP in Burlington.

Underground Storage Tanks One registered underground storage tank is within the 100m buffer. It is registered to Mediapolis School Bus Garage, Blaine Street, Mediapolis.

Railroads The route crosses three railroads. One is located south of Mediapolis, the other two are north of Mediapolis.

Wetlands The following wetlands are identified in the National Wetlands Inventory. The following list includes township, range, section number, the number and type of wetland and approximate acreages. The five letter identification code is identified below the listing. The listed acreage are for the entire wetland, not just the area intersected by the GIS buffer zone.

T73N,R03W, Section 22, one PUBGh ~.8 acres

T72N,R03W, Section 2,3, five PUBGh total ~3.9acres

T72N,R03W, Section 3, one PEMC ~<1/4 acre

T70N,R03W, Section 11, three PUBGh ~1.8 acres

T70N,R03W, Section 14, two PUBGh ~2.6 acres

T70N,R03W, Section 24, three PEMC ~1.1 acres

T70N,R03W, Section 24, one PUBGh ~0.9 acres

T70N,R03W, Section 24, one PFO1C ~7.1 acres

T70N,R03W, Section 24, one PSS1A ~1.1 acres

PUBGh - Palustrine, Unconsolidated Bottom, Intermittently Exposed, Diked/Impounded.

PEMC - Palustrine, Emergent, Seasonally Flooded.

PFO1C - Palustrine, Forested, Broad-Leaved Deciduous, Seasonally Flooded.

PSS1A - Palustrine, Scrub-Shrub, Broad-Leaved Deciduous, Temporarily Flooded.

Corridor Conflicts Identified Through OPP's Interagency Correspondence

The following agencies identified potential conflicts with the route in response to OPP correspondence.

Federal Emergency Management Agency (FEMA) FEMA identified that Des Moines and Louisa counties participate in the National Flood Insurance Program. As participators in this program, the Iowa DOT must obtain permits before building in a delineated flood plain.

Des Moines County Engineer The Des Moines County engineer identified two potential hazardous waste sites. One is an abandoned gas station and the other is an abandoned road house which may have sold gasoline. The locations were circled on an enclosed paper map.

Iowa DNR The Iowa DNR identified that the project may intersect habitats which contain protected species or rare natural communities. They made recommendations to minimize disturbance to these habitats.

U.S. Army Corps of Engineers The U.S. Army Corps of Engineers stated that wetlands should be avoided. Any wetlands that will be filled or dredged will need to be mitigated. Also, floodplain issues will need to be assessed when more detailed plans are available.

U.S. Fish and Wildlife Service The U.S. Fish and Wildlife Service identified federal endangered and threatened species that may reside in the project area. They included descriptions of likely habitats.

Comparison of GIS and Traditional Methods

The traditional research method of interagency correspondence has several benefits which GIS cannot match. The correspondence with local authorities revealed two possible unregistered underground storage tanks. This reveals that GIS cannot replace a local pool of knowledge. Interagency correspondence also gives planners and engineers the assurance that other agencies give their approval of the project.

GIS has benefits which traditional methods cannot match. It produces quantifiable results, letting the user know specific conflicts. Feedback is relatively fast, so some problems are discovered quicker. GIS will not replace the traditional methods of interagency correspondence, but serves as an enhancement to it.

CONCLUSION

GIS coverages downloaded from the WWW are useful to Iowa DOT's OPP. They allow for the sharing of geospatial data between agencies. GIS allows for the spatial analysis of these datasets. When used to analyze a specific route alignment, GIS can identify objects located near the project. This identification does not replace the interaction with other agencies currently taking place in the OPP, but serves to enhance it.

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Estimating the Value of Commercial Vehicle Time: An Assessment of Methods

INTRODUCTION

Economics is, by definition, the decisions involved in the allocation of scarce resources that have alternative uses.*(1)* Time is undeniably a scarce resource that has alternative uses, yet it is difficult to assign time an economic value. Nonetheless, in any transportation economic analysis it is imperative that the economic value of time be determined. A majority of the benefits derived from highway improvements or other types of transportation infrastructure modifications are assignable to time savings. In some cases, upwards of 70 to 80 percent of the total benefits are derived from time savings.*(2)* Without these benefits, many highway improvements would not be cost effective and, therefore, it would be difficult to justify their construction.

While there has been substantial review of the value of travel time savings (VTTS) to automotive drivers and transit users, very little has been done on the analysis of the value of commercial vehicle time savings.*(3)* In the past, there has been debate about the value of time savings to private users during non-work time but little question that time savings to commercial vehicles has an economic value. There are three recognized methods for calculating the value of commercial vehicle time savings (VCVTS). This paper will explain the economic principles used in developing the value of travel time savings and examine the three methods available in determining VCVTS.

OBJECTIVES

The objectives of this paper are to provide an overview of the theory and problems in estimating VTTS and to provide an understanding of the principles in estimating VCVTS. The first section of the paper will explore certain general issues in determining VTTS that are also applicable to VCVTS such as aggregate value of time and the differences between working and non-working time. The purpose of this section is to acquaint the reader with the idea of time savings in general and to provide a background for discussions in subsequent sections. Second, this paper will explore actual methods for determining VCVTS. This section will also identify issues in the application of the values of time savings to economic analysis. Finally, a summary of all identified methods will be offered.

VALUE OF TRAVEL TIME SAVINGS

Introduction

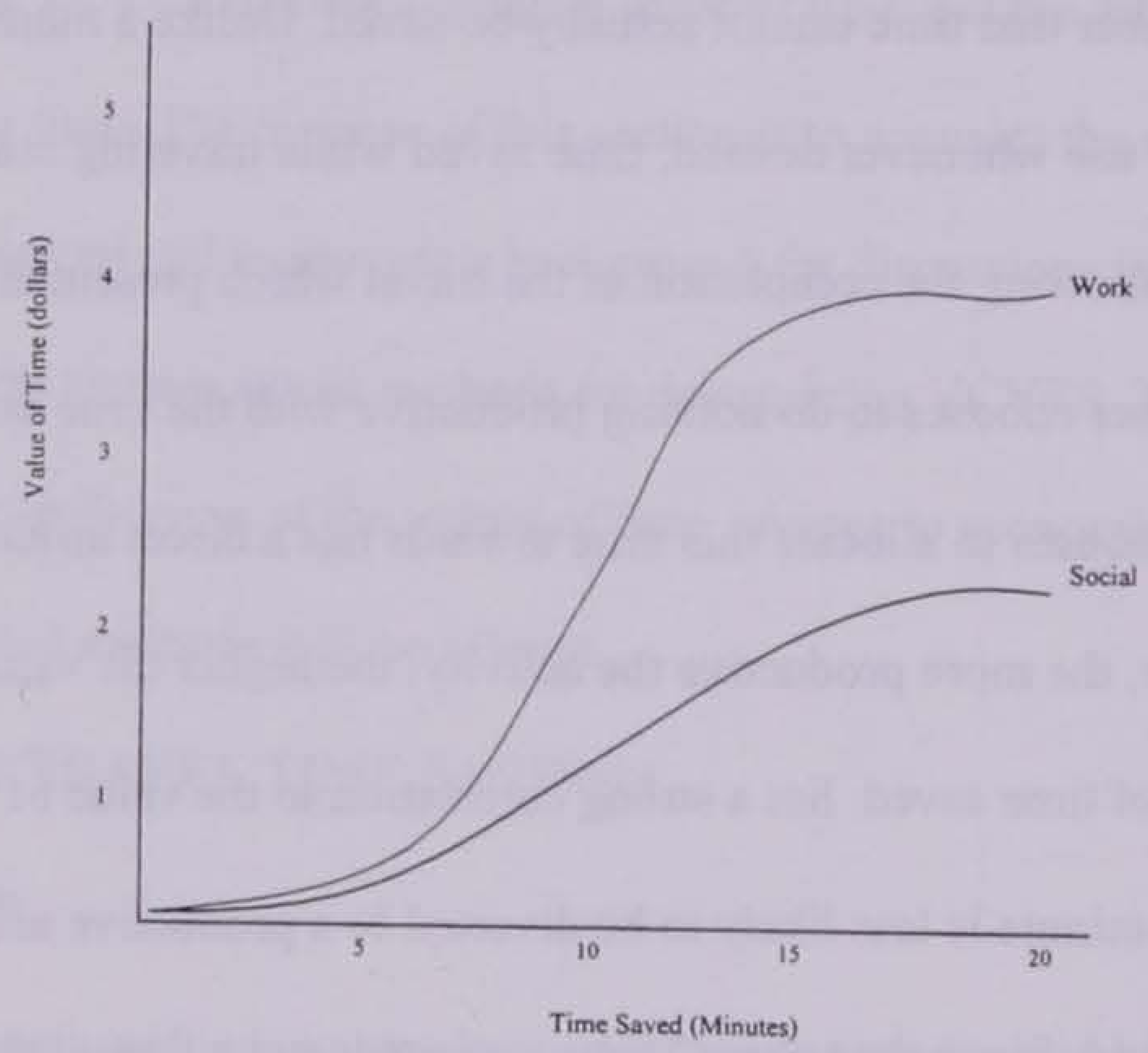
In any developed country, most people can travel to any place they desire using the existing transportation network. Any improvement to the network is, in most cases, not providing any new access that did not exist before. Typically when improvements are made to the transportation network, this results in a reduction in travel time somewhere on the network. This reduction of travel time has an economic value to the user and in some cases to society in general. Obviously, this value of time is influenced by a large number of factors. For example, if the time saved was a reduction in commuting time, it may have a higher value than if the user was simply shopping. In addition, the transportation system user's income or the mode of travel will impact the value of time saved. Regardless of the difficulties, most governmental transportation authorities try to estimate the value of this time savings since it is fundamental in any benefit-cost analysis of transportation improvements. Errors in estimating the value of this time can lead to misallocation of transportation resources.

Concepts In Estimating Travel Time Savings

It is important to remember that time cannot actually be saved. Unlike a monetary benefit, which the user could choose to use whenever desired, time saved while traveling must be used on another activity sometime following the completion of the travel which presented the savings. This time savings, even if the user chooses to do nothing productive with the time savings, must be used. The activity the user chooses to allocate this time towards has a direct influence on determining its value. Naturally, the more productive the activity, the higher the value of time.

Obviously, the amount of time saved has a strong correlation to the value of time savings. A time savings of one minute is less likely to be diverted to a productive activity as a time savings of six minutes would. Since the value of time savings is not a linear relationship, it does not necessarily follow that if one minute of savings is worth $0.60 then three minutes of savings is worth $1.80. Figure 1, taken from the American Association of State Highway and Transportation Officials (AASHTO) publication entitled *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (4)*, conveys this principal. The value of time savings is shown to have relatively low value until total travel time savings accrued is more than five minutes. After the total time savings is more than five minutes, the value of time increases. Also, note that time saved during working hours has a higher value than time saved during social hours.

FIGURE 1
The Value of Travel Time Savings (1977 values) *(4)*



When dealing with VTTS for non-commercial vehicles, there are generally two classes into which travel time savings are divided, non-working and working time. Non-working travel time could further be divided into commuter and leisure time. Time savings during working time are similar to time savings for commercial savings because they occur during working hours. Since the activity is economically more productive, working time savings would typically have higher values than commuter time savings, and in turn higher values than leisure time savings. This is typically reflected in assessments of travel time, though some will not make the additional distinction between non-working time.

Interestingly, when dealing with commuter time savings, there are theories which suggest that people have a fixed supply of time which they are willing to donate to commuting. *(1)* This ultimately implies that improvements which result in a reduction of commuter travel time will result in people relocating further away over time and returning their travel time to the previous level. This theory is supported by empirical evidence from a Multinational Project study *(1)*. The study yielded evidence that workers in countries with more efficient travel means spent nearly the same amount of time commuting as those in countries without faster modes of transport. *(1)*

Time savings accrued to road users through a reduction of travel time can be attributed to improvements in the transportation network. The National Highway Cooperative Research Program Report 33 *(5)* cited the followings causes of time savings:

- Improved running speed
- Shortened traveling distance
- Higher speed limits
- Improvements in equipment
- Off-peak scheduling of travel movements

These improvements, in addition to time savings, could result in lower vehicle operating costs such as fuel, tires and other fixed costs. These costs savings are not included in the value of travel time savings.

VALUE OF COMMERCIAL VEHICLE TIME SAVED

Introduction

Commercial vehicles are major users of the highway network. In some cases almost 10% of the traffic volume consists of commercial vehicles. *(3)* Some 1.2 million tractor units, 3.7 million commercial trailer units and 36.5 million light duty trucks utilize the United States highway system. *(6)* Besides the number of commercial vehicles on the highway network, commercial vehicles spend more *time* on the network. Commercial vehicles may be present on the network anywhere from six to twelve hours a day while commuter traffic may only be present two and a half to three hours a day (this is the time of peak commuter flows rather than individual travel times). *(7)* Since commercial vehicles utilize the highway network for longer periods of time, reductions in travel time have a greater potential for being diverted to productive uses and have a greater economic value. While there are ambiguities in the calculation of an appropriate VTTS for non-commercial vehicles, the methods for the determination of VCVTS are relatively clear. Since most commercial vehicle time savings occur by definition during working hours there is less confusion about the value of time savings. There are, however, still differing opinions about the best method for calculating VCVTS. In general, VCVTS consists of the value of time savings for the driver, the vehicle and the cargo. In research, VCVTS is typically calculated for differing sizes of commercial vehicles and differing types of carrier. The size of vehicle is usually classified by number of axles and the type of carrier is classified by what types of goods are transported. Typical types of carriers include bulk commodity and general/dry freight.

Because of the differing methods and assumptions involved in calculating VCVTS, it is possible to obtain a range of values. Table 1 presents values of recent numbers for VCVTS. Notice that while there are different axle configurations, most agencies only have values for one or two classes of truck. In addition, notice the variation in the value of the time savings.

TABLE 1
Value of Commercial Vehicle Time Savings
In 1993 U.S. dollars per hour *(3)*

Region	2 Axle	3 Axle	4 Axle	5 Axle	6 Axle
AASHTO (1977)	15.72	15.72	17.97	17.97	17.97
Highway Economic Requirement Systems	23.37	26.71	29.69	29.86	29.86
California	16.22	16.22	16.22	16.22	16.22
Florida	13.63	13.63	17.01	17.01	18.89
New York	15.78	15.78	15.78	15.78	15.78
Alberta	19.86	19.86	19.86	19.86	19.86
Quebec	11.92	11.92	12.87	12.87	12.87
Ontario	31.60	31.60	31.60	31.60	31.60

Analysis Of Different Methodologies

Net Operating Profit Method

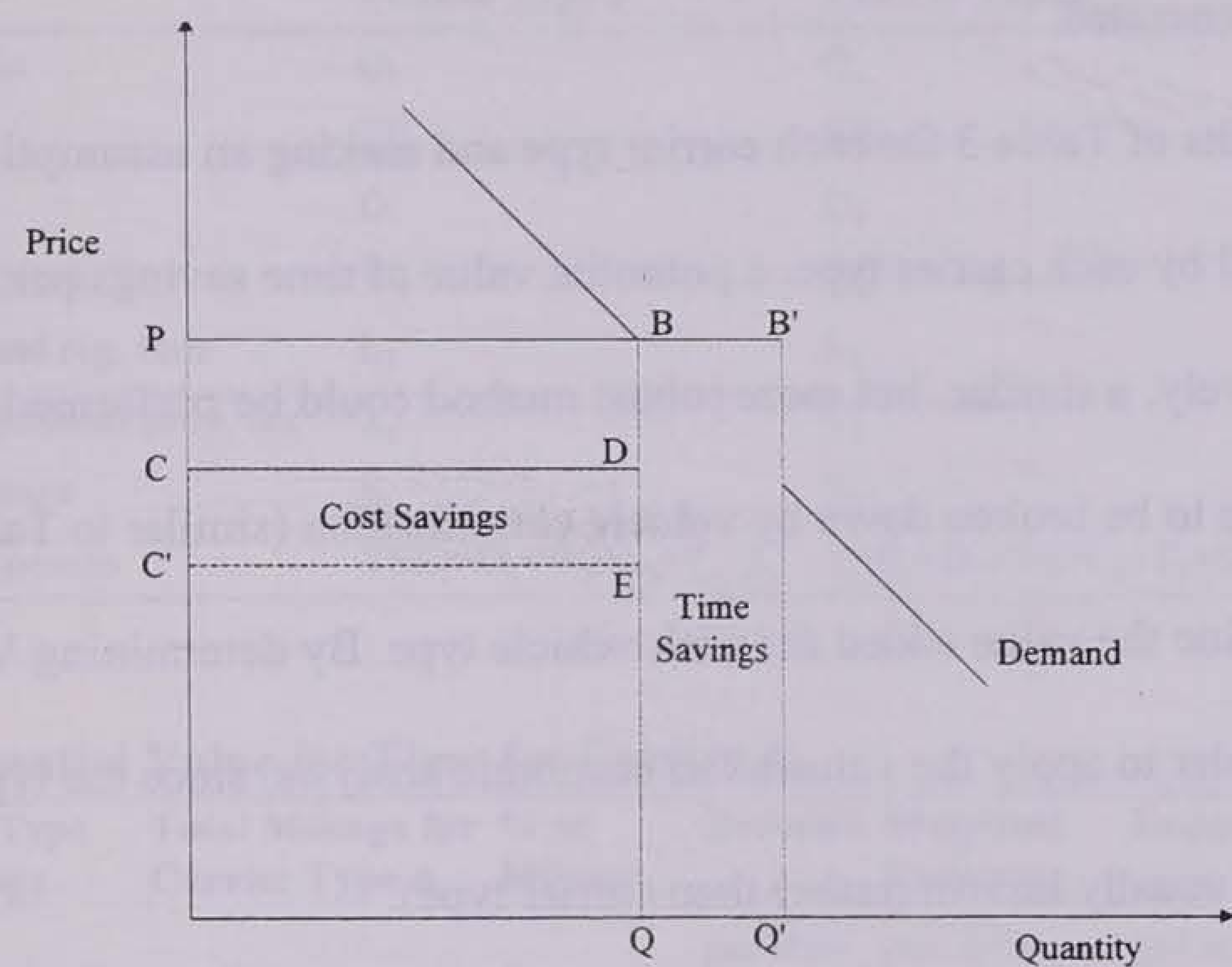
The net operating profit (revenue) method is based on the assumption that resources freed by the time savings are used to supply additional output. *(3)* In the revenue method, it is assumed that one hour of time savings will result in one additional hour of operation with no increase in certain expenses plus one additional hour of net operating profit. The value of time is calculated as the difference between the incremental gross revenue and the incremental expenses The savings is then equal to the selected expenses (described later) plus the average net profit per unit. *(8)*

The following items are used to calculate the selected expenses for use in the valuation of time in the revenue method: 1. drivers' wages; 2. workmen's compensation; 3. Social Security tax; 4. license and registration fees; and 5. real estate and personal property tax.

Drivers' wages are included in the determination of VCVTS because drivers' hours are variable during normal operation. Workers' compensation and Social Security tax are included because they are a function of drivers' wages. License and registration fees are included because the additional revenue miles would be operated with the same number of vehicles and hence there would be no increase in these costs while operating during the time savings period. Real estate and personal property tax are included because "a portion of the personal property which is taxable is related to and kept for facilitation of the line haul operation, even though line haul equipment is not classed as personal property in most states." *(8)* The drivers' wage is the dominant variable in the revenue method. A significant amount of the value of time savings is derived from this factor.

The revenue method can be explained in theory by examining Figure 2. In the figure, P is the existing price paid by the consumer and C is the cost to the commercial vehicle operator before the time savings. Time savings reduce the cost to C' and the total cost savings is the area C-D-E-C'. This cost savings is assumed to produce an increase in output, Q-Q' at price P. The value of time savings is then B-B'-Q'-Q. This assumes that the demand is elastic, and that the market can absorb the increased output. *(3)*

FIGURE 2
Revenue Method



A typical example of the methodology is documented below (following Hanning) *(8)*. Data is collected by carrier type and by vehicle type. The information required of each carrier type on a per mile and vehicle type basis is shown in Table 2. Using this data, a potential value of time saved per mile can be determined. The required calculations are demonstrated in Table 3. Information is required on the number of vehicle miles traveled by each vehicle type for the carrier group. The operating revenue per mile for each vehicle type, O_n, is multiplied by the percentage of miles traveled by that vehicle type to determine the weighted revenue per mile. The expenses by vehicle type per mile is the total expenses per mile (during normal operation) minus the total selected expenses. The weighted expenses is then determined in a similar manner to the weighted revenue. The difference between the sum of the weighted revenue and expenses is the potential value of the time savings on a per mile basis. This analysis would be carried out for different carrier types. A composite table, listing the values of time savings for each carrier type, would then be generated.

Using the results of Table 3 for each carrier type and making an assumption about the average speed traveled by each carrier type, a potential value of time savings per hour could be determined. Alternatively, a similar, but more robust method could be performed that would allow each carrier type to be broken down by vehicle classification (similar to Table 1). This method would determine the value added for each vehicle type. By determining VCVTS for each vehicle type, it is simpler to apply the value to an economic analysis, since the types of vehicles in the traffic stream is usually known (rather than carrier type).

The primary criticism of the revenue method is the inclusion of the additional revenue in the value of time savings. In theory, the question arises whether it is appropriate to include the additional revenue simply because the commercial vehicle operators (CVO) have the opportunity to operate additional miles as a result of time savings. In reality, they have this opportunity even without the time savings but restrictions may prevent them from doing so. *(5)* If this opportunity exists before time savings, then equating the incremental profit implies an increase in demand (as shown in Figure 2). As stated earlier, this implies that the market can absorb this increased output, which may or may not be true.

TABLE 2
Information Required on a Per Mile Basis for Carrier Type A

Item	Vehicle Type 1	Vehicle Type 2	Vehicle Type 3
Operating revenue	O_1	O_2	O_3
Total expenses	TE_1	TE_2	TE_3
Driver's wages	D_1	D_2	D_3
Workmen's compensation	W_1	W_2	W_3
Vehicle license and reg. fees	L_1	L_2	L_3
Real estate and personal prop. tax	T_1	T_2	T_3
Social Security taxes	S_1	S_2	S_3
Total selected expenses	$TSE_1=D_1+W_1+L_1+T_1+S_1$	$TSE_2=D_2+W_2+L_2+T_2+S_2$	$TSE_3=D_3+W_3+L_3+T_3+S_3$

TABLE 3
Weighted Potential Value for Time for Carrier A

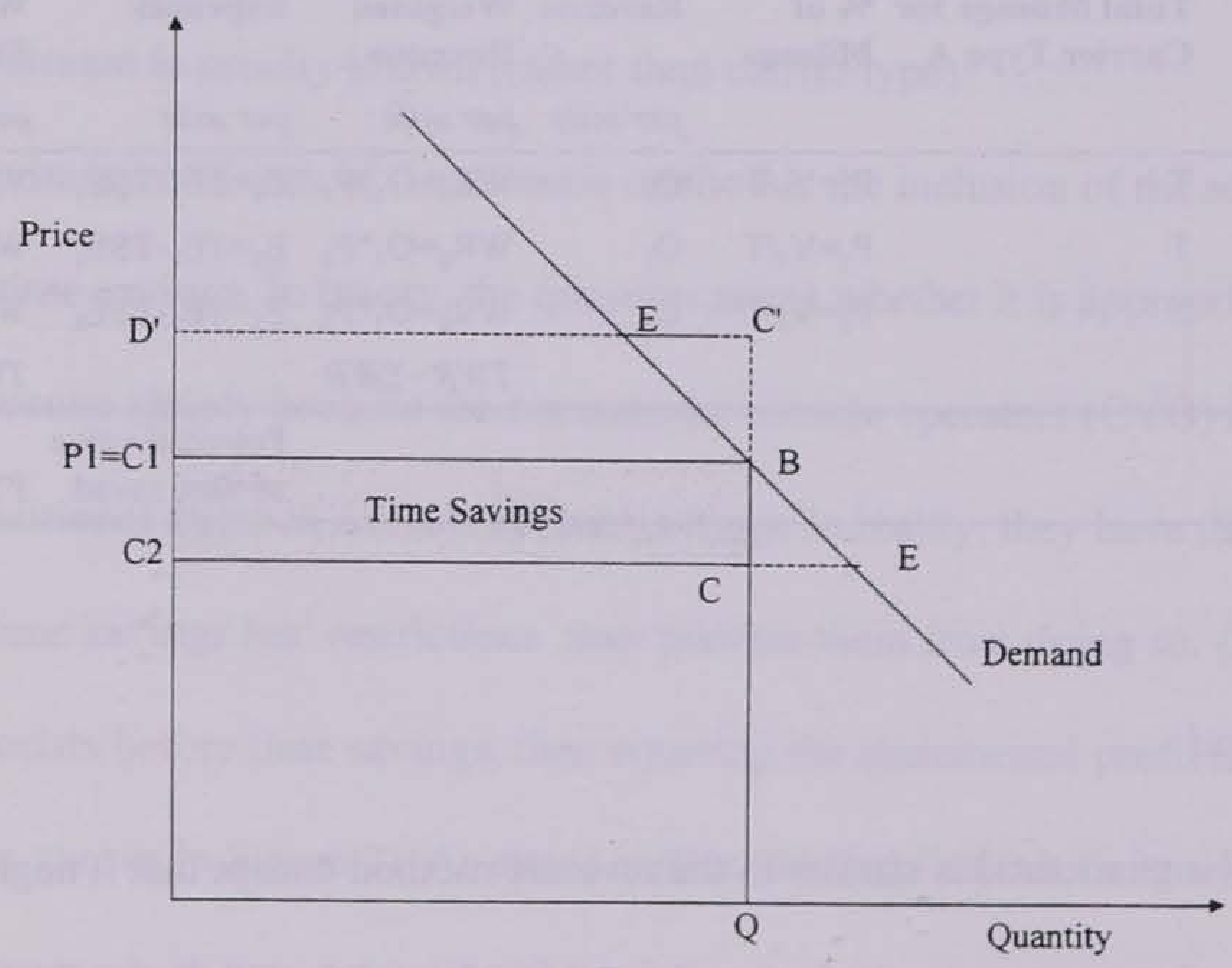
Vehicle Type	Veh. Type Mileage	Total Mileage for Carrier Type A	% of Mileage	Revenue *per mile*	Weighted Revenue *per mile*	Expenses *per mile*	Weighted Expenses *per mile*
1	V_1	T	$P_1=V_1/T$	O_1	$WR_1=O_1*P_1$	$E_1=TE_1-TSE_1$	$WE_1=E_1*P_1$
2	V_2	T	$P_2=V_2/T$	O_2	$WR_2=O_2*P_2$	$E_2=TE_2-TSE_2$	$WE_2=E_2*P_2$
3	V_3	T	$P_2=V_3/T$	O_3	$WR_3=O_3*P_2$	$E_3=TE_3-TSE_3$	$WE_2=E_3*P_2$
					$TWR=\Sigma WR$		$TWE=\Sigma WE$
						Potential value of time saved	$PV_A=TWR-TWE$

Cost Savings Method

The cost savings method is similar to the revenue method except that it neglects to include the additional revenue generated per mile to the value of time savings. Cost savings allow the CVO to supply the same output at lower costs. The method proposes that in the long run, time savings will allow the same number of miles to be operated by fewer vehicles. In this method the value of time is determined by the costs that are saved due to the time reduction. The cost savings method can be explained in theory by examining Figure 3.

Assuming a competitive market, the price P^1 is equal to the marginal cost C^1 of supplying Q output. If time savings yield a reduction in cost, the new cost would be C^2. The value of time is equated to the total cost savings, or C^1-B-C-C^2. One would expect the lower cost to be passed on to the consumer, yielding an increase in the quantity of output. By convention, the additional cost savings (B-C-E) arising from this situation is ignored in the calculation of the value of time savings.*(3)*

FIGURE 3
Cost Savings Method



Similar to the revenue method, only costs assignable to time savings may be included in the calculation of the value of time savings. Which type of costs to include in the method is sometimes debated but the majority of work on this subject has included the basic costs listed below, each of which can be related to time savings *(5)*: 1. interest on investment; 2.

depreciation; 3. property tax; 4. drivers' wages; 5. workmen's compensation; and 6. Social Security tax

The interest on investment is included in the method because equipment needs will be reduced by time savings (in the long run). Less interest will have to be paid on capital investment which will yield a cost savings.

Depreciation is a considered as a component of the time savings value because it is partly attributable to time. Depreciation can be a result of many different factors, including time and mileage. These factors both contribute to depreciation, so cost savings from depreciation may be assigned to either one. In this model, depreciation is assigned completely to the time component. This assumption may be modified for different circumstances.

Property taxes are included for much the same reason as interest. Less equipment will eventually lead to lower taxes. Including drivers' wages and non-wage benefits such as Social Security taxes and workers' compensation is not as apparent. Drivers may be paid either on a mileage basis or a time basis. If the driver is paid on a mileage basis, then there is no time related cost savings from drivers' wages. For most applications, however, it is practical to assign drivers' wages to time savings. In addition, some drivers are paid on an hourly basis and time savings to these drivers will certainly result in a cost savings.

If drivers' wages were not attributable to time savings and were all attributed to mileage savings then undercounting of highway benefits would most likely occur. On the other hand, if drivers' wages were assigned to both time and mileage savings then some double counting of benefits may occur. For simplicity, drivers' wages are fully assignable to time savings in this method. *(5)* Social Security taxes, and workmen's compensation are included for the same reasons.

An example of the cost savings method is presented in Table 4. Data from a carrier would be collected for those variables that are not calculated variables (this would be variables with nothing shown in the formula column, i.e. drivers' hours paid, number of tractors).

Drivers' hours were adjusted to show the time drivers spent in vehicles owned by the carrier from which the data was gathered (H_2). This number is used when determining any costs associated with equipment, since no cost savings would be available for leased vehicles on items such as interest and depreciation. The acquisition and replacement costs are used in determination of the interest, depreciation and property tax categories. An adjustment for the "excess" trailers is intended to reflect that a long term reduction in equipment cost would also include a reduction in standby equipment.

Two alternative costs savings per hour are calculated, one using replacement cost and the other using acquisition costs. The replacement cost numbers will usually result in a higher per hour savings. The interest savings is calculated by multiplying either the adjusted replacement or acquisition costs by 0.50 and the interest rate. This assumes that the equipment was on the average, one half worn. Drivers' wages, workmen's compensation and Social Security costs per hour are calculated by simply dividing the total costs by the total hours. The value of time savings is the sum of all per hour cost savings. As in the net operating profit method, the drivers' wage is the predominate variable.

TABLE 4
Cost Savings Method Example *(5)*

Drivers' Hours		
Drivers' hours paid	H_1	
Number of drivers	D	
Vehicle miles, owned	OM	
Vehicle miles, owned and leased	TM	
Drivers hours operating owned units	H_2	OM/TM (H_1)
Equipment Costs		
Acquisition costs of equipment	CE_1	
Calculated replacement costs	CE_2	
Ratio	R_1	CE_1/CE_2
Number of tractors	TR	
Number of trailers	ST	
Number of excess trailers	ET	
Average cost of trailer	ETC	
Aquistion costs less excess trailers	CE_3	CE_1-ETC
Ratio	R_2	CE_3/CE_1
Replacement costs of equip. less excess trailers	CE_4	CE_2(Ratio)
Aquistion costs of vehicle	AV	CE_3/D
Replacement costs of vehicle	RV	CE_4/D
Interest (*i*) on Investment		
i on invest. in equip. at acquisition cost	C_1	CE_3(.5) (*i%*)
i on invest. in equip. at replacement cost	C_1^*	CE_4(.5) (*i%*)
i per drvr. hr on equip. at acquisition cst	S_1	C_1/H_2
i per driver hr on equip at replcmnt. cost	S_1^*	C_1^*/H_2

Depreciation Expense		
Depreciation on all equipment	D	
Deprec. on equip. less extra trailers	C_2	D*R_2
Depreciation on replacement costs	C_2^*	C_2/R_1
Depreciation per hour using C_2	S_2	C_2/H_2
Depreciation per hour using C_2^*	S_2^*	C_2^*/H_2
Property Tax		
Property tax on real estate & equip	PT	
Real estate & acquisition cst of equip.	VP	
Prop. tax on equip less excess trailers	C_3	CE_3(PT/VP)
Property tax on replacement costs	C_3^*	C_3/R_1
Property tax per hour using C_3	S_3	C_3/H_2
Property tax per hour using C_3^*	S_3^*	C_3^*/H_2
Drivers' Wages		
All drivers' wages	C_4	
Drivers' wages per H_1 hours	S_4	C_4/H_1
Drivers' Workmen's Comp.		
All drivers' workmen's compensation	C_5	
Drivers' workmen's comp per H_1 hours	S_5	C_5/H_1
Drivers' Social Security		
All drivers Social Security	C_6	
Drivers' Social Security per H_1 hour	S_6	C_6/H_1
Value of Time Savings per hour		
$S_1+S_2+S_3+S_3+S_4+S_5+S_6$		

The cost savings method is the most straight forward of any of the methods used to calculate VCVTS. It can readily be determined from published statistics. It has all the advantages of the net operating profit method but is simpler to apply.

Willingness To Pay Method

Willingness to pay methods are based on economic principles. In mainstream economics, the idea that the utility obtained from a commodity is determined by the characteristics of that commodity is well established. Fowkes writes that it follows from the notion that

> the utility obtained from a commodity may be modeled as sum of 'part worths' of these characteristics. It is customary to talk of the commodity having attributes, each set to a particular level. By taking the ratios of these 'levels' we obtain relative cost of one attribute in terms of another. *(9)*

In this application, time is the commodity under study. The willingness to pay methods infer a value of time from investigating the ratios of the utilities of travel time and cost of travel. Historically, these types of studies have been done for automobile and transit users. Typical scenarios examined to determine the value of time include situations where the transport user has more than one mode of travel from which to choose. In mode choice models, consumer choices about which mode is chosen reveals how individuals value time. Willingness to pay methods can be classified into two types; revealed preference and stated preference.

Revealed Preference Method Revealed preference methods attempt to infer consumer valuation of time from observing consumer choice. The difference between the two methods is that the revealed preference method is, as the name suggests, a study of choices "revealed" by consumers through their behavior. Any fixed origin destination journey with alternate travel choices is particularly attractive to the revealed preference method. This explains why a large proportion of these studies have been done examining the work to home journey. The revealed preference method has three key assumptions *(10)*: 1. there must be alternative routes or modes available to the user; 2. a real choice exists;and 3. sufficient variance exists in the distribution of the alternative trips to enable a meaningful estimation of VTTS.

The transport users value of time is determined by analyzing the trade offs between cost and time and an attempt to save either time or cost. One factor that contributes to the accuracy of values as a result of this method is the users' knowledge of their actual costs. In the majority of cases, automotive users have little knowledge of the actual costs of vehicle operation. Maze and Maggio said commercial carriers "are very knowledgeable about the costs of equipment, fuel, repair services and other items they commonly purchase." *(6)* Since CVOs have an accurate idea of their operation, the results from a revealed preference study could be more accurate. In order to perform this study for commercial vehicles one would need to identify a journey that had alternate routes and differing costs. In general, a situation where a CVO has a choice of using tolled or untolled facilities which both traverse similar routes would present a case study for the revealed preference method.

Stated Preference Method Stated preference models are similar to revealed preference studies except that instead of examining consumer behavior, they study the results of consumer answers to hypothetical questions. The fundamental aspect of stated preferences studies is that they "provide respondents with hypothetical data on alternatives involving tradeoffs among the various attributes of these alternatives." *(9)* The questions will allow respondents the opportunity to either rank or give a rating of their response. The value of time is determined in the same way as the revealed preference method. The primary advantage of the stated preference method is that problems associated with revealed preference method can be avoided. Revealed preference methods have problems with correlation of data. In stated preference methods, surveys can be organized to eliminate correlation. Another advantage is that respondents can be allowed to answer questions that will provide a more interesting range of tradeoffs than revealed preference studies. *(9)* The stated preference method may therefore hold promise of being applied to the determination of VCVTS.

Common Issues In Application

Regardless of which method is used to determine VCVTS, the actual goal is to use the numbers in an economic analysis. As mentioned, the value of time savings is an important part of these analyses. Variation in the value of time, either commercial or private, can have a measurable effect on the viability of a project.

One of the critical assumptions in both applying and determining the value of time is that time savings are additive. Many would debate this assumption claiming that clearly one minute time savings to sixty people cannot be the same as sixty minutes time savings to one person. If one accepts this as axiomatic, then it follows that there is a minimum time savings, below which there is little benefit to the user. It also follows that the marginal value of time has increasing value (as illustrated in Figure 1) and that it would not be possible to simply add all the incremental time savings.

There are two major counter points when addressing the additivity argument. First, many elements are involved in the time savings. Simultaneous improvements on different roadways may be influencing the marginal value of time savings on another roadway. In addition, improvements on individual roadways occur over time. Adjustments to grade and alignment may be made over a period of time that will result in substantial time savings. Between Portland and Grants Pass, for example, the Oregon State Highway between them was shortened by 30.55 miles between 1935 and 1960. *(11)* Without the assumption of additivity and the value of small time savings, it would be difficult to justify some of the minor improvements which result in major time savings.*(3)* Time savings on one project may be offset or added to by another project. Rigorous application to the principle of the increasing marginal value of time may lead to the summed value of time savings from individual projects to be less than the total for all projects combined. *(5)* Second, it is obvious that some vehicles may accrue large time savings and others only minimal time savings. Assuming that fewer vehicles accrue large time savings and many accrue smaller savings, an average value could still be appropriate, implying additivity.

The time period between project completion and benefit accrual is also an issue. In his twenty five year case study of how time savings affect CVO, Fleischer concluded that there was up to a ten year lag in the realization of benefits before carriers could adjust operating procedure to take advantage of the benefits. *(11)* He argues that some adjustment should be made to the value of time when analyzing a project to account for this lag. Others, such as Beesley and Reynolds, have argued that realization of benefits are immediate and no adjustment is necessary. *(12)* The difference in the amount of lag is largely a result of viewpoint. Fleischer was interested in the benefits accruing to an individual carrier, while Beesley and Reynolds were interested in benefits "to whomever they may accrue" *(12)*. The problem of lag, like additivity, is diluted by the complexity of the transportation system. There is definitely a lag period to the full realization of benefits but it is not long enough to warrant adjustment.

Another issue is that the value of time savings commonly used are not indicative of the actual value of time to the CVO. Typical values from Table 1 range from $15 to $30 per hour. When asked to place a time value on a typical tractor-trailer unit as part of a survey, however, carriers indicated the time value of their equipment to be anywhere from $25 to $100 per hour. *(6)* These values are representative of the rate at which a commercial carrier might lease out this equipment to another user. From this evidence, it is clear that the methods used to determine VCVTS calculate very conservative figures. Unfortunately, just as the wage rate cannot provide a definitive value of time it would seem that it is unlikely that the values supplied by the CVO could be used directly in a highway economic analysis.

SUMMARY

Determining the value of time, in either a commercial vehicle or private vehicle sense, is not a simple task. The three methods reviewed in this paper are generally accepted ways of determining the value of time. Of the three, the revenue and the cost saving method are most commonly used for the determination of VCVTS. The net operating profit method and the cost savings method are theoretically similar. The net operating profit method assumes that additional mileage generates additional revenue. The cost savings method values time savings as the sum of the costs that are assignable to the time savings. Waters, Wong and Meagle identified no real difference in the methods and called them both essentially a "resource savings approach". *(3)* The literature is divided about which method, net operating profit or cost savings, is the most appropriate. Upon review of both methods, the cost savings method is shown to be the most accurate and practical approach option.

While a willingness to pay method is a reasonable, if not the only, way to determine the value of time savings for the private vehicles, the literature reveals very little application of the willingness to pay method to commercial vehicles. As mentioned earlier, an interesting case study could be undertaken where toll and untolled routes are parallel.

There is a wealth of literature available on all aspects of the determination of the value of time, but no source could claim a definitive way to estimate it. For commercial vehicles the value of time savings is a rather neglected issue when compared to the other literature available on the value of time savings. Current literature on the subject of VCVTS is sparse. Other researchers (Waters, Wong and Meagle) concur with this observation.

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