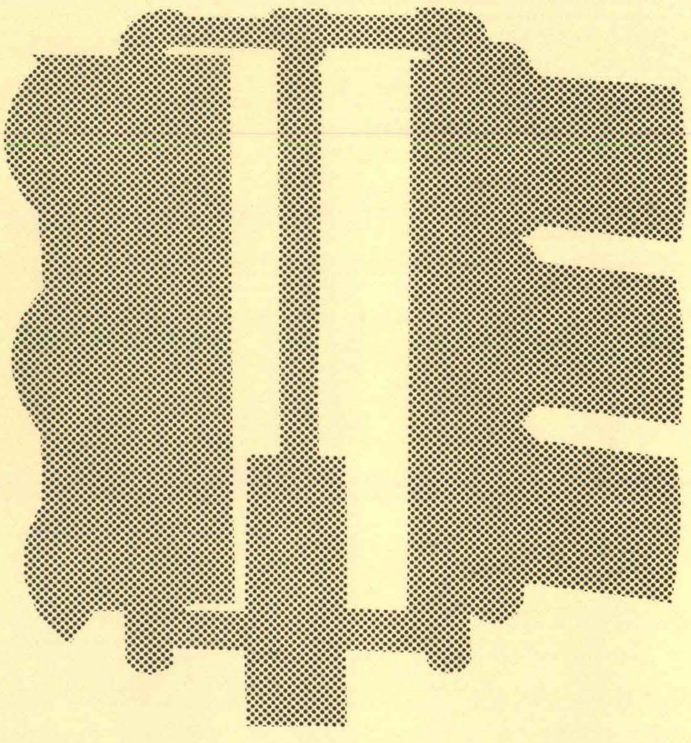
CITY OF DES MOINES FLEUR DRIVE/ARMY POST ROAD SIGNAL SYSTEM STUDY



FINAL REPORT

Prepared for

Des Moines Traffic Engineering Department

Des Moines, Iowa

April 1980

jhk & associates

CITY OF DES MOINES
FLEUR DRIVE/ARMY POST ROAD
SIGNAL SYSTEM STUDY

FINAL REPORT

Prepared for
Des Moines Traffic Engineering Department
Des Moines, Iowa

Prepared by
JHK & Associates
6600 Powers Ferry Road
Atlanta, Georgia

April 1980

PRELIMINARY

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

I INTRODUCTION

This report summarizes a study undertaken by the City of Des Moines to determine the feasibility of providing coordinated traffic signal operation along Fleur Drive and along a portion of Army Post Road. The City was assisted during the conduct of the study by JHK & Associates through a project partially funded under the Governor's Highway Safety Program. The study procedures, findings, and recommendations are presented herein. This report is supplemented by supporting documentation, interim technical reports, and an implementation plan including preliminary construction bid documents that were delivered to the City separately.

BACKGROUND

Fleur Drive is one of the primary transportation facilities in Des Moines. It provides access to the Central Business District from the southwest and directly serves the Des Moines Municipal Airport. Major reconstruction was completed in 1970 and Fleur Drive provides a high level arterial type facility consisting of four through lanes with a raised median. However, traffic volumes have increased dramatically since the reconstruction and Fleur Drive now experiences substantial congestion and an increased accident experience.

Although the heavy traffic volumes would be expected to contribute to the accident experience, this study was undertaken to assess improvements in traffic operations and safety that could be realized by interconnecting the signals. Each signal currently operates in an isolated mode, responding to local demand without any consideration being given to signal operation at adjacent signals. As a result, vehicles are required to stop unnecessarily, which increases traffic congestion and greatly increases the opportunity for an accident to occur.

Study Area

The Study Area initially consisted of a three-mile section of Fleur Drive bounded at the north by the entrance to Gray's Lake Park and at the south by Army Post Road. Eight signalized intersections existed within the Study Area at the beginning of the study. An additional signal, at Stanton Avenue, was installed during the Spring of 1979.

As work on the study progressed, it was determined that traffic characteristics of Army Post Road were such that benefits would be obtained by including two signals on Army Post Road with the Fleur Drive signal system. The signals at Southwest 14th Street and at Southwest 9th Street are well spaced for system operation and are close to the pivotal intersection of Fleur Drive and Army Post Road. In addition, they are presently being operated as non-interconnected signals. The final Study Area is shown in Figure 1.

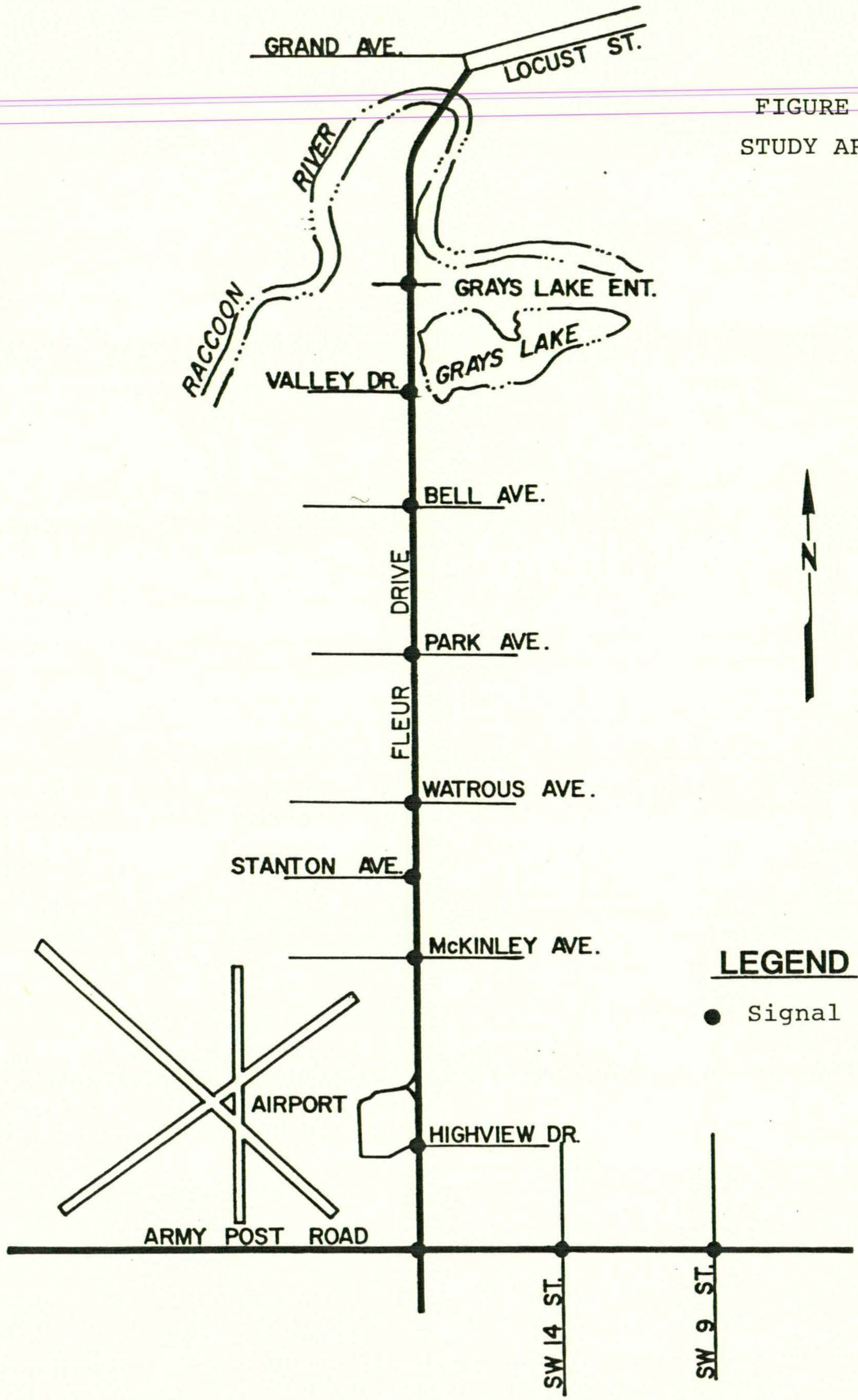
Goals And Objectives

The stated goals of the study were to determine the feasibility of providing system operation, to select the best technology to achieve coordinated signal operation, and to provide design guidelines for implementing the selected approach. The objective is to improve transportation efficiency and increase motorist safety by enhancing the quality and stability of traffic flow within the Study Area.

The Study Area was selected for improvement based on the obvious need to reduce congestion and increase safety within the constraints of existing right-of-way and roadway facilities. The Study Area was also selected to serve as a pilot project to demonstrate the benefits that can be realized through relatively low cost, systematic operation of traffic signals. Similar projects in other cities have provided evidence that the coordinated operation

FIGURE 1

STUDY AREA



of traffic signals will result in savings that cannot be matched by any other improvement project of the same cost. This study was undertaken to demonstrate that these same principles apply in Des Moines.

Ensuring that the proposed signal improvements could be easily maintained and efficiently operated by the City was a primary consideration during the conduct of the study. The ability in the future to interface the Fleur Drive/Army Post Road system to an area-wide traffic control system was also an important factor. Thus, the study was performed such that the importance given to on-the-street capabilities was balanced by the need to provide a system that does not negatively impact City resources or future programs.

Work Plan

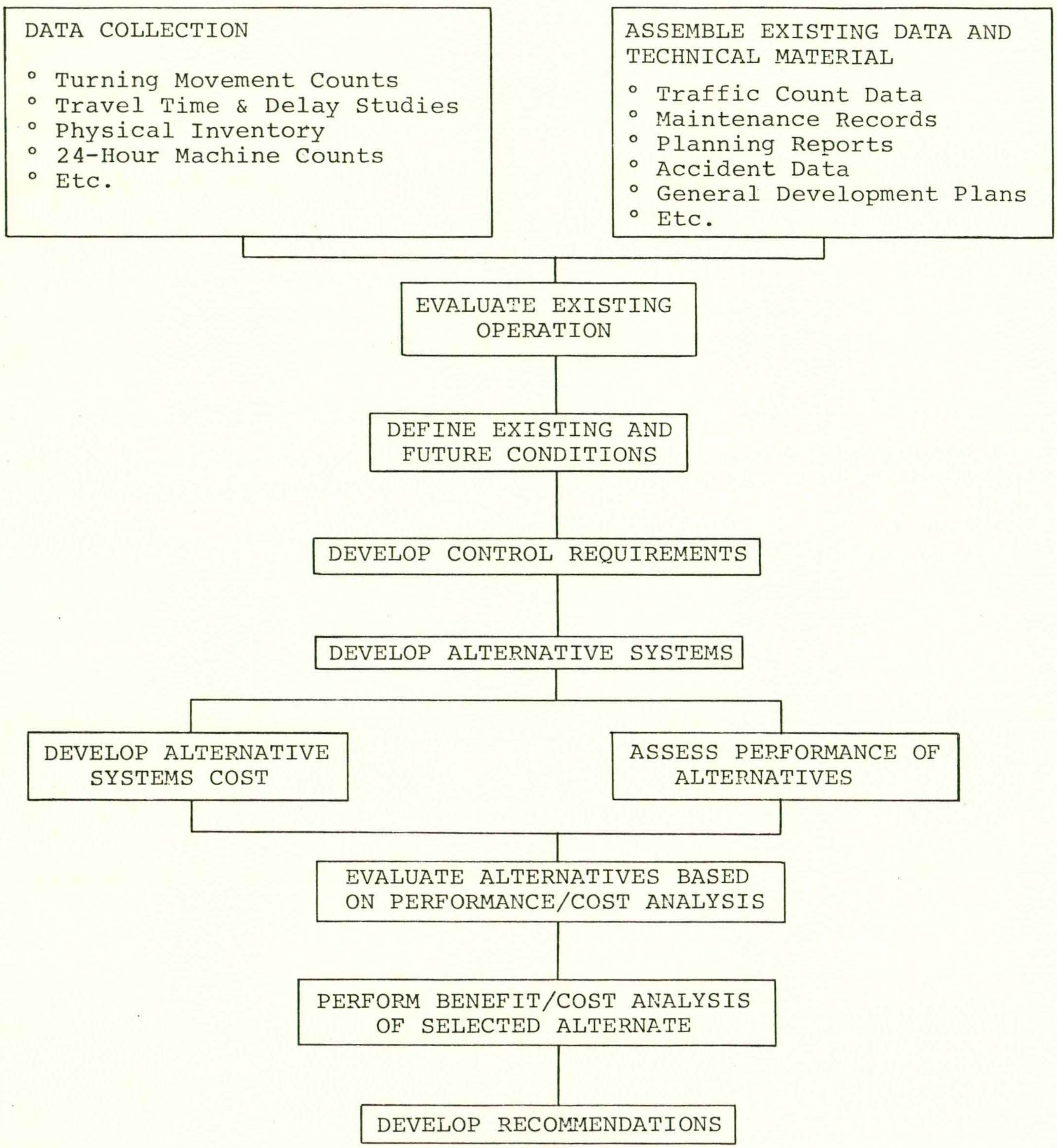
The project work plan is shown in Figure 2. The initial project tasks were concerned with compiling and reviewing data on existing conditions. This information included City-supplied traffic count data as well as all studies and reports that were relevant. Additional data, including a ten-hour turning movement count at each signalized intersection, were collected as required to create the data file necessary for the project.

An analysis of existing and future conditions, including an evaluation of the existing signal operation, was performed to establish the opportunities for signal control. These were then used to develop the control requirements that served as the basis for developing system hardware configuration and as the criteria for evaluating alternatives. The control requirements were reviewed in detail with the Technical Steering Committee; whose membership was comprised of representatives of various City, State, and Federal Highway Administration agencies.

Alternative signal systems were configured to address various aspects of the control requirements defined. The system costs were estimated and the ability of each alternative system

FIGURE 2

STUDY WORK PLAN



to meet the requirements was determined. As a last step, the alternatives were evaluated and the benefits of the most effective system were determined. These findings were also reviewed with the Technical Steering Committee.

During the study, deficiencies in intersection operation capabilities were identified and modifications were proposed to improve both safety and efficiency. Implementation plans showing the proposed modifications and details of the integration of each signal into the system were prepared. A detailed description of the equipment and hardware required for the system was also developed.

II EXISTING CONDITIONS

An analysis of existing conditions was performed to define the physical characteristics of the roadway network and to determine the characteristics of the traffic flow as it interacts with the physical network. This analysis then provided the basis to investigate the changes that may occur and permitted their impact on future traffic characteristics to be estimated.

Clearly defining the current and future traffic characteristics the signal system must respond to are critical steps in the study. Over-designing a system would result in unnecessary costs to the public for capabilities that are never used. On the other hand, even greater costs could result if the system did not provide needed functions or did not have the flexibility to accommodate changes. This analysis provided the foundation for subsequent tasks.

EXISTING SIGNAL OPERATION

Existing signal operation within the Study Area is provided by non-interconnected, traffic actuated controllers of solid-state construction. Extensive use is made of "volume density" controller features with vehicle detectors appropriately located. Due to the severe grades at Bell Avenue, modifications are made to the controller operation during the winter. The southbound approach is detected by a presence detector located near the stop bar instead of the usual volume density detector located well in advance of the intersection. In addition, the southbound recall is turned "ON" and the initial and time-to-reduce controller settings are increased for both southbound and eastbound traffic.

A controller inventory and an investigation of maintenance records was made to evaluate the feasibility of incorporating existing equipment into a new system. The controller inventory included an assessment of the equipment conditions. A summary of the inventory is shown in Table 1.

TABLE 1

Summary of Controller Equipment

Intersection	CONTROLLER				
	Manufacturer	Model	Phases	Age	Condition
Fleur Drive at:					
Grays Lake Entrance	ASD	ST827	2	8	Good
Valley Drive	ASD	MF80	5	9	Average
Bell Avenue	ASD	MF80	6	9	Average
Park Avenue	ASD	MF80	6	9	Average
Watrous Avenue	ASD	MF80	5	9	Fair
Stanton Avenue	ASD	118M	5	0	New
McKinley Avenue	ASD	118B	5	2	Good
Highview Drive	ASD	MF10	3	7	Good
Army Post Road	ASD	118B	5	2	Good
Army Post Road at:					
S.W. 14th Street	ASD	102	2	2	Good
S.W. 9th Street	*		8 (proposed)		

* To be installed in concurrent project. Presently two phase controller.

The equipment is well maintained and falls into one of two categories; old and new. The new equipment conforms to the National Electrical Manufacturers Association (NEMA) interface standards. A review of maintenance records indicates that there are an average of 2.3 non-scheduled maintenance calls per year. Signals with an excessive number of maintenance calls included Fleur Drive at Army Post Road, Watrous Avenue, and Bell Avenue. Most of the maintenance calls at Fleur Drive and Army Post Road occured while the controller was under warranty and were attributed to some extent to a knockdown that resulted in controller damage.

Protected/permissive left turn phasing is provided at the intersection of Fleur Drive at Army Post Road and at Airport Exit/Highview Drive. Protected only left turn phasing is provided elsewhere. The signal phasing provides conventional operation except at Fleur Drive and Bell Avenue, which has a split phase eastbound and then westbound, and at Fleur Drive and Park Avenue, where both left turns on Park Avenue are provided on the same phase. Signal display conforms to the Manual on Uniform Traffic Control Devices standards.

SIGNAL MAINTENANCE

The Des Moines traffic signal maintenance shop is located in the basement of a building at 216 Southeast 5th Street. The shop, which covers about 6000 square feet, includes controller maintenance facilities and storage for controllers, cabinets, signal heads, parts and electric cable. Approximately 1200 square feet of space is devoted to controller and detector maintenance with several workbench and storage areas. This area is quite crowded. Some outside area is available for pole and scrap storage.

The shop has been subject to flooding during heavy rains. Usually, the water level does not exceed one foot depth inside the shop, but flood waters during recent years have been as deep as five feet.

Generally well equipped, the shop has two oscilloscopes and assorted multimeters and test equipment. Parts shelves line one wall, and spare controllers are kept in a back room.

The signal shop is staffed by a Traffic Services Coordinator, three traffic signal electricians, one traffic signal maintenance worker and one laborer. Three of the personnel, including the Traffic Services Coordinator, hold Associate Degrees in Electronics. The traffic signal maintenance man's responsibilities include bench work on electromechanical equipment, responding to knockdowns, relamping, and performing construction activities. The signal electricians assist in these activities and also perform the repair of solid-state equipment.

A preventative maintenance program allows all electromechanical equipment to be serviced in the shop every one and one-half to two years. Up to two controllers can be serviced each day. Preventative maintenance on solid-state equipment is limited primarily to cleaning the cabinet, changing filters, and generally inspecting the controller and cabinet.

Presently, the City maintains about 268 signals and flashers. Of these, approximately 226 are either pretimed controllers or are flashers. The remaining 42 controllers are of actuated solid-state design. Eight are digital; two microprocessor controllers have recently been installed. Solid-state controller repair is performed at the component level; however, the primary exposure has been to analog equipment.

ROADWAY CHARACTERISTICS

Fleur Drive, in southwest Des Moines, is a major north-south arterial, terminating to the north at Grand Avenue in the western edge of the Central Business District. For approximately four miles, Fleur Drive is a four lane arterial street with substantial strip development north of Army Post Road. South of Army Post Road, Fleur Drive becomes a two-lane, unpaved roadway in a rural surrounding.

Within the Study Area, Fleur Drive has four, twelve-foot through lanes and a raised median varying in width from four to twenty feet. Median openings are located at most cross streets and at entrances to major traffic generators. Left turn storage is provided at all signalized intersections and at most other median openings. Right turn lanes exist at five intersections, with non-signal controlled right turn operation at two of the locations. Presently, there are nine signalized intersections on Fleur Drive.

The speed limit along Fleur Drive is 40 miles per hour from Army Post Road to just south of Locust Street in the Central Business District where it drops to 25 miles per hour. At Locust

Street, one northbound lane turns right onto Locust, while the other lane continues north for one block where there are provisions for a dual left turn onto Grand Avenue.

Fleur Drive traverses through a rolling terrain which results in appreciable vertical grades at several locations. The steepest grade, eight percent, is encountered at the south approach to Bell Avenue. Railroad yard overpasses are provided at two locations: one just north of Bell Avenue; the other just south of Locust Street. The Raccoon River also crosses under Fleur Drive north of the Study Area.

Army Post Road is a major east-west arterial near the southern boundary of the City Limits. Army Post Road connects Interstate 35 with areas to the southeast of Des Moines and is designated as State Route 5. Within the Des Moines City Limits it is a four lane undivided highway. At the intersection with Fleur Drive, Army Post Road widens to provide left turn lanes with raised medians. Westbound traffic has a non-signal controlled free right turn onto northbound Fleur Drive. Presently, left turn storage is not provided for vehicles on Army Post Road at either Southwest 14th Street or Southwest 9th Street. Widening, along with resignalization, is proposed at the intersection of Southwest 9th Street and plans are being prepared for this improvement.

Army Post Road does not have the vertical grades found on Fleur Drive as the terrain in this area is generally flat. Within the Study Area the speed limit is 35 miles per hour. However, the speed limit east of Southwest 9th Street is 40 miles per hour and west of Fleur Drive the speed limit is 45 miles per hour.

Street lighting is provided on both Fleur Drive and Army Post Road and illumination levels appear to be adequate.

RELATIONSHIP WITH THE CITY TRANSPORTATION NETWORK

Fleur Drive is one of three arterials providing access to the Central Business District from the south with Fleur Drive being the westernmost of the three. Due to substantial physical barriers, such as the airport and the Raccoon River, Fleur Drive serves the entire area southwest of the city. It provides access from the adjacent residential areas for traffic destined to or north of the Central Business District and provides direct access for the growing developments to the southwest in the vicinity of Lakewood, Cumming and Norwalk.

Fleur Drive also provides the primary access to the Des Moines Municipal Airport. The airport, which serves commercial carriers, general aviation, cargo, and the Iowa Air National Guard, is a major traffic generator. Many motels and restaurants along both Fleur Drive and Army Post Road cater to the air traveler.

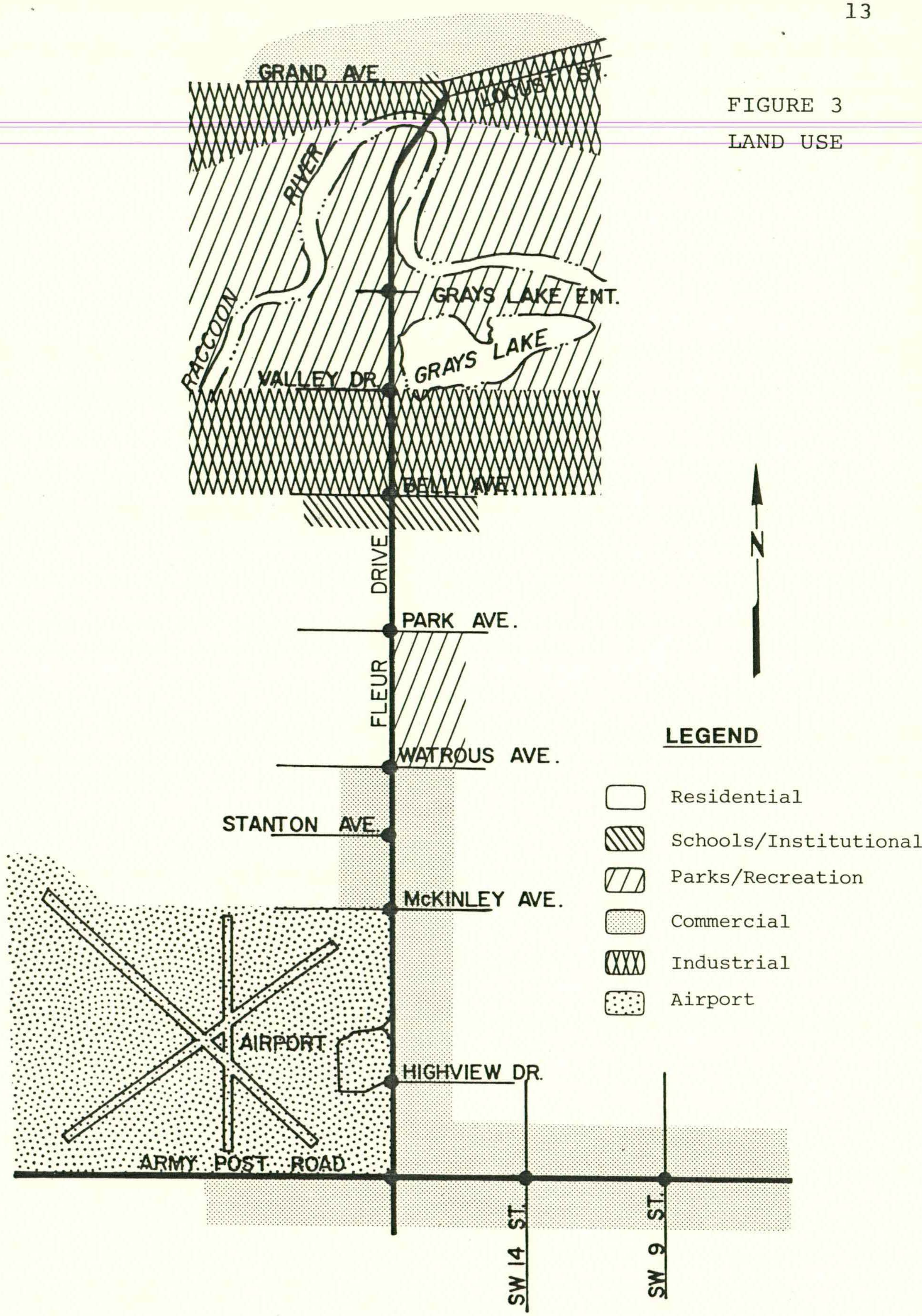
A large commercial area and a number of schools and small colleges are served by Fleur Drive, as is a major industrial and warehousing area. Fleur Drive also provides access to the Gray's Lake/Waterworks Park/Raccoon River recreational area just south of downtown.

Army Post Road is the southernmost east-west arterial within the City Limits. It serves as a collector for adjacent residential areas to both the north and south of Army Post Road. It also provides access from outlying areas in the southeast and southwest to the Central Business District via major north-south arterials, such as Fleur Drive and Southwest 9th Street. A major shopping complex, which includes Southridge Mall, is located east of the Study Area near Southeast 14th Street. Army Post Road provides the major access to the shopping complex for persons residing west of Southwest 9th Street.

LAND USE

Land use is an important factor in determining existing traffic characteristics. Of more importance, the changing of land use characteristics over time is the primary determinant of future traffic conditions. To permit these assessments to be made, an investigation of existing land use was made and the results are shown in Figure 3. Land use along the southern portion of

FIGURE 3
LAND USE



Fleur Drive is generally strip commercial, except for the Des Moines Municipal Airport located west of Fleur Drive between Army Post Road and McKinley Avenue. On the east side of Fleur, opposite the airport, are several motels and restaurants. Behind this is an established residential area.

Two major shopping complexes are located on the east side of Fleur Drive that extends from McKinley Avenue to Watrous Avenue. The southern complex consists of a major discount store, a grocery store, and several smaller retail shops. The northern complex, which is the larger of the two, contains a grocery store, a drug store, and several restaurants and smaller retail shops. On the west side of Fleur Drive, opposite the shopping complexes, land use is strip commercial. A new housing development and several small farms are located behind the commercial area.

The Wakonda Country Club is located on the east side of Fleur Drive between Watrous and Park Avenues. On the west side of Fleur Drive opposite the country club, land use is residential with limited new development underway on previously undeveloped areas. North of Watrous Avenue extending almost to Bell Avenue, land use is mixed single family residences and high density apartments on both sides of Fleur Drive.

The American Insitute of Business, a two year college, is located on the southwest corner of Fleur Drive at Bell Avenue. In addition, the Open Bible College is located on the southeast corner. Both schools have dormitories located on their grounds. West of Fleur Drive along Bell Avenue is a clean industrial area consisting of warehousing and some offices. The major employment centers include a large Massey-Ferguson farm equipment assembly plant and the offices of an insurance company.

North of Massey-Ferguson a major railroad yard extends under Fleur Drive to the west. A large motel is located on the east side of Fleur Drive north of the railroad yard with an entrance opposite Valley Drive. The railroad yard and Valley Drive act as a dividing line between commercial and recreational land use to the north.

The Des Moines Waterworks is situated north of Valley Drive on the west side of Fleur Drive. Much of the area has been developed as a park and recreational area. To the east of Fleur Drive is Grays Lake which covers about sixty acres. The surrounding park area provides access to the Lake and recreational facilities and to the Raccoon River.

Land use along Army Post Road east of Fleur Drive is similar to that along the southern portion of Fleur Drive. The Des Moines Airport is located on the north side of Army Post Road west of Fleur Drive. A small residential area is situated on the south side of Army Post Road, across from the airport. Beyond that lies farm land and scattered residential housing.

On both sides of Army Post Road east of Fleur Drive, land use is strip commercial development; behind which lies established residential areas. East of Southwest 9th Street, Fort Des Moines is located south of Army Post Road. Southridge Mall, a large, totally enclosed shopping mall, part of the shopping complex centered around Southeast 14th Street, is located east of Fort Des Moines.

GENERAL TRAFFIC CHARACTERISTICS

Fleur Drive is a heavily traveled arterial that provides access to residential, recreational, and commercial areas. Army Post Road traffic has similar trip purpose characteristics, however, it is less heavily traveled. To permit traffic characteristics to be assessed, a series of analyses were performed. These included determining total daily traffic volumes, determining volume characteristics, analyzing intersection turning movements, conducting travel time and delay studies, and conducting intersection delay studies.

Daily Traffic Volumes

Machine traffic volume counts studies were performed and tabulated by the City of Des Moines in October 1978. Each approach to the nine signalized intersections on Fleur Drive was counted for a minimum of twenty-four hours. Additional counts were made by the City during the study as required. These included two week counts on Fleur Drive and approach counts to one of the intersections on Army Post Road. These data were used to develop two-way Average Daily Traffic (ADT) for the network shown in Figure 4.

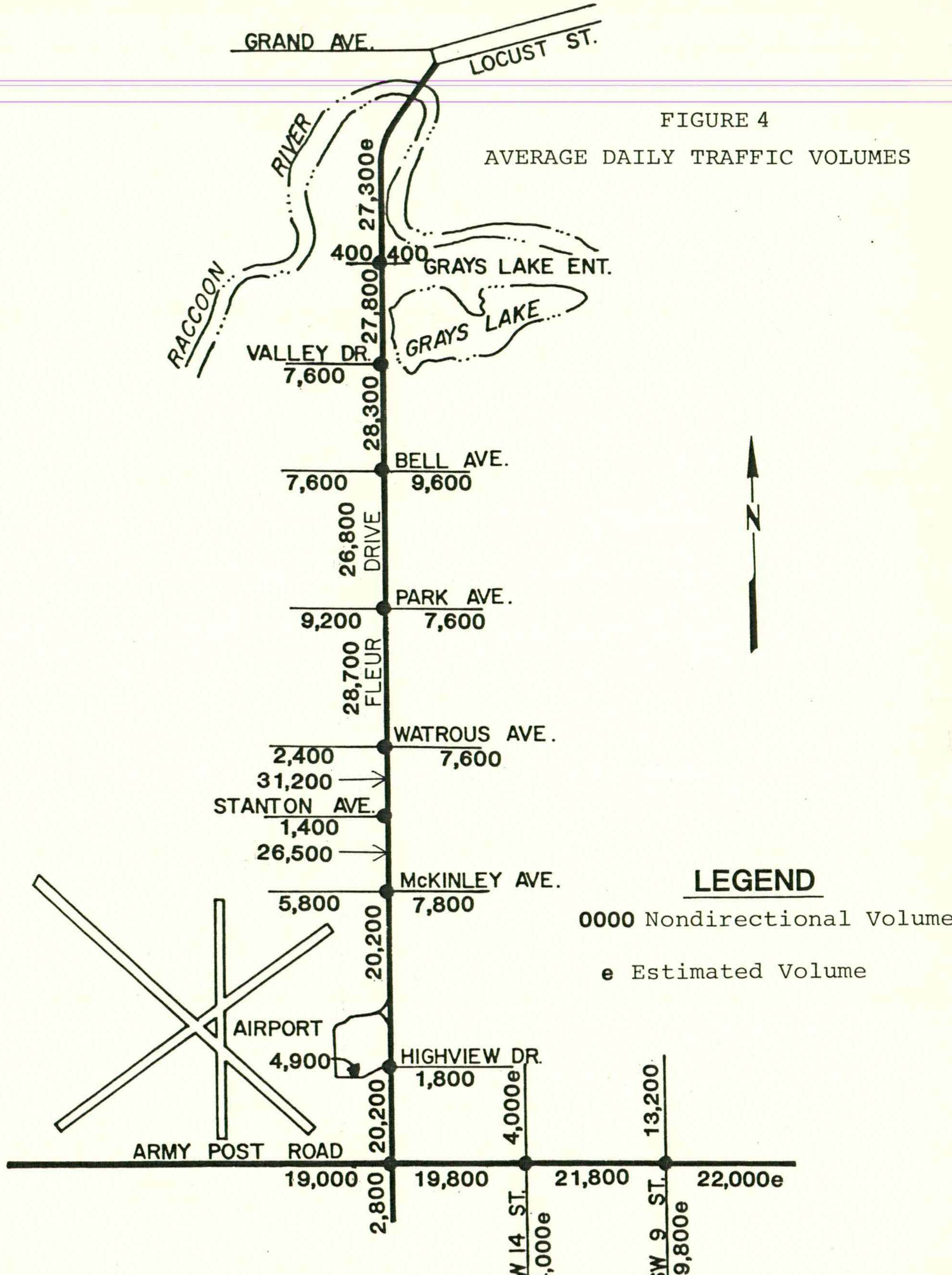
Traffic volumes along Fleur Drive varied from 20,200 vehicles per day just north of Army Post Road, to 27,800 vehicles per day south of Gray's Lake Entrance. South of Army Post Road, where Fleur becomes a two lane dirt road, traffic volumes drop to 2,800 vehicles per day.

Several of the streets crossing Fleur Drive are major traffic carriers. Both Park Avenue and Bell Avenue have an ADT of approximately 8,500 vehicles. Watrous Avenue and McKinley Avenue east of Fleur Drive have similar traffic volumes of approximately 7,800 vehicles per day. West of Fleur Drive, however, traffic volume on Watrous Avenue is less then half of the traffic on McKinley Avenue. Gray's Lake and the Waterworks Park area attract few vehicles during the winter, but the area becomes a major recreational attraction during the summer months.

Army Post Road also is a heavily traveled arterial, with average daily traffic of approximately 19,000 vehicles between Fleur Drive and Southwest 9th Street. Southwest 9th Street crosses Army Post Road and is a major north-south route, paralleling Fleur Drive. Average daily traffic along Southwest 9th Street north of Army Post Road is about 13,200 vehicles. Southwest 14th Street, the only other major street to cross Army Post Road, is a collector street for residential areas to both the north and south of Army Post Road. It extends from approximately half a mile south of Army Post Road north to near Bell Avenue.

Truck traffic is not a major factor along either Fleur Drive or Army Post Road as most of the major commercial areas nearby are served by rail. Truck traffic was found to account for only about one percent of all vehicles.

FIGURE 4
AVERAGE DAILY TRAFFIC VOLUMES



Volume Characteristics

The machine traffic counts were used to permit an analysis of traffic volume characteristics. Items of interest were the peaking characteristics (e.g., how fast does the peak develop and dissipate, what is the duration, etc.) and the relative directional variations in traffic.

A plot of traffic volume versus time for both traffic directions was made at each of the count locations. An example of the resulting graphs for Fleur Drive and for Army Post Road are shown in Figure 5 and Figure 6, respectively. With the exception of differences in the magnitude of traffic volume, these graphs are typical of the traffic characteristics found at all count locations along the arterials.

Fleur Drive experiences very sharp peaking characteristics with highly preferential traffic volumes during both the AM and PM peak period. During midday, traffic is relatively constant northbound, through the PM peak. Traffic southbound is slightly greater than northbound traffic from about 11:00 AM, with the peak period beginning about 3:30 PM and ending about 5:30 PM.

Army Post Road experiences a preferential AM peak period; but less pronounced than Fleur Drive. Midday traffic is also similar to Fleur Drive with a slightly higher westbound preferential. However, Army Post Road does not have the pronounced noon - 1:00 PM peak experienced on Fleur Drive. The characteristics of the PM peak on Army Post Road are different than that experienced on Fleur Drive. For example, the peak hour traffic volume is approximately equal to the AM peak hour volume, the peak period begins earlier, and the extreme preferential traffic flows are not evident.

Intersection Turning Movement Analysis

Ten-hour intersection turning movement count studies were performed at eight of the nine signal locations on Fleur Drive during February and March 1979. The signal at the entrance to

FIGURE 5
HOURLY VOLUMES
SOUTH OF BELL AVENUE

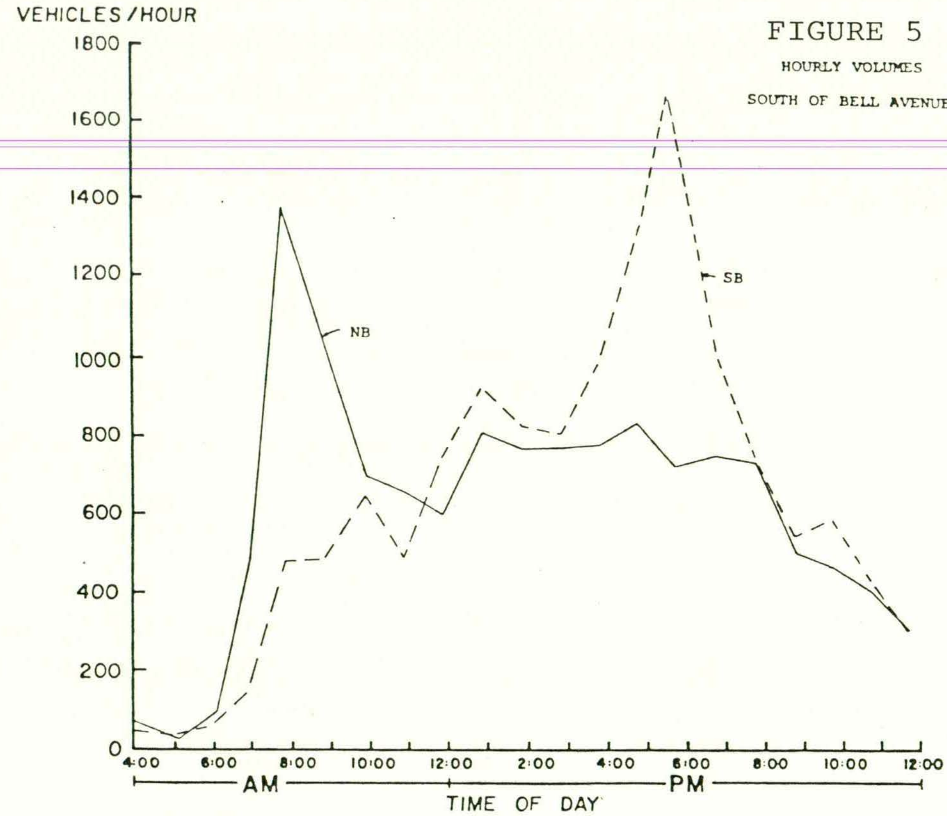
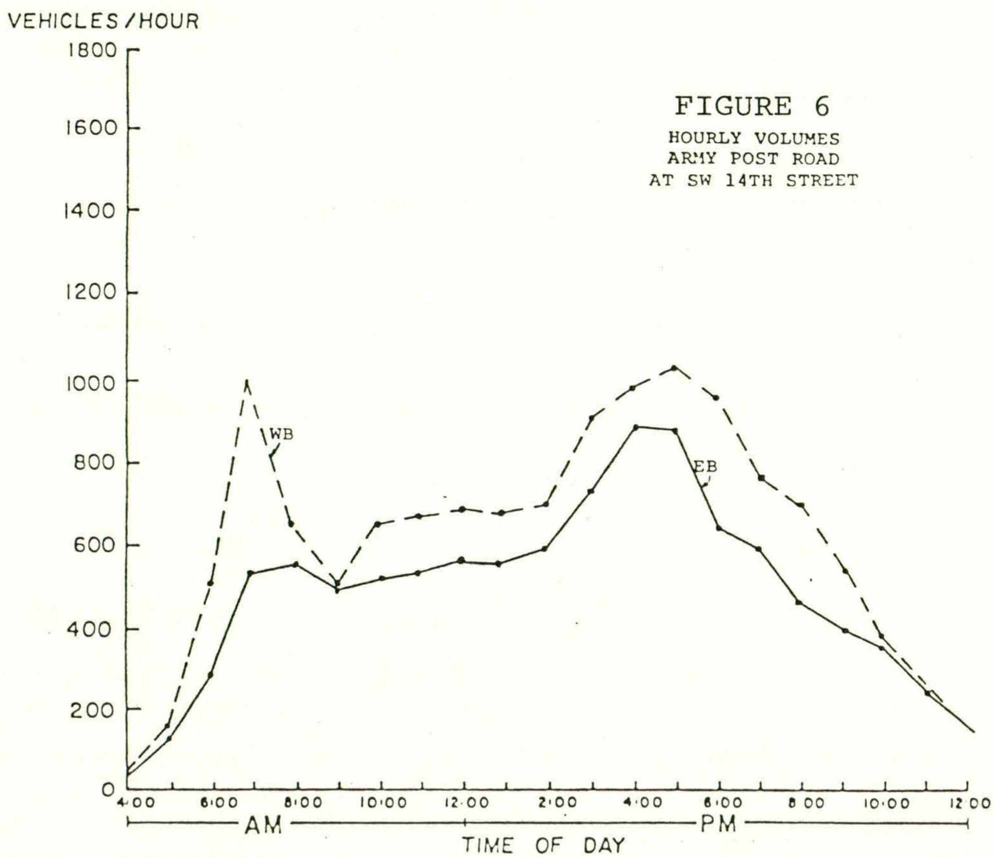


FIGURE 6
HOURLY VOLUMES
ARMY POST ROAD
AT SW 14TH STREET



Grays Lake Park was not counted at that time because of the seasonal attraction of the Grays Lake Park recreational area. In August, 1979, Grays Lake Entrance as well as the two signalized intersections on Army Post Road were counted. A summary of these counts are presented in Appendix A.

From the turning movement counts, visual displays of the primary AM and PM peak period turning movements were developed and are shown in Figure 7 and Figure 8, respectively. The displays were developed to provide a pictorial representation of major conflict points and to provide an indication of trip length.

Major turning movements occur at most signalized intersections on Fleur Drive and at Army Post Road and Southwest 9th Street during both the AM and PM peak hours. In general, the turning movements indicate heavy commuter type traffic with the PM peak hour traffic retracing the AM peak hour route. The intersections of Fleur Drive with Bell Avenue and with Army Post Road, however, experience similar turning movements during both the AM and PM peak periods. In addition, they have heavy conflicting turning movements indicating the critical nature of these signals.

Pedestrians were also counted during the movement studies. As most of the counts were performed during the winter, they may not provide an accurate indication of pedestrian demands. However, short term observations during the following summer indicated that pedestrians were virtually nonexistant except for a limited number observed at locations where pedestrian signals have already been installed.

Travel Time and Delay Studies

Travel time and delay studies are useful in identifying locations where excessive delays to the motorist are common. They can also be used to isolate delay resulting from signal operation and delay resulting from side friction. In addition, the data from travel time studies are an important input in developing system

FIGURE 7
MAJOR TURNING MOVEMENTS
AM PEAK

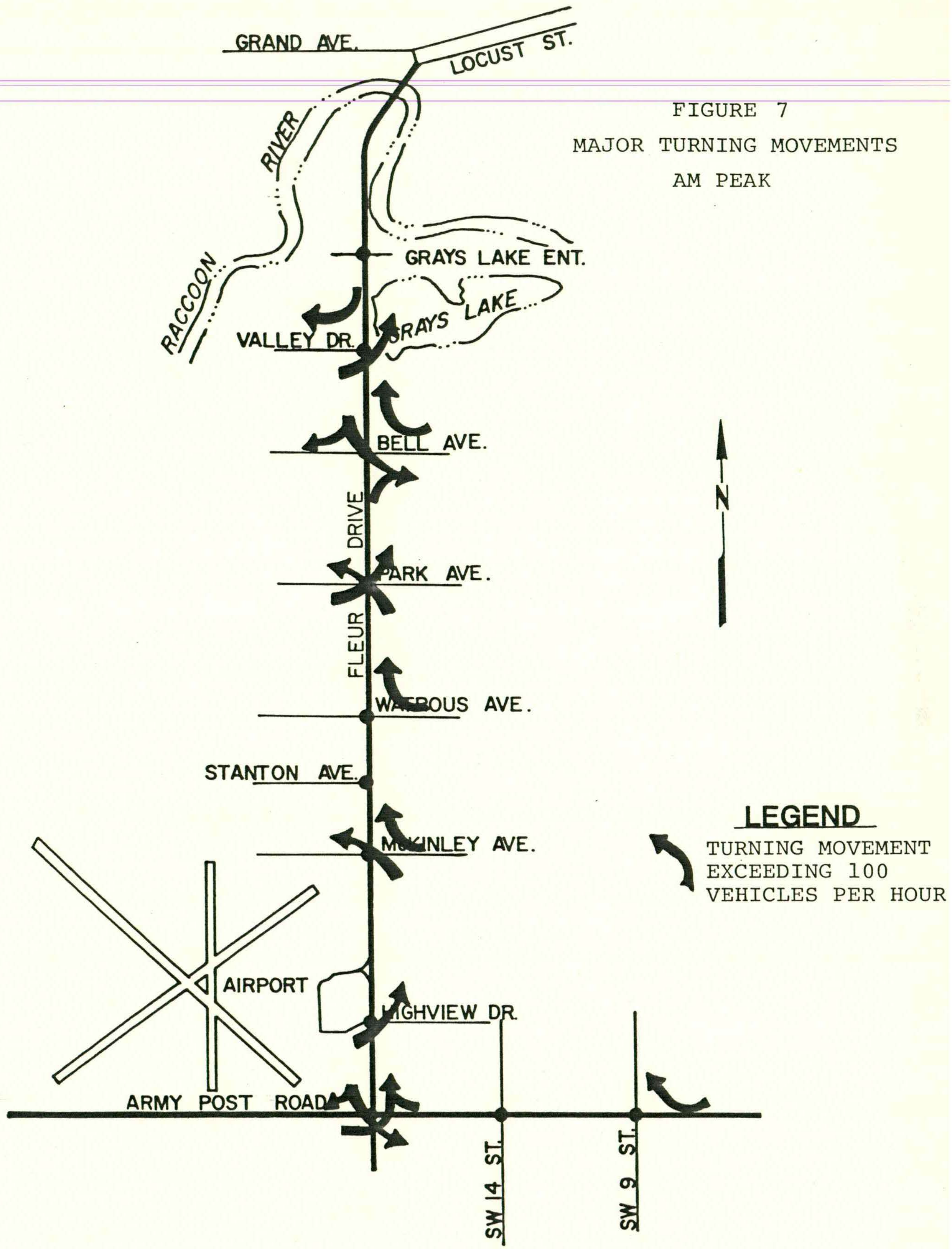
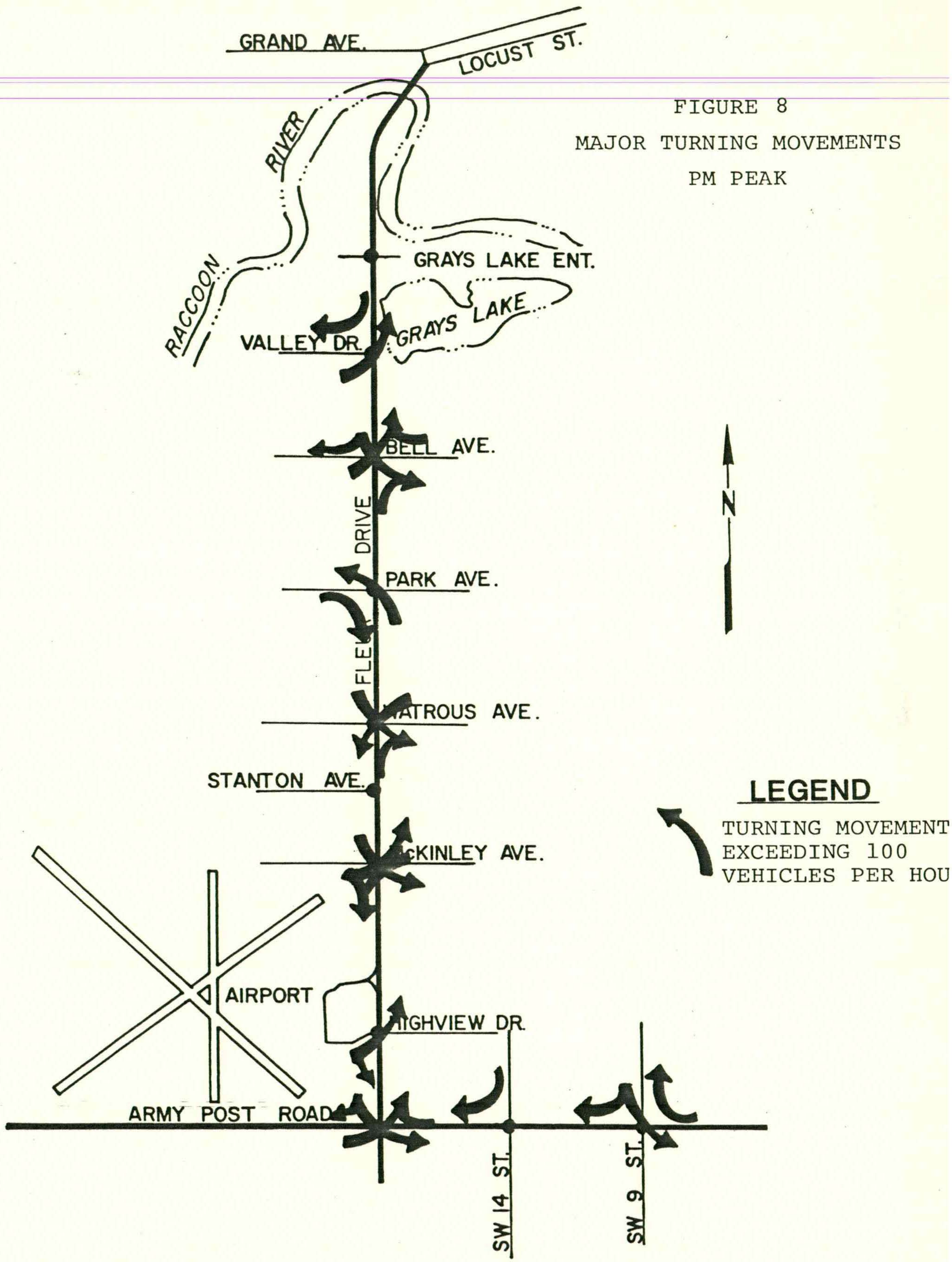


FIGURE 8

MAJOR TURNING MOVEMENTS

PM PEAK



timing plans to determine the level of benefits, if any, that can be realized through signal coordination.

Travel time and delay studies were conducted along Fleur Drive with end points at Locust Street to the north and Army Post Road to the south. Travel time runs were made in both directions of travel during morning and afternoon peak periods in March, 1979, using the "floating car" technique. All travel time runs were performed before the installation of the signal at Stanton Avenue. An additional set of morning peak runs were conducted immediately after a six inch snowfall.

As new construction is planned for the intersection of Army Post Road and Southwest 9th Street, and no major delays were observed at Southwest 14th Street, speed and delay runs were not performed along Army Post Road.

The travel time and delay run data were analyzed by computer program EVALUT which computes various parameters relating to average speed, delay, and the probability of stopping on both a trip and a link basis, where a link is the roadway section between two signalized intersections. The northbound and southbound average link speeds were plotted and are shown in Figure 9 and Figure 10, respectively. Northbound during both the AM and PM peak period there is a considerable reduction in the average link speed approaching Bell Avenue. A similar but less pronounced reduction in average speed occurs approaching Watrous Avenue during the AM peak period.

The southbound average link speeds also drop approaching Bell Avenue, as well as Park Avenue, during both the AM and PM peak. Some reduction in average speed also occured during the AM period at McKinley.

The average speed during snow conditions tended to parallel the AM period normal conditions at approximately ten miles per hour less, except approaching Park Avenue northbound. This difference may have been due to an equipment malfunction that only affected northbound traffic as the southbound average does not show the same characteristic.

FIGURE 9

AVERAGE LINK SPEEDS

NORTHBOUND

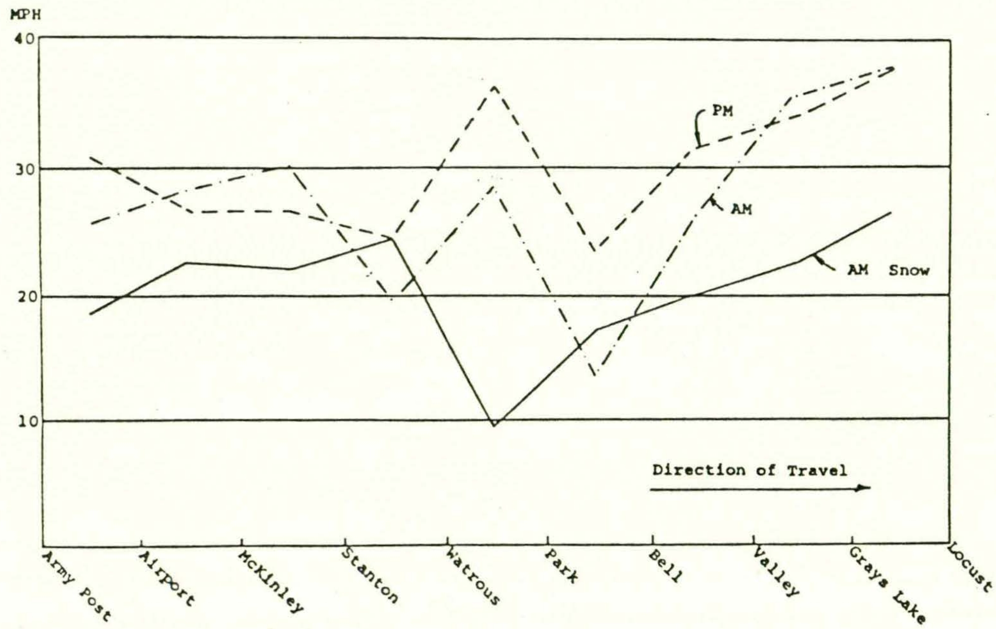
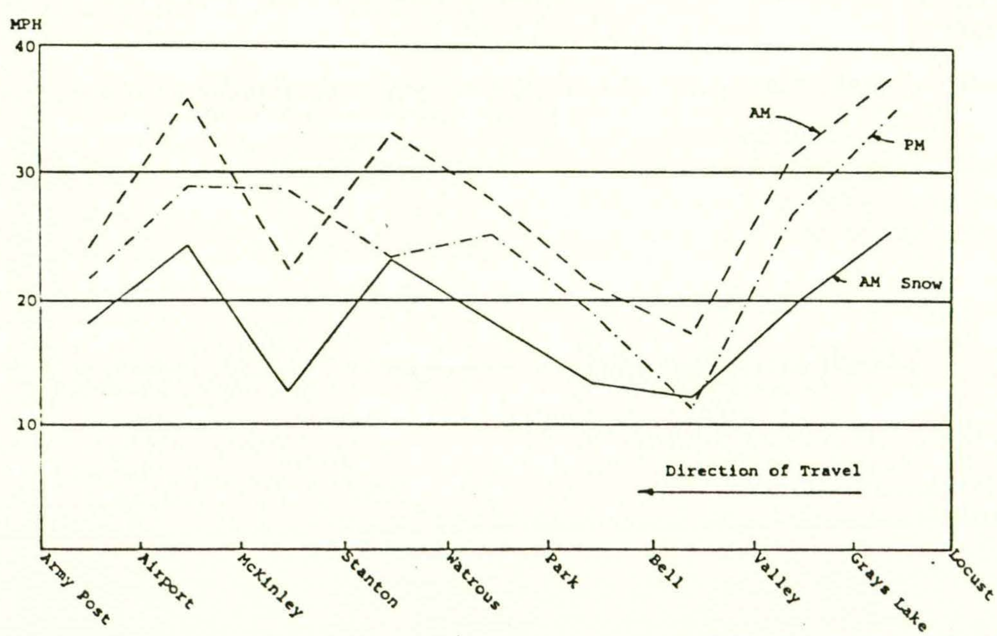


FIGURE 10

AVERAGE LINK SPEEDS

SOUTHBOUND



To investigate the travel characteristics exclusive of signal operation, the average link running speed was computed. This was performed by deducting the amount of time stopped, if any, due to signal operation. Although this approach does not totally remove the impact of signal operation, it provides a strong indicator of the impact of side friction when compared to the average speed. The average link running speed northbound and southbound is shown in Figure 11 and Figure 12.

The average running speed tended to be more uniform than the average speed for all links and all time periods. Average running speeds tended to be lower south of Watrous Avenue; particularly northbound. This reflects the impact on traffic resulting from the strip commercial characteristics of the southern portion of Fleur Drive. Of more importance, a comparison of the average speed to the average running speed clearly indicates the impact of existing signal operation on traffic.

Intersection Delay Studies

Determining delay at an intersection gives a good indication of the intersection efficiency and of the effects of its relationship to adjacent signalized intersections. Intersection delay studies were performed at two signalized intersections. Fleur Drive at Bell Avenue was selected as a study site due to the apparently high delays observed during other studies. The intersection of Army Post Road and Fleur Drive was selected for study due to the high traffic volumes on conflicting signal phases. The studies were conducted by a point sampling technique where the volume and stopped time for each approach were collected for seven and one-half minutes during the mid-afternoon and for fifteen minutes during the first portion of the peak hour.

The studies provide three measures of intersection efficiency. The first measure, average delay per stopping vehicle, indicates the actual delay to vehicles using the intersection. The second measure,

FIGURE 11
AVERAGE LINK RUNNING SPEEDS
NORTHBOUND

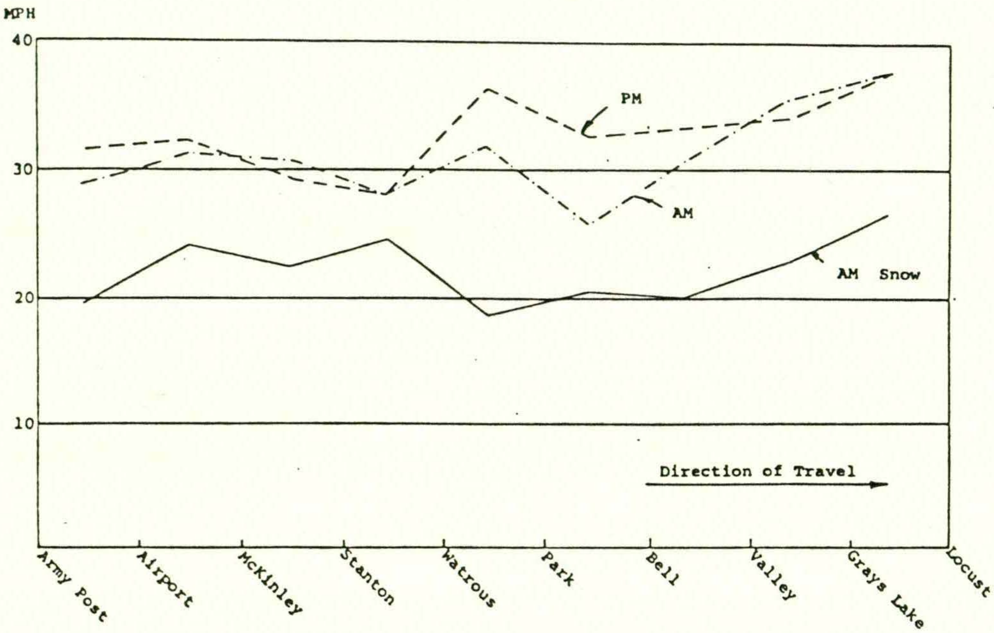
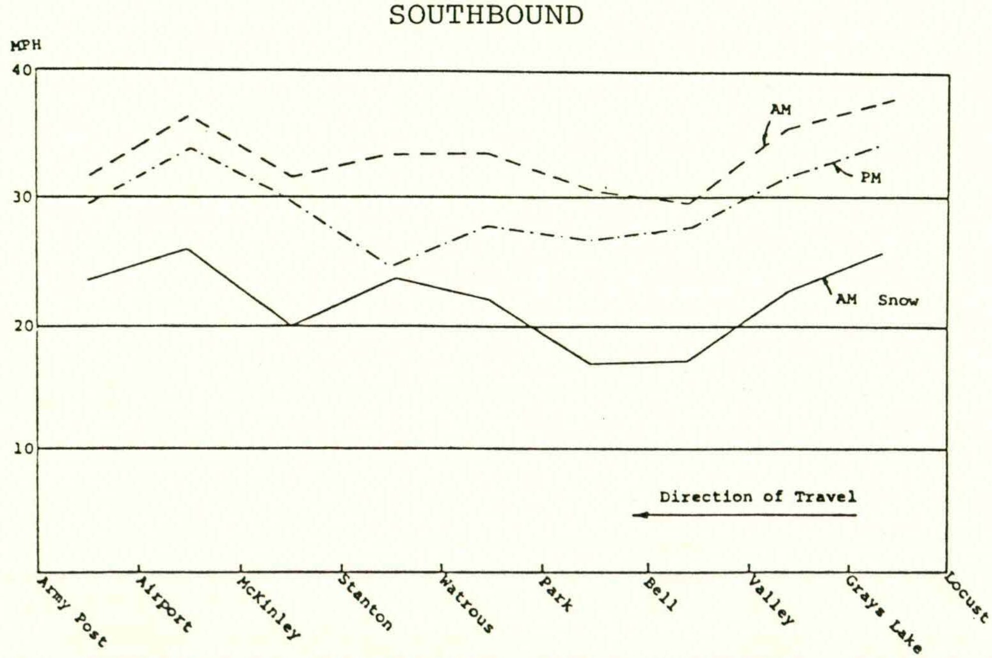


FIGURE 12
AVERAGE LINK RUNNING SPEEDS
SOUTHBOUND



average delay per approaching vehicle, provides a performance measure of the intersection The third measure, percent of vehicles stopping, indicates the probability of a vehicle being stopped at least once while approaching the signal.

A summary of the results of the intersection delay studies is shown in Table 2. During both study periods, delays at Bell Avenue were high and motorists faced a high probability of being stopped by the signal. Lower delays were found at Army Post Road along with a lower stopping probability. The average delay per approaching vehicle was lower at Army Post Road. However, there is less variation by intersection approach in average delay per approaching vehicle at Bell Avenue than at Army Post Road indicating a more equitable allocation of signal green time.

TABLE 2

Summary of Fleur Drive Intersection Delay Studies

STUDY PERIOD	Army Post Road				Bell Avenue			
	NB	SB	EB	WB	NB	WB	EB	WB
PM OFF PEAK - (2:15 - 3:15 PM)								
Average Delay/Stopping Vehicle (sec)	22.5	34.7	17.3	17.6	34.0	32.9	31.2	28.6
Average Delay/Approaching Vehicle (sec)	9.0	14.3	9.4	4.7	24.0	22.8	20.3	18.2
Percent of Vehicles Stopping	40	41	57	26	71	69	65	64
PM PEAK - (4:00 - 5:00 PM)								
Average Delay/Stopping Vehicle (sec)	30.0	21.6	22.4	23.1	41.3	33.5	38.7	47.8
Average Delay/Approaching Vehicle (sec)	16.3	9.4	11.9	10.7	25.5	20.4	30.5	30.8
Percent of Vehicles Stopping	54	44	53	46	62	61	79	65

ACCIDENT ANALYSIS

Traffic accident statistics are one of the most useful tools available for the identification and analysis of roadway deficiencies. For this reason, police accident reports for Fleur Drive and Army Post Road during the years 1977 and 1978 were reviewed and used to prepare collision diagrams for each of the signalized intersections within the Study Area. These diagrams, shown in

Appendix B, were then used to identify accident patterns and possible operational deficiencies.

Presented in Table 3 is a summary of the type of accidents during the analysis period and the accident rate for each intersection. Note that the three intersections on Army Post Road had the highest accident rates.

TABLE 3
Accident Rates

INTERSECTION	Rear End	Side Swipe	Right Angle	Left Turn	Pedestrian	Other	Total	Accident Rate *
Fleur Drive at:								
Grays Lake Entrance	6	0	1	3	0	4	14	0.71
Valley Drive	14	5	3	2	0	4	28	1.12
Bell Avenue	12	1	1	1	1	5	21	0.83
Park Avenue	13	2	5	2	0	4	26	1.01
Watrous Avenue	9	0	2	4	1	2	18	0.68
Stanton Avenue**	2	2	8	0	0	3	15	0.74
McKinley Avenue	6	2	6	4	0	0	18	0.76
Airport Exit	0	1	3	4	0	0	8	0.46
Army Post Road	16	7	8	25	0	5	61	2.70
Army Post Road at:								
SW 14th Street	4	2	6	11	1	0	24	1.35
SW 9th Street	11	7	12	42	3	7	82	3.62

* Accidents per million entering vehicles
** Prior to signal installation

Accidents appear to be a problem at all signalized intersections within the Study Area with rear end collisions being prevalent. Locations particularly prone to rear end type collisions were Fleur Drive at Valley Drive, at Bell Avenue, and at Park Avenue, and the intersection of Army Post Road and Southwest 9th Street. Rear end type collisions are frequently signal related and correctable through signal coordination.

Left turning accidents were a major problem at all three signalized intersections on Army Post Road. For example, of the two year total of 82 accidents at Southwest 9th Street and Army Post Road, 40 of these involved vehicles turning left from Army Post Road. At Fleur Drive and Army Post Road, 21 of the 61 reported accidents involved eastbound vehicles turning left onto Fleur Drive.

An intensive analysis of the left turn accidents at Fleur Drive and Army Post Road was performed to investigate any possible relationships between the accident pattern and signal phasing changes, weather conditions, seasonal fluctuations, traffic volumes or equipment problems that occured during the two year analysis period. The analysis indicated that the left turn accidents are proportional to the total accidents reported and are related to inclement weather conditions and volumes entering the intersection. No other relationships were found.

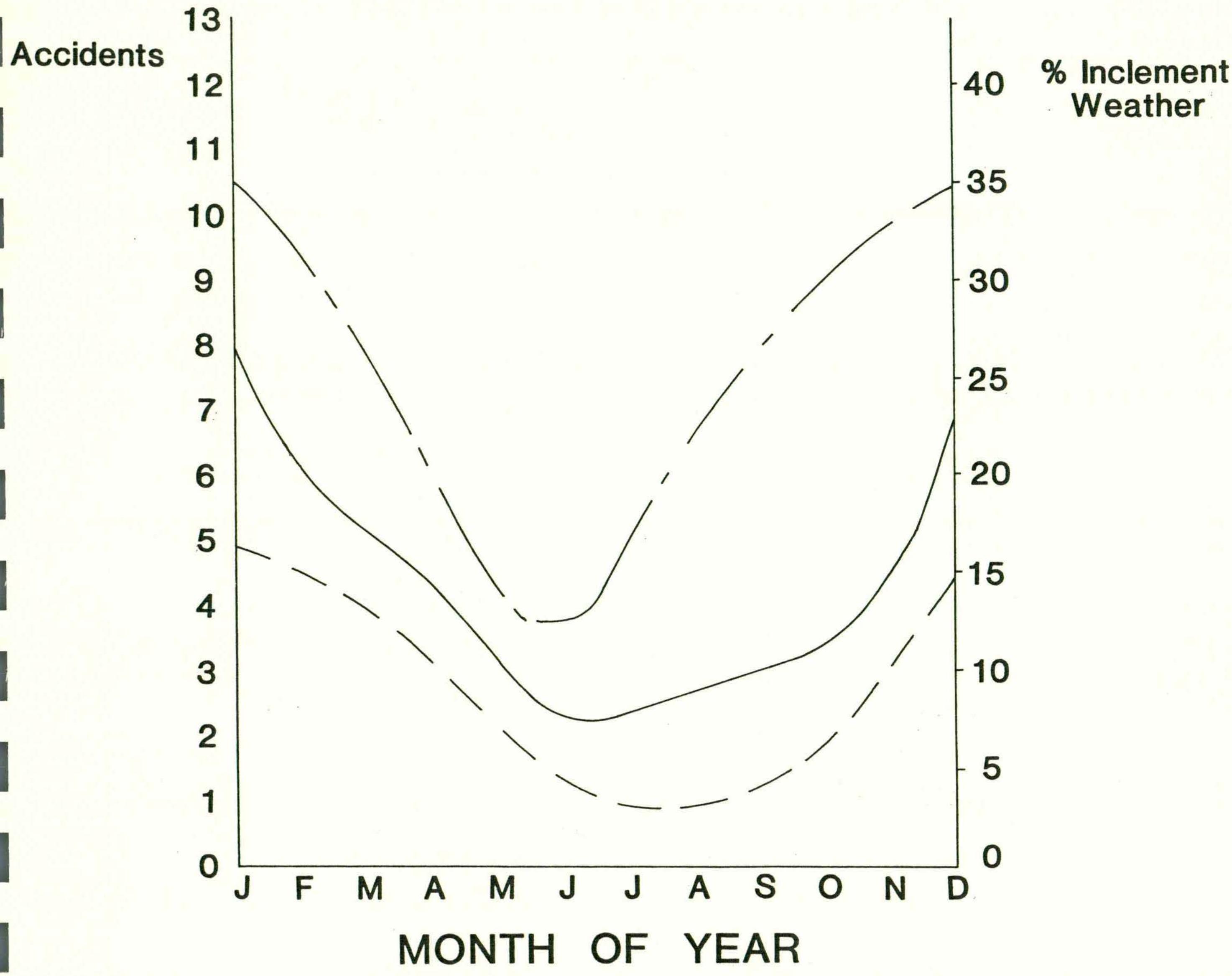
INCLEMENT WEATHER

Inclement weather, including conditions such as fog, rain, snow, and sleet, can greatly influence traffic characteristics. To assess the impact of inclement weather, data from the National Oceanic and Atmospheric Administration's Environmental Data Service was compared to the accident experience in the Study Area. Figure 13 presents the relationship between inclement weather, total accidents, and rear end type accidents. This would tend to indicate a direct relationship between accident experience and weather conditions. This, when considered with the results of the travel time and delay studies, indicates that weather is a factor to be considered for efficient signal system operation.

EMERGENCY VEHICLES

An investigation was made to determine if there was a need to provide special signal operation to facilitate emergency vehicles. During consultation with the Des Moines Fire Department, it was learned that Fire Department vehicles use both Fleur Drive and Army Post Road. However, routes are not predefined and are left to the discretion of the driver of the individual apparatus. This indicates that fixed route preemption would be of little value. Assistant Chief Patrick Murray expressed interest in local signal preemption, but indicated that local preemption of other intersections located outside the Study Area would be of

FIGURE 13
EFFECTS OF INCLEMENT WEATHER



Rear End Accidents per Month

% Time of Inclement Weather During Month

Average Accidents per Month

greater benefit as signal operation in the Study Area has not proven to be a problem to fire apparatus in the past.

It was also learned that Police Department patrol cars operate in zones and would not benefit from a route type emergency vehicle preemption system. It was therefore concluded that special consideration to emergency vehicles was not a factor in the study.

TRANSIT

Presently, Des Moines Metropolitan Transit Authority (MTA) buses do not have scheduled routes within the Study Area on either Fleur Drive or Army Post Road. However, two routes bisect the network; Route 8 crosses Army Post Road at Southwest 14th Street and crosses Fleur Drive at both Watrous Avenue and Bell Avenue, and Route 7, crosses Army Post Road at Southwest 9th Street. In view of the limited exposure of transit vehicles to signal operation, it was determined that special consideration to transit was not a factor in the study.

PUBLIC SCHOOLS

Seven public schools are located in the vicinity of the Study Area as follows:

School	Location
Mann Elementary	SW 11th at Amos
Park Avenue Elementary	SW 9th at Park
Watrous Elementary	SW 14th at Army Post
Brody Junior High	2501 Park
Kurtz Junior High	SW 12th at Porter
Lincoln High	SW 9th at Loomis
Tech High	Grand at Fleur

Elementary school districts, however, are configured such that students need not cross Fleur Drive or Army Post Road en route to school. Thus, special signal operation to accommodate students was determined not to be a factor in the study.

III FUTURE TRAFFIC CONDITIONS

The economic life of a traffic control system ranges from ten to fifteen years. As changes in traffic characteristics within this time period could render the system prematurely obsolete, the initial design must allow for expansion capabilities. An analysis of development adjacent to the Study Area and traffic growth projections was therefore performed.

AREA GROWTH

The potential for growth that would affect the Fleur Drive and Army Post Road signal system appears to be limited. Major development of land to the south of Army Post Road is restricted for the next five to seven years until construction of a sewage treatment plant is completed. This area also lies in the final approach pattern to the Des Moines Municipal Airport main runway, creating a noise situation that would be undesirable to many possible residents. Therefore, development would be limited to usage compatible to the resultant noise (e.g., warehousing, etc.) and the area will most likely remain as a low density residential and agricultural area.

Growth immediately to the west of Fleur Drive is greatly restricted by physical boundaries. New development is limited by the airport to the south and west, and by the Raccoon River floodplains and the Chicago and North Western Railroad tracks to the west and north. Significant redevelopment of this low density residential area is not anticipated. The area to the east of Fleur Drive is also already developed and major growth or redevelopment is not expected.

The area around Army Post Road and Southeast 14th Street has experienced the most rapid growth in the southern portion of Des Moines. The recent completion of Southridge Mall has resulted in the area becoming a major shopping attraction. Although the mall is located on Army Post Road, it is expected to have minimal effect on traffic within the Study Area as there is more direct access by way of Southwest 9th Street and Southeast 14th Street. In addition, Southwest 9th Street will be improved in the next few years to provide more attractive access to the southeastern area of the city.

A freeway connector is proposed south of Army Post Road connecting Interstate 35 southwest of Des Moines with areas southeast of town. As the new connector would be a parallel facility, it is expected to reduce traffic along Army Post Road, as it replaces it as a major east-west route.

DES MOINES MUNICIPAL AIRPORT

Major changes in access to the Des Moines Municipal Airport facilities have been proposed as part of an Airport Master Plan prepared in 1978. Under this plan, access from Fleur Drive will be provided by separate roadways to the cargo handling area, to the main terminal, and to the general aviation area. Each of the access road intersections with Fleur Drive will probably require signalization, thus creating three new signalized intersections between the two existing signals at the Airport Exit/Highview Avenue and McKinley Avenue.

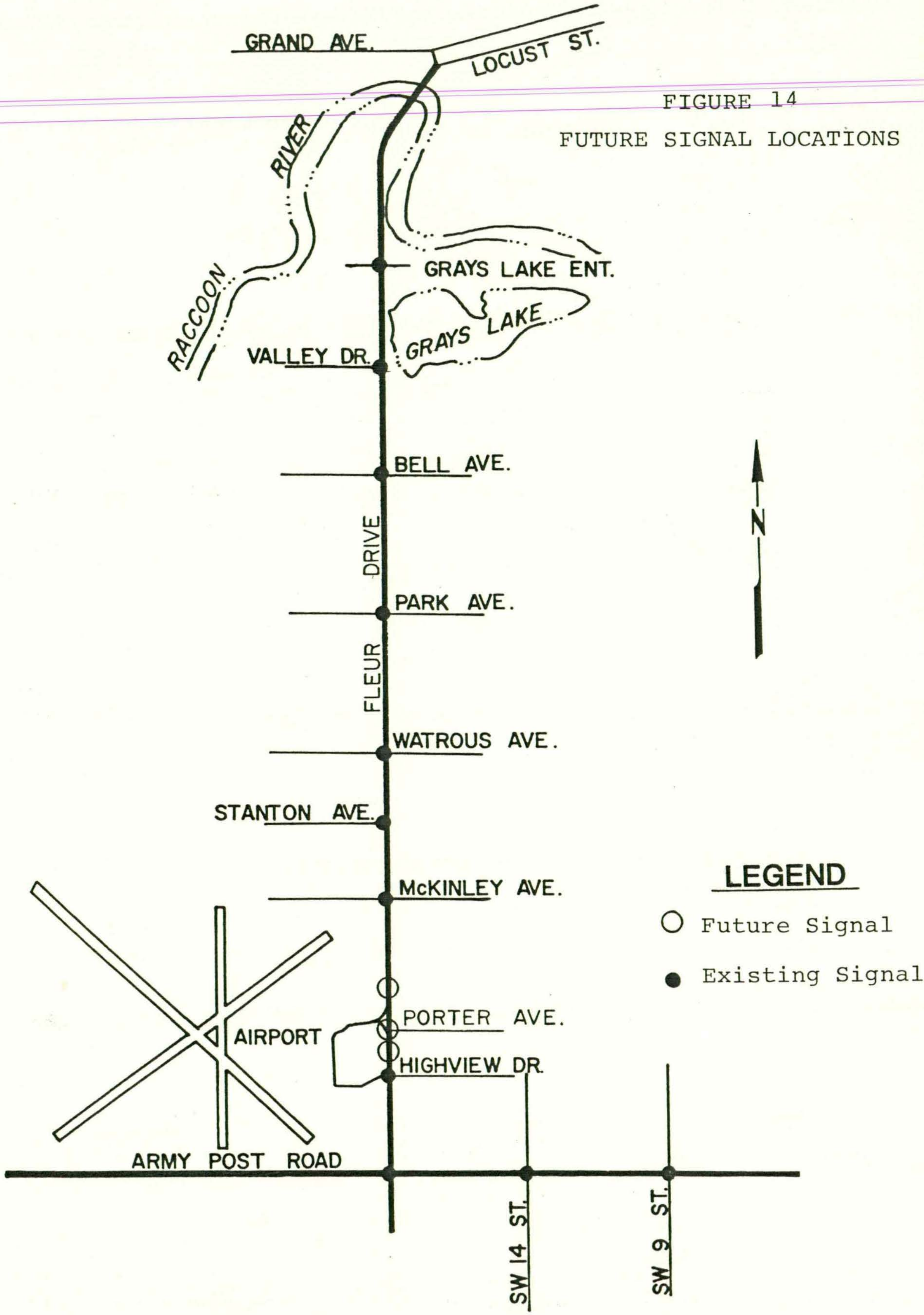
FUTURE SIGNAL LOCATIONS

Only three locations were identified as being possible future signal locations. All three signals are in the airport area, as described above. The future signal locations are shown in Figure 14.

Signalization of Fleur Drive and Porter Avenue may be warranted in the future regardless of any changes in airport access, Porter Avenue is becoming increasingly popular as a route from Southwest 9th Street to Fleur Drive. As Porter Avenue intersects Fleur Drive directly across from the present airport entrance, this would be a logical location for a signal based on geometric considerations.

FIGURE 14

FUTURE SIGNAL LOCATIONS



IV SYSTEM REQUIREMENTS

The operational requirements of a traffic control system are dependent on the existing and future conditions within the controlled area. This section provides an overview of the development and definition of the system requirements which were considered in the development and evaluation of system alternatives.

SECTIONS

A section is defined as an area which experienced homogeneous traffic signal control requirements. The primary objective of the section boundary definition is to define areas in which all signals provide uniform operational efficiency when subjected to a common control strategy. This is a major step in defining the requirements that the upgraded traffic control system should accommodate.

The initial section boundaries were developed by first grouping signals that appeared to be interrelated (e.g., closely spaced, similar land use, etc.) into analysis areas. Within each analysis area, the cycle length requirements were investigated to determine whether compatible cycle lengths could be used in the total area. This was done by computing the cycle length at selected key intersections for the AM, PM, and off-peak periods, using Webster's formula for optimum cycle length for reduction of delay, which was then modified as required to provide minimum pedestrian crossing times. The cycle length requirements within the analysis area were then compared to determine whether the initial grouping was properly configured or if it should be further subdivided.

From this analysis it was concluded that there were not sufficient differences in cycle length requirements to suggest sectional boundaries. Differences in cycle length requirements were found between major and minor intersections, as was expected. However, the cycle length requirements at all major intersections were very similar and they are intersperced throughout the Study Area such that no criteria could be established to justify subdividing the study area into more than one section based on cycle length.

However, there were sufficient differences in traffic characteristics on Army Post Road and on Fleur Drive to establish the need to operate these two arterials as separate sections. While both sections would operate efficiently on the same cycle length, offset requirements vary during the day. During the morning peak, there is a 76/24 northbound traffic directional split on Fleur Drive. At the same time, Army Post Road experiences a 69/31 westbound directional split. However, during the evening peak, Fleur Drive has a 68/32 southbound directional split while Army Post Road still has a predominantly westbound 60/40 preferential split. Therefore, the use of two separate control sections is desired as this will allow greater flexibility in offset selection.

Due to the differences in land use characteristics and the spatial differences of intersections along Fleur Drive, an additional investigation was made of this section to ensure that further subdivision was not required; although subdivision was not justified based on cycle length requirements. This investigation consisted of examining the time-space relationship by means of the computer timing program SIGART. SIGART is an arterial timing program that computes all possible two-way progressions within a speed range defined by the user. Different groupings of signals on Fleur Drive were input into SIGART for various periods of the day. The results were then examined to determine if there were any improvements in the progression band to be realized by further subdividing Fleur Drive into several sections.

An example of the results of this analysis is shown in Table 4 which indicates the progression band speed and the progression band efficiency, expressed as the ratio of progression band time to the green time of the constraining signal, for a 70 second cycle length. From this it was determined that some increase in efficiency could be achieved by subdividing Fleur Drive, but at the expense of progression speed. In addition, the increases in efficiency were not substantial.

TABLE 4
Example of SIGART Analysis of Fleur Drive

ANALYSIS LIMITS	Progression Speed	Efficiency (%)
Grays Lake/Army Post Road	33.4	68.9
Grays Lake/Park Avenue	30.9	79.2
Watrous/Army Post Road	30.9	78.5
Grays Lake/Watrous Avenue	33.4	68.9

From this it was concluded that the system should provide for the operation of two sections; one for Fleur Drive and one for Army Post Road. From the SIGART analysis it was also concluded that good system timing can be developed that will provide substantial benefit to traffic. This was an important finding from the study.

Reassignment of Coordinated Phase

The section analysis also indicated that it would be desirable to operate the signal at Army Post and Fleur Drive with the Fleur Drive section during the morning peak, with the eastbound traffic movement as the coordinated phase. As most of the traffic during the morning comes from the west and turns left onto Fleur Drive, the platoon will be formed at this signal and will be able to continue on Fleur Drive with a minimum of stops.

During the evening peak, however, the intersection should operate with the Army Post Road section, with the southbound traffic movement as the coordinated phase. This may result in stopping southbound motorists, however, the platoon can then continue through the remaining intersections on Army Post Road. The free right turn from the westbound approach, which carries a high percentage of traffic, reduces the need to coordinate the westbound phase with the Army Post Road section during the evening. Therefore, coordinating the southbound phase provides the most benefit.

Coordination Between Sections (Interface)

The interaction of traffic between the two sections indicates that coordination to reduce boundary disruption, when the sections are operating on the same cycle length, is required. This coordination would permit both sections to have the same zero offset reference point. In addition, interface capabilities to a future Southwest 9th Street control system is desired, to allow all three arterials to operate together when cycle length requirements permit.

SIGNAL TIMING PLANS

Identifying the number of different signal timing plans necessary for each section is an important step in defining the capabilities required of a signal system. A detailed traffic flow analysis was performed to provide an indication of the number of timing plans that would be required on a recurring basis to accommodate traffic on a typical day.

Data from the long term volume counts along Fleur Drive and Army Post Road were plotted by time-of-day by the computer program VOLPLOT. The volume plots were divided into time periods of similar volume characteristics, with each time period a candidate for a separate timing plan.

Cycle length and split requirements were then calculated for each intersection during each time period and SIGART timing runs were made. Where cycle length, split, and offset requirements were similar during different periods of the day, one plan was assumed to be suitable for both time periods.

The traffic flow analysis identified the need to provide a minimum of four signal timing plans within each section for efficient traffic operations. These plans would be developed to accommodate the following conditions:

- AM Peak Period
- Off Peak Period
- PM Peak Period
- Nighttime

These plans are required on a repetitive basis to meet "normal" daily traffic conditions. In addition, the off peak plan would provide an adequate level of service for Saturdays and a combination of the Nighttime and off peak timing plans would be utilized on Sundays and Holidays.

As Des Moines is in a northern climate, snow and ice often affects traffic operations during the winter. The effect of inclement weather on average running speed, as determined during speed and delay runs during such conditions, indicates the need for special timing plans during ice or fresh snow conditions. Additional SIGART runs, with splits adjusted to give maximum possible time to the arterial, were made for the lower speed ranges found during snow conditions. The inclement weather timing plans were added to those identified for repetitive conditions and provided the basis for determining the timing plan capabilities required.

TIMING PLAN SELECTION

Because of the arterial nature of Fleur Drive, traffic responsive timing plan selection is required for efficient operation. Traffic responsive operation will provide the flexibility necessary to cope with varying peak periods and short term changes due to shift changes and other conditions typical of arterial systems.

However, a time-of-day, day-of-week override is required due to the short, high volume peak periods, due to the employment concentration on portions of the Study Area. The time-of-day override will serve as an anticipator, eliminating the response delay inherent to traffic responsive systems. This will permit signal timing for the repetitive peak periods to be implemented and stabilized before the peak begins.

Inclement weather timing plans should be selected manually. This can be accomplished either at the master or remotely by use of telephone lines.

INTERSECTION OPERATION STRATEGY

An important step in developing the system requirements for Fleur Drive and Army Post Road is defining a control strategy for each signal to maximize its operational efficiency. Intersection efficiency is heavily dependent upon signal phasing and in general, the intersection efficiency decreases as the signal phasing complexity increases. Thus, a two phase signal would tend to be more efficient than a three phase signal--unless the third phase was warranted based on conflict severity, visibility obstructions, and/or accident experience.

When signalizing an new intersection the designer can develop the phasing based on an engineering analysis and the agency's general signalization policy. However, when conducting a phasing analysis at an existing signal, such as those within the study area, the designer must also consider driver expectation due to current signal operation, and the analysis is generally performed without a full understanding of the prior conditions (and whether they still exist) that resulted in the current phasing.

To develop the local signal control strategy required, a detailed analysis was performed at each intersection. The investigation was directed to determine the mode of control (e.g., pretimed or traffic actuated), signal phasing, and whether special control techniques such as Critical Intersection Control were required.

Phasing Analysis

Eight of the eleven signalized intersections within the Study Area have more than two signal phases with a protected left turn phase on at least one intersection approach. Of these, six intersections use a protected only left turn operation (left turns can only be made during the green arrow interval and not during the circular green indication) and two provide for protected/permissive left turns.

While protected left turn phases are valuable where heavy left turns conflict with high opposing traffic volumes, unnecessary phases may create long delays to traffic. Additional phases also result in long cycle lengths and/or reduce the time available for the progression band and can thereby reduce the effectiveness of the system.

There is no standard criteria to provide guidance as to when left turn signal phases are warranted. The Traffic Institute at Northwestern University has developed nomographs in the Intersection Capacity Analysis Charts and Procedures which provide an indication of capacity of non-protected left turn lanes. The left turn lane capacity is based upon opposing traffic, cycle split, and percentage of truck traffic. If actual left turn volumes exceed the computed left turn lane's capacity, then left turn phasing should be considered.

The State of California utilizes a different and more simplistic procedure for analyzing left turn phasing requirements. If left turns exceed 50 vehicles per hour during the peak hour and if the product of the left turn and conflicting through peak hour volumes exceeds 100,000, then the left turn phasing is warranted by the California method.

Each intersection in the Study Area was analyzed by both of the above methods. The results of this analysis, shown in

Table 5, indicates that multi-phase signal operation is required at six intersections for one or more of the left turn traffic movements.

TABLE 5

Left Turn Phases Warranted

INTERSECTION	Left Turn Direction	LEFT TURN PHASE WARRANTED BY Traffic Institute Method	California Method
Bell Avenue at Fleur Drive	SB	X	X
	EB	X	
	WB	X	
Park Avenue at Fleur Drive	NB	X	X
	WB	X	
Watrous Avenue at Fleur Drive	SB	X	X
McKinley Avenue at Fleur Drive	SB	X	X
Army Post Road at Fleur Drive	EB	X	X
Army Post Road at SW 9th Street	EB	X	

As left turn signal phases are currently provided for several left turn traffic movements that the previous analysis did not indicate should be protected, an investigation was made to determine what the impact would be if protected operation was retained. This was necessary as the motorist is accustomed to protected left turn phases and their removal may result in confusion. In addition, due to the arterial characteristics of both Fleur Drive and Army Post Road, a consistency in arterial traffic signalization treatment for all intersections is desirable. Uniformity of signalization would not be achieved if signal phasing for only selected turning movements at six of the eleven intersections.

The investigation was performed through a capacity analysis of each intersection to determine the level of service provided by alternative signal phasing and controller operation strategies. From this, it was determined that:

- Protected only left turn phasing would result in a reduced level of service.
- Protected/permissive left turn signal phasing provides a substantially increased level of service. The analysis indicated that there is adequate time for a significant portion of the left turning traffic to be made during the green or clearance period due to the intersection preferential traffic characteristics.
- Leading left turn phases were found to be ineffective at numerous locations as the protected portion of the left turn phase would be displayed for one or two vehicles that could easily and safely make the turn during the permissive. However, lagging protected/ permissive left turns pose a safety problem and are unacceptable.
- The time allocated to the protected portion of the left turn phase should be individually established as a function of the timing plan in effect to accommodate the differences in AM peak and PM peak preferential traffic movements.

As a result of these findings, signal phasing and an operational strategy was developed for each intersection. The recommended signal phasing is shown in Table 6..

TABLE 6

Recommended Signal Phasing

INTERSECTION	EXISTING	RECOMMENDED
Fleur Drive/Grays Lake	2Ø	2Ø
Fleur Drive/Valley Drive	5Ø	5Ø
Fleur Drive/Bell Avenue	6Ø	8Ø
Fleur Drive/Park Avenue	6Ø	8Ø
Fleur Drive/Watrous Avenue	5Ø	5Ø
Fleur Drive/Stanton Avenue	5Ø	5Ø
Fleur Drive/McKinley Avenue	5Ø	5Ø
Fleur Drive/Highview Drive	3Ø	3Ø
Fleur Drive/Army Post Road	5Ø	4Ø*
Army Post Road/SW 14th Street	2Ø	2Ø
Army Post Road/SW 9th Street	2Ø	8Ø

* Sequential Operation

Signal Control Mode

Although all of the signals in the Study Area are traffic actuated, an investigation was performed to determine if pretimed controller operation would be applicable. If adequate system operation could be provided by replacing the actuated controllers with pretimed controllers, a substantial reduction in initial and maintenance costs could be realized. The following conclusions resulted from this investigation:

- The SIGART analysis indicated that there were sufficient differences in signal spacing to adversly affect the progression band. Increased efficiency could be realized at critical locations by returning "unused" side street green time to the arterial.
- The turning movement counts indicated considerable variation in side street traffic.
- The left turn phasing and control strategy is dependent upon traffic actuated control.

Therefore, the controller equipment should remain traffic actuated.

Special Operation

An analysis was conducted to determine if other conditions existed that would warrant special control strategies. Examples of special control strategies include congestion detection and Critical Intersection Control (CIC).

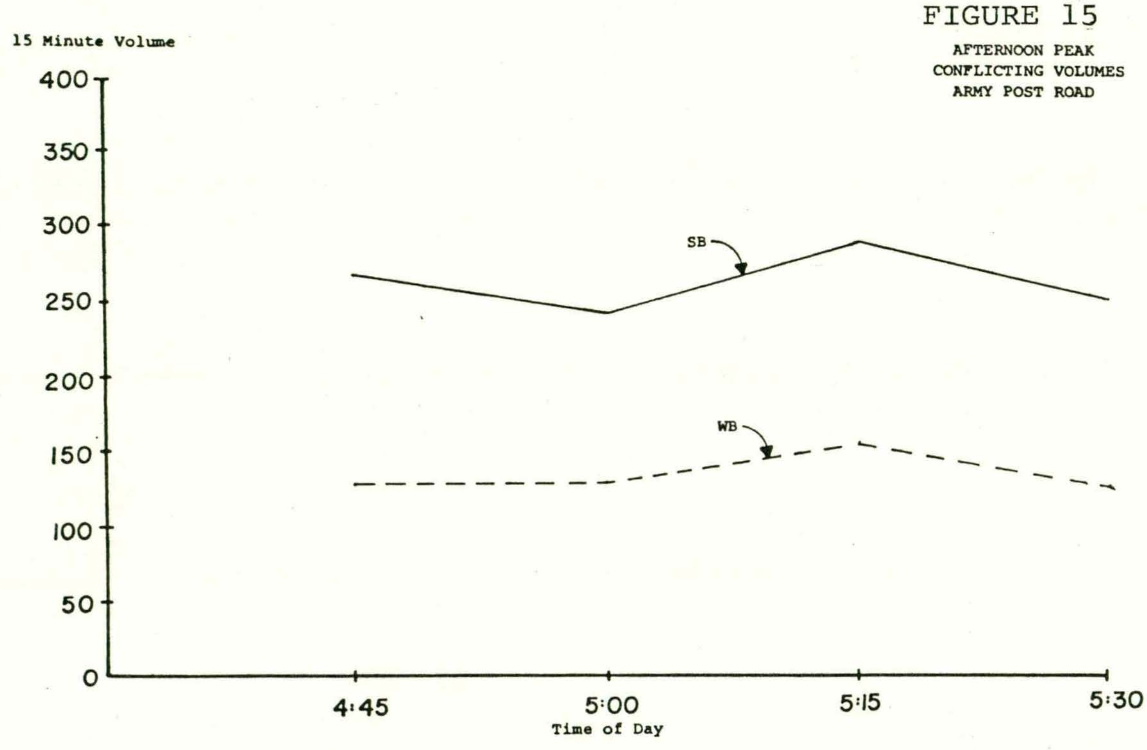
Although congestion is a common occurance in the Study Area, it was found to be predictable. Of more importance, the conditions resulting in congestion do not lend themselves to correction through different control strategies, such as diversion, signal phasing changes, etc. Anticipating peak periods by time-of-day plan selection and efficient signal phasing were found to be the best techniques for reducing congestion.

An analysis of CIC control also indicated that this strategy was not required for the Fleur Drive/Army Post Road system. CIC control is applicable for signals near capacity where there are variations in the controlling conflicting traffic volumes. Several signals in the

Study Area meet the capacity criteria, however, the variation in conflicting traffic volumes do not exist. Figure 15 shows a plot of the southbound and westbound traffic volumes at Fleur Drive and Army Post Road. As can be seen, there are differences in the traffic volume on each approach during the peak hour; however, they "track" each other. This is typical of all intersections in the Study Area. Therefore, CIC control is not applicable.

It was determined, however, that there is the need to provide special operation during certain inclement weather conditions. This consists of the ability to degrade the normal controller response during snow and ice conditions as part of the inclement weather timing plans.

FIGURE 15
AFTERNOON PEAK
CONFLICTING VOLUMES
ARMY POST ROAD



SYSTEM FLEXIBILITY

An important aspect considered during the system analysis was the flexibility required to accommodate future conditions. The proposed system must have the capability of adding signals that may be installed within the system boundaries. Within the design life of the system, three additional signals along Fleur Drive may be installed. These signals would result due to the redesign of access to the Municipal Airport. The system must have the capability to incorporate these future signals.

The analyses of existing and future traffic conditions indicated that semi-annual signal retiming may be required to accommodate seasonal traffic characteristics. This retiming may require only minor modifications such as changes in the split or offset of one or two signals. Development of new timing plans and a major system retiming may be required every two or three years as traffic conditions change. The ability to easily implement new timing plans will be important in maintaining a high level of service. The system should be designed with a future tie-in to the City wide control system in mind. Although some components may not be compatible with a computer based system, controllers and communications facilities should be capable of being incorporated into a future area-wide system.

V CANDIDATE SIGNAL SYSTEMS

During the past five years there has been substantial signal system development activity. New traffic control concepts and techniques have been developed by traffic engineers, researchers, and manufacturers. In addition, major advances in digital and microprocessor electronics have increased the flexibility and reliability, while reducing the cost, of arterial control systems.

As part of this project, a description of state-of-the-art, traffic responsive arterial type signal systems were prepared. This report, presented as Interim Report Number 3, briefly detailed equipment presently offered by the major controller manufacturers.

Numerous alternative signal systems can be configured by combining various traffic control strategies and types of hardware. As an evaluation of all possible system configurations would cloud the decision process, it is necessary to define only those system alternatives that are viable candidates for implementation on Fleur Drive and Army Post Road. Thus, the objective in candidate system development is to define a limited number of alternatives where each alternative, when considered individually, is a good choice.

The procedure used to develop candidates for the Fleur Drive/Army Post Road system was based on system analysis procedures which incorporated the influence of local conditions. Each alternative was measured against the system requirements to determine whether it deserved further consideration as a candidate system. In addition, only those systems that had distinct differences in capabilities or configuration characteristics were defined as candidate systems. This permits the difference in system capabilities to be measured in terms of incremental utility and cost.

CANDIDATE SYSTEM DESCRIPTIONS

Six candidate systems were defined for evaluation, ranging in complexity from a conventional traffic responsive, three cycle length, three offset system using existing intersection control equipment, to a centrally located mini-computer based system

The existing signal operation was not included as a candidate for evaluation purposes. It was excluded as an alternative as safer and more efficient signal operation requires the synchronization of the presently non-interconnected signals.

Following are descriptions of the six candidate systems. A graphic representation follows each candidate description.

CANDIDATE 1

Candidate 1 is designed to provide traffic responsive operation while utilizing existing intersection control equipment. The system will be divided into two sections but due to equipment limitations, the section boundary will be between McKinley Avenue and Highview Drive instead of at Fleur Drive and Army Post Road, as shown in Figure 16.

Two solid-state masters will be provided, one for each section. Each master will select timing plans on a traffic responsive basis but will be provided with a programmable time-of-day/day-of-week override, accomplished by either internal circuits or by a separate solid-state timing device. The master will be capable of selecting three cycle lengths with three offsets per cycle. One split will be provided for each cycle.

Twelve sampling detectors will be installed. Eight detectors will provide volume and occupancy data to the Fleur Drive Master.

Each intersection will be equipped with a coordination unit that performs system function timing, based on cycle length and offset selection commands and resynchronization pulses from the master controller. Coordination units will have to be compatible with their associated controller, as not all existing controllers meet NEMA interface standards.

The intersection controllers and cabinets at Fleur Drive and Bell Avenue and at Fleur Drive and Park Avenue will be

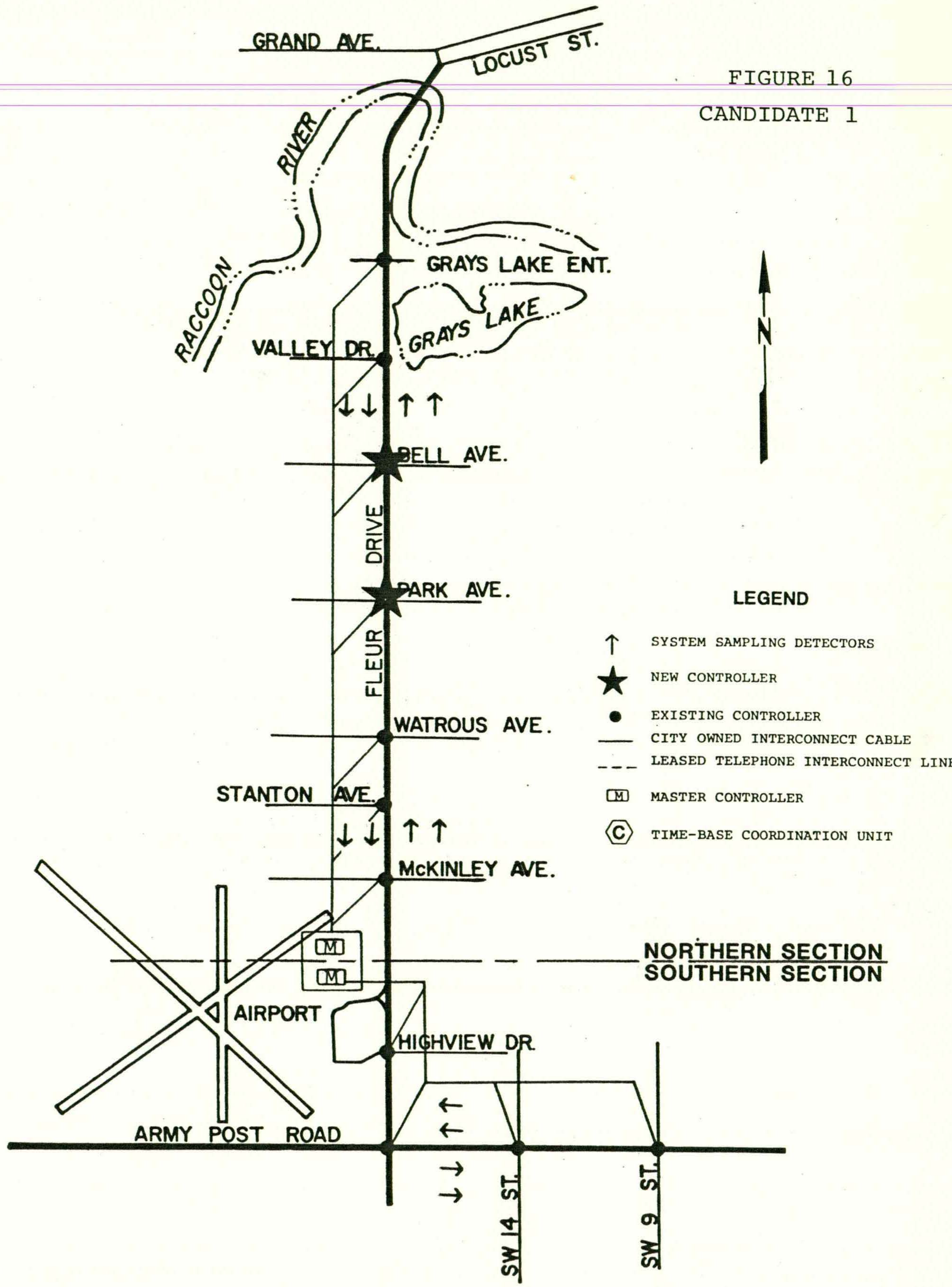


FIGURE 16

CANDIDATE 1

replaced because of proposed phasing changes. However, all other controllers will be retained. Communications will be provided by City owned multi-conductor cable located in underground telephone company ducts. One duct is reserved for City use, free of charge, as a provision of the franchise agreement between Northwestern Bell Telephone and the City.

CANDIDATE 2

Candidate 2 is similar to Candidate 1, as shown in Figure 17, except that controllers that do not meet NEMA interface standards would be replaced.

- Fleur Drive and Grays Lake Entrance
- Fleur Drive and Valley Drive
- Fleur Drive and Bell Avenue
- Fleur Drive and Park Avenue
- Fleur Drive and Watrous Avenue
- Fleur Drive and Highview Drive

State-of-the-art coordination units, designed to provide controller inputs defined by NEMA standards, would be provided. Replacing non-NEMA controllers eliminates the non-interchangeability of coordinating units in Candidate 1 that results by modifying them to interface with the older controllers.

Interconnection will be accomplished by the same method as described for Candidate 1, using City owned cable.

CANDIDATE 3

Candidate 3 utilizes new technology to provide coordinated operation without the use of a communications link between signals. This is accomplished by a local coordination unit that has precision time-keeping capabilities derived from the 60 hertz power source. The system configuration is shown in Figure 18.

FIGURE 17

CANDIDATE 2

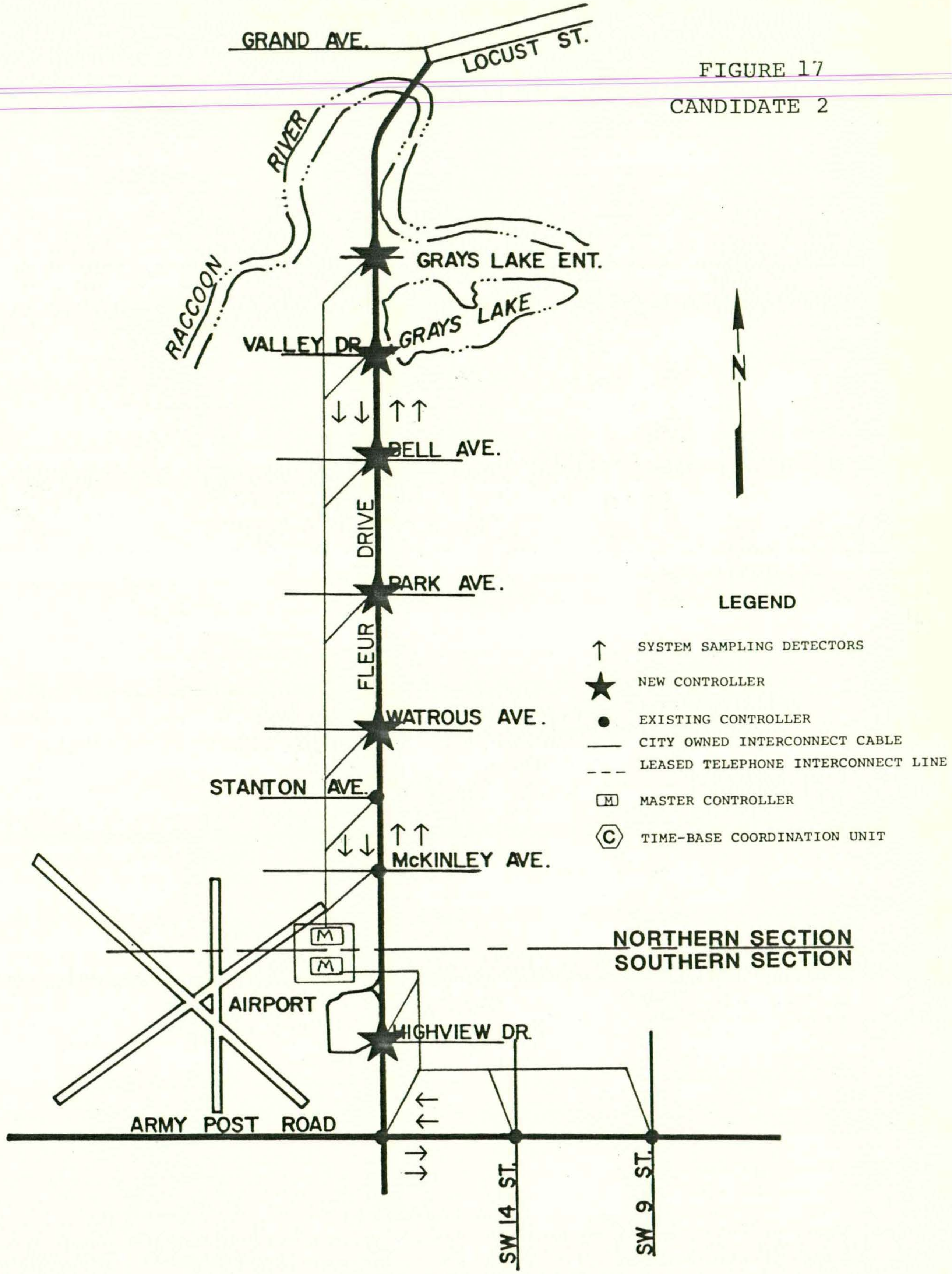
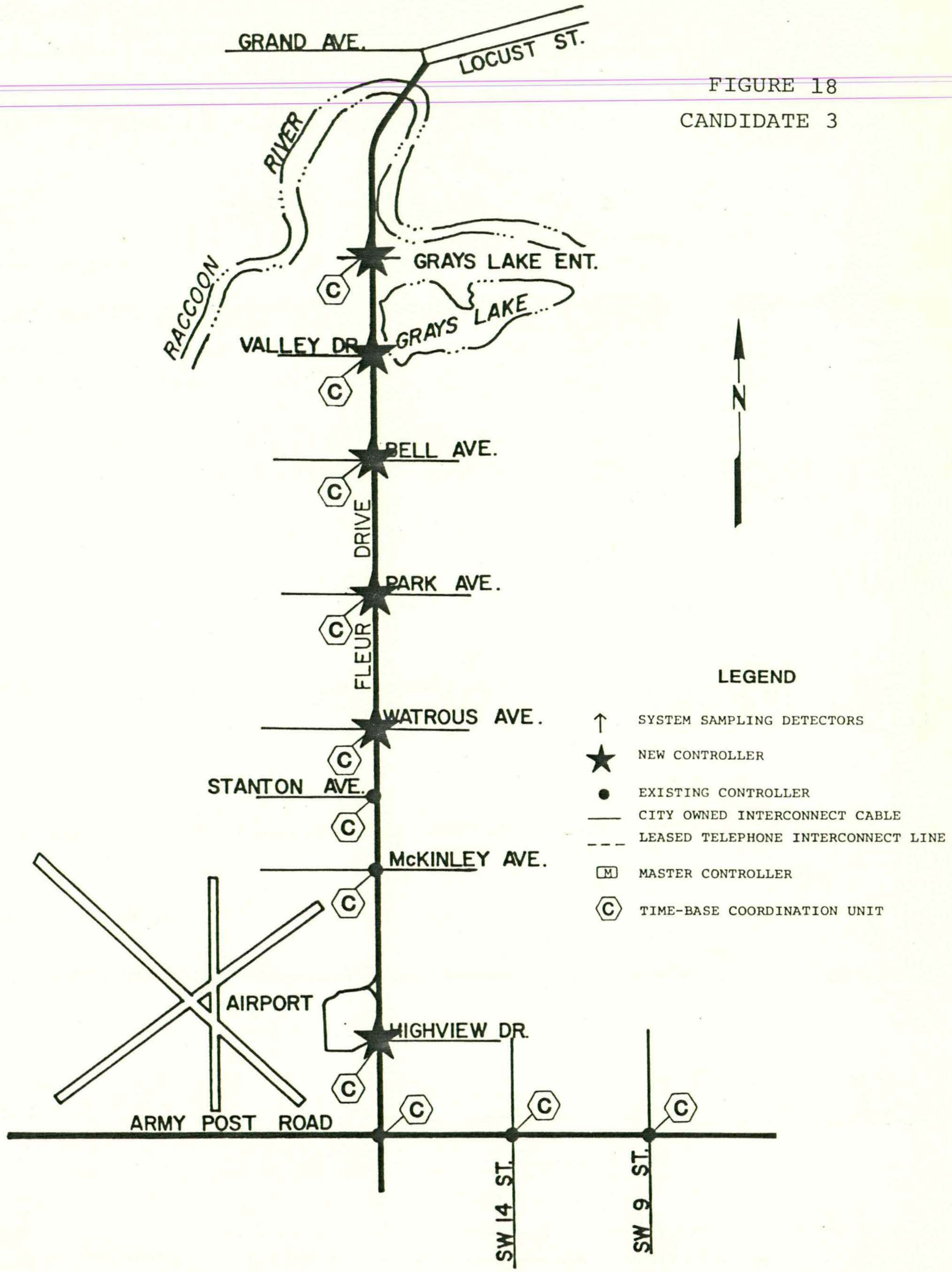


FIGURE 18
CANDIDATE 3



Each "time based" coordinator is provided with a time-of-day/day-of-week schedular to permit different cycle length, split and offsets (timing plans) to be implemented. Although the system does not contain a master as such, the time keeping capabilities and scheduler permit the correct relationship between signals to be maintained and provide up to nine different signal timing plans.

In the event of a power outage, battery backup timing is provided such that when power returns the coordination units maintain the correct time. In the event the power outage exceeds the battery limits, the controller assumes "free" operation when power returns.

CANDIDATE 4

This Candidate is a traffic responsive system that "down-loads" controller timing data stored by the master to each local controller at the start of every new timing plan. Therefore, only the active timing program is resident at the controller. This permits each intersection to run an unlimited number of patterns with the only restriction being the pattern storage capabilities of the master.

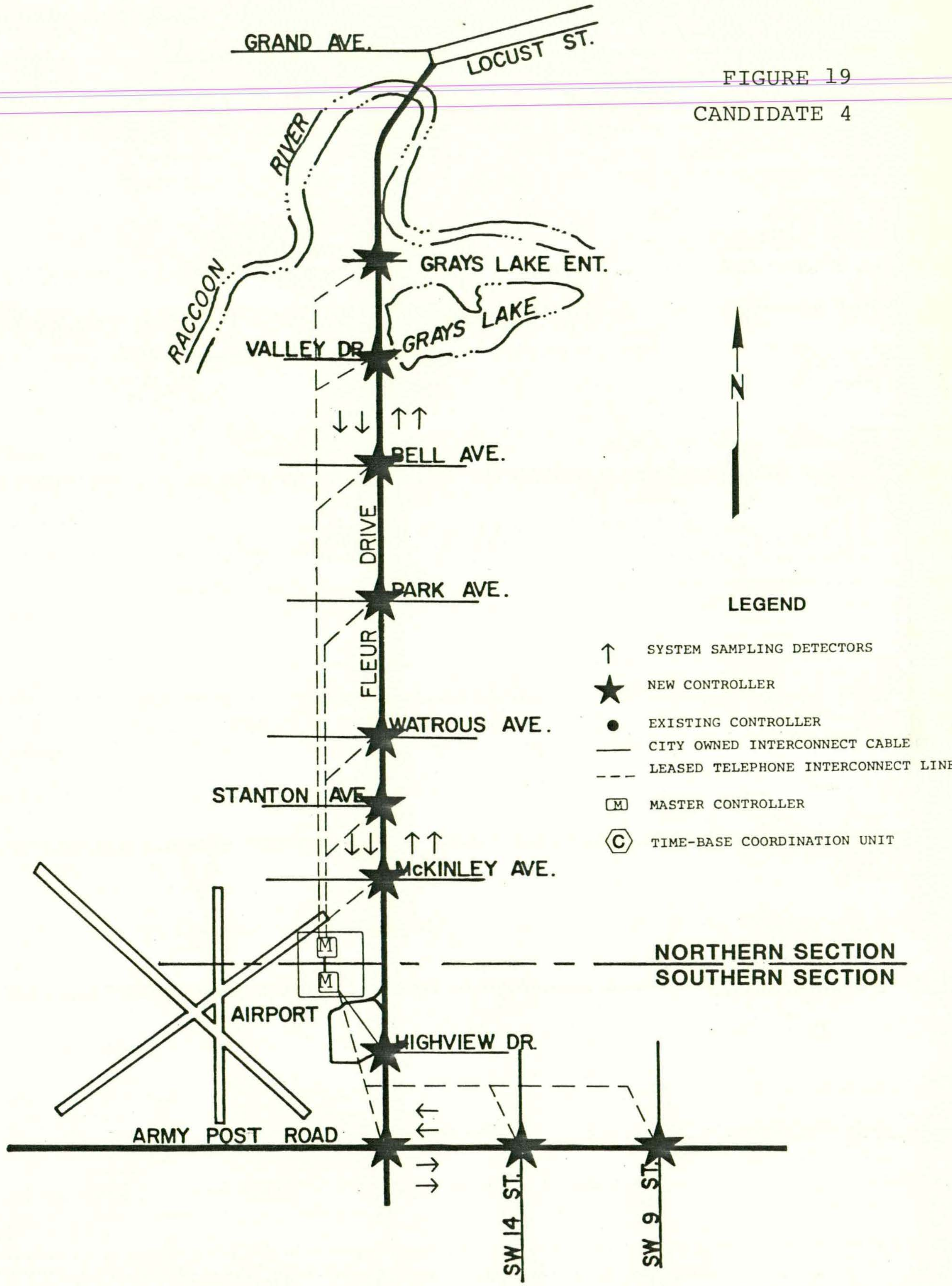
Two masters will be required, one for each section. The section boundary will be north of Highview Drive on Fleur Drive as shown in Figure 19. The masters will synchronize with each other when they are on a common cycle length.

Each master has the capability of ten timing plans. The plans are selectable on a traffic responsive basis with a time-of-day/day-of-week override. The master has the capability of modifying the signal phasing sequence and changing the coordinated phase, depending on the timing plan in effect. New timing plans, changes to existing timing, or modifications to timing plan selection criteria are installed by programming performed only at the master.

Twelve sampling detectors will be installed to provide data for the traffic responsive timing plan selection process.

FIGURE 19

CANDIDATE 4



Eight of these detectors will be assigned to the Fleur Drive section, with the remaining four connected to the Army Post Road section.

Local coordination units are not required, as coordination is accomplished by controller software that acts on the timing plan data transmitted by the master. As a result all intersection controllers will be replaced. The controllers meet NEMA standards, but contain additional special circuits to provide the coordination function. As a result, these controllers can be substituted for NEMA controllers at other locations but other NEMA controllers can not be used to replace the Candidate 4 controllers and provide system operation.

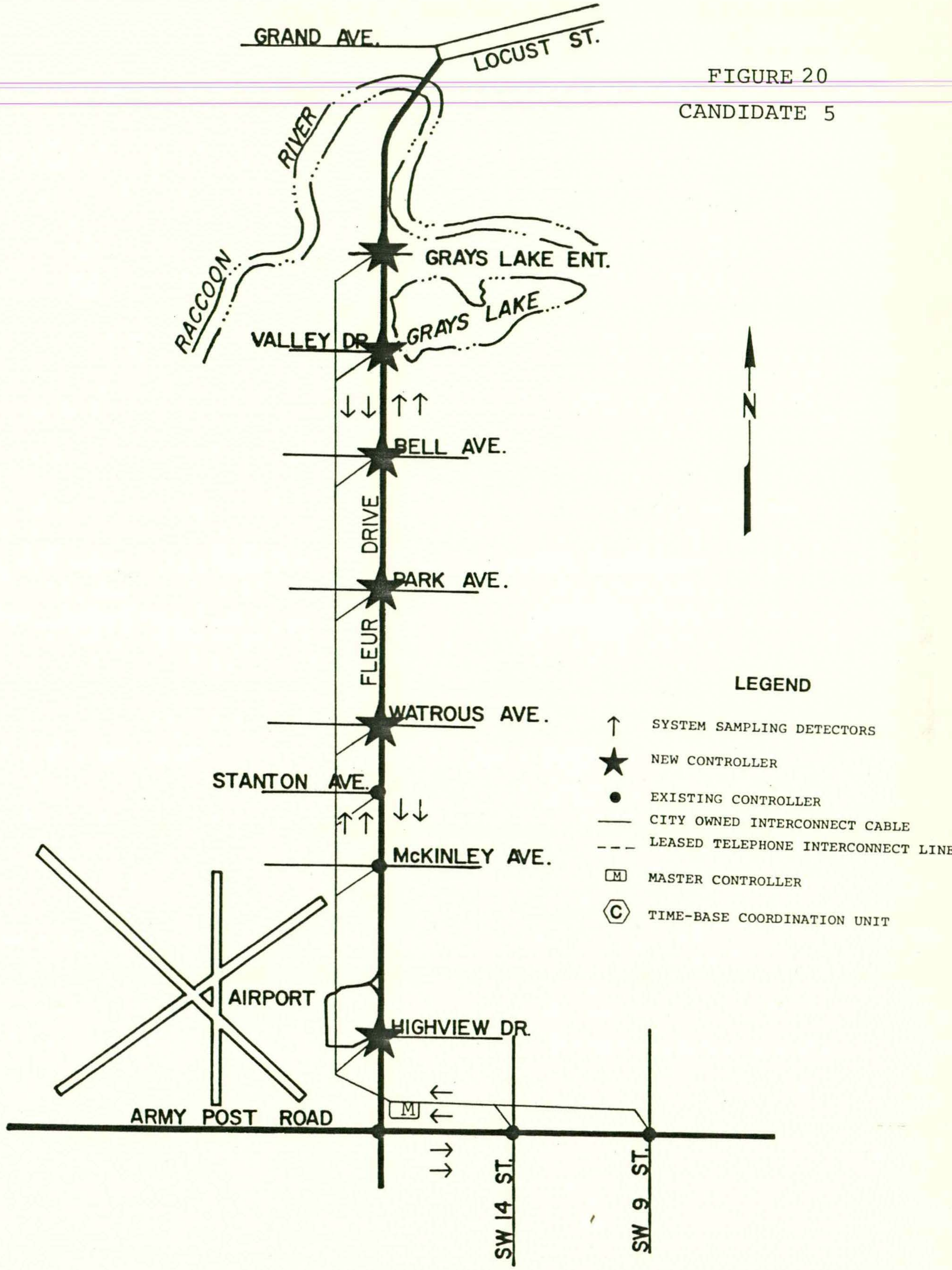
Three standard voice grade telephone circuits are required for communications. As each two-wire circuit can control four signals, two circuits will be required for the northern section of Fleur Drive and one circuit is required for the four signals in the southern section of the system. Standard Bell Telephone type 202D modems are required at each intersection and for each telephone circuit at the master.

CANDIDATE 5

Candidate 5 is a traffic responsive system in which the master supervises each controller directly without the use of local coordination units or special circuits. The master stores twelve timing plans, with each plan providing a unique cycle length, offset, and split for each intersection in the system. Plan selection for nine of the timing plans is performed on a traffic responsive basis with time-of-day override. Three of the plans are selected only by a manual switch, or other device, in the master controller cabinet and would be used for inclement weather timing plan selection.

Candidate 5 will not be divided into sections as both Army Post Road and Fleur Drive can be operated on the same cycle length. The flexibility lost by configuring the system as one section, however, is compensated by the systems' ability to

FIGURE 20
CANDIDATE 5



reassign the coordinated phase at Army Post Road and Fleur Drive as required to accommodate the differences in AM and PM peak hour traffic.

Local coordination units are not required as the master transmits the required hold and force-off commands directly to the controller. However, non-NEMA controllers will be replaced to permit standardization of outputs from the master and standardization of controller interface.

Twelve sampling detectors will provide information necessary for traffic responsive plan selection. The master checks for the reasonability of detector data so that a failed detector will not affect timing plan selection. If several detectors fail, so that insufficient traffic data are available to the master, the system will revert to time-of-day pattern selection.

Interconnection will be accomplished through city owned, multi-conductor, 19-gauge cable, located in underground telephone company duct.

CANDIDATE 6

Candidate 6 represents a major change in concept from the preceeding alternatives. In this concept, timing plans are stored at a centrally located computer rather than a master located at street side. In addition, controller status information is made available to the master for monitoring and failure identification purposes.

The master consists of a digital mini- or micro-computer that is capable of storing a large number of signal timing plans for both recurring and special event traffic patterns. Plan selection can be performed by time-of-day/day-of-week or by traffic responsive modes of operation. Sections are established by input parameters to the software and they can be easily reconstructed as frequently as required to respond to changes in traffic conditions.

Two sections will be configured initially, with their boundary at the intersection of Fleur Drive and Army Post Road as shown in Figure 21. The intersection will be assigned to either section based on timing plans in effect. When both sections have the same cycle length they will be synchronized to the same zero offset reference point.

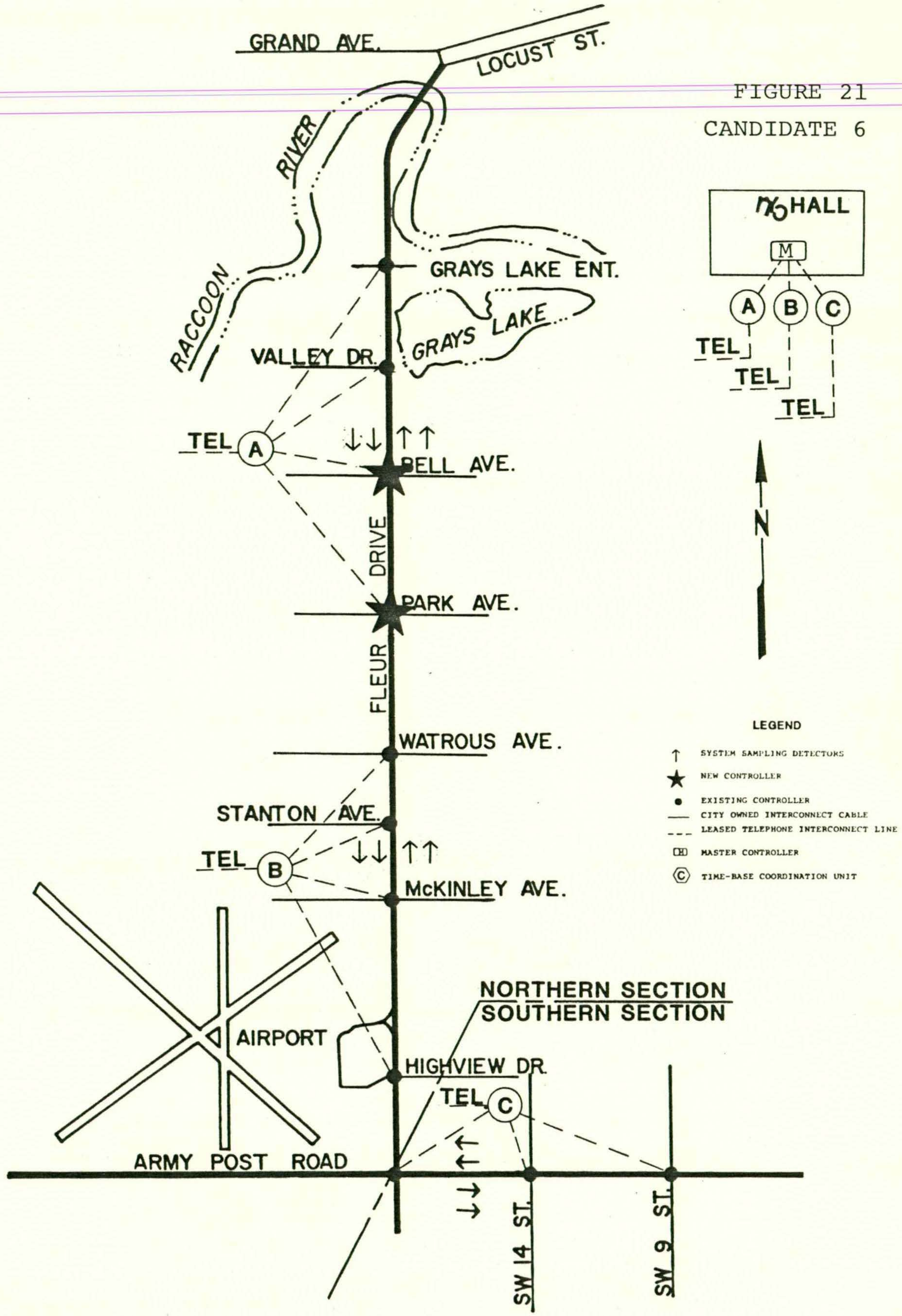
The master will supervise each local controller by issuing phase advance commands. Local controllers, detectors, and communications equipment will be constantly monitored by the master for malfunctions.

The master for Candidate 6 is more sensitive to environmental conditions than the equipment in previous alternatives. Therefore, the master will be located at the Traffic Engineering office in City Hall or at some other suitable location.

Two intersection controllers (Fleur Drive at Bell Avenue and at Park Avenue) will be replaced due to phasing changes. All other existing controllers will be retained.

Communications will be by telephone lines, with one circuit required for four intersections. Therefore, three circuits will be required into City Hall, with a multi-drop arrangement for each group of four controllers.

FIGURE 21
CANDIDATE 6



VI CANDIDATE SYSTEM EVALUATION

The six signal system configurations, defined as candidate systems for implementation within the Study Area, were selected as they provided specific features that satisfied some, or all, of the requirements that had been defined through analysis. In a similar manner, these same requirements were used in the evaluation of candidates to select the most cost-effective system. However, as these requirements were primarily directed to provide methods to address "on the street" problems (e.g., number of timing plans), it was necessary to supplement them with non-traffic related operational considerations (e.g., system reliability) to ensure that all pertinent factors were included in the decision process. Since the evaluation included elements that are defined through analysis and elements that are intangible in nature, a modified form of the Utility/Cost Evaluation Procedure, in which the value or benefit is measured by a proxy value termed "utility", was employed. As the Utility/Cost Evaluation Procedure is best suited for the evaluation of an area-wide signal system, the procedure was altered to place more emphasis on evaluating the relative performance of each candidate. The resulting Fleur Drive/Army Post Road System evaluation procedure consisted of the following activities:

- A set of performance goals were established to describe the system characteristics.
- Each of the goals were then assigned a point value to indicate its importance in the decision process.
- Where practical, the major components within the goal were defined and its relative importance within the goal established.
- Each candidate was then rated as to its ability to satisfy each goal and the goal values summed to indicate each candidate's total performance rating.
- The cost of each candidate was estimated and the performance ratio obtained by dividing the performance rating by the estimated cost.

- The candidate obtaining the best performance ratio (i.e., the most cost effective candidate) was then subjected to a Benefit/Cost Analysis to determine the economic return anticipated if the candidate is implemented.

This procedure ensured that all candidates were evaluated within a consistant framework. Furthermore, the procedure considered only those factors that were relevant to the Study Area.

PERFORMANCE GOALS

The performance goals were defined through analysis procedures and by direct participation of the Technical Advisory Committee. Requirements relative to traffic operations strategies were defined through an evaluation of existing and future traffic conditions. System operations or management objectives were defined through an analysis of current operating procedures and capabilities and through guidance provided by the Technical Advisory Committee; with the City's active participation.

Goal 1 - Section Considerations

This goal consists of being able to physically structure and operate the candidate to provide certain traffic operations features within the sectional hierarchy of the system (where a section is defined as a grouping of signals that operate in unison). Within this goal there are three major elements as follows:

- Configuration - The ability of the candidate to efficiently provide for the operation of two sections containing the signals defined through analysis. It should be noted that most of the candidates could be physically connected to provide two sections. However, some could not provide the operational strategy required for certain signals within the desired boundaries.

- Signal Reassignment - The ability to reassign the signal at Fleur Drive and Army Post Road to operate either in the section containing the signals on Fleur Drive or the section containing the signals on Army Post Road is a key factor in obtaining the required sectional operation.

° Section Coordination - For those candidates that permitted multiple section configuration, the ability to maintain a common offset reference when the sections were implementating the same cycle length is required to minimize disruption to traffic flow at the section boundaries.

To some extent, the elements describing the section considerations may be dependent. For example, a candidate that can only be configured as a single section automatically provides section coordination. However, the flexibility provided by configuring the system as two sections are lost. This would not be the case for other candidates, thus the elements permit clear definition of a candidates' capabilities to satisfy this goal.

Goal 2 - Timing Plans

The efficiency of signal operation within the Study Area is comprised of two strategy levels. The first level consists of the signal timing and operation provided locally. The second level consists of the restraints that are superimposed upon the local strategy to operate all signals within a section to optimize performance on an areawide or systems basis. This goal consists of the candidates ability to provide the capability and flexibility to implement timing plans within the systems context. The goal is described for the Fleur Drive/Army Post Road Systems by four major elements as follows:

° Repetitive Timing Plans - this is the ability of the candidate to provide the number and type of system timing plans required for normal day-by-day operation. This includes both weekdays and weekend requirements.

° Inclement Weather Timing Plans - this pertains to the ability of the candidate to select and provide system timing plans designed to accommodate traffic characteristics during the inclement weather.

° Traffic Responsive Plan Selection - this is the ability of the candidate to select and implement system timing plans based on traffic parameters obtained by system sampling detectors placed at strategic locations within the system.

- Time-of-Day/Day-of-Week (TOD/DOW) Plan Selection - this is the ability of the candidate to select and implement system timing plans at a preprogrammed time in anticipation of events that are known to occur on a repetitive basis. This would override plans selected by traffic responsive plan selection.

In contrast to the elements comprising the section consideration performance goal, the elements describing the timing plan performance goal are exclusive.

Goal 3 - Local Control

This goal addresses the signal timing and operational capabilities provided locally; the first strategy level that defines operational efficiency. In each of the candidates evaluated, the phasing and mode of operation required to maximize efficient isolated signal operation was included. However, the features to be provided by a system to satisfy the local control requirements goal are described by the following elements:

- Reassignment of Coordinated Phase - this pertains to the ability at the intersection of Fleur Drive and Army Post Road to assign the corrdinated phase to either street as required based on traffic characteristics. In effect, this capability permits facilitating the traffic movement that will result in the greatest overall benefit at this key intersection.

- Independent Phase Timing - this described the ability to individually time the duration of each signal phase as a function only of the timing plan in effect. This is particularly important for opposing left turn phases where it is necessary to provide more green time for one phase during the AM Peak and to provide the reverse during the PM Peak.

- Special Function - this is the ability of the candidate to provide for a specialized operation, such as changes in detector configuration, as a function of one or more timing plans.

The definition of the local control performance goal through analysis is critical in ensuring that the features to be provided are neither too complex, and therefore unused, nor inadequate to accommodate traffic demands.

Goal 4 - Complexity

Within the previous performance goals, the objective is to attain complete satisfaction of all elements. However, the objective of the complexity performance goal is to minimize the intricacy of the system. Achieving this goal assures that the functions provided are easily and clearly understood. This tends to encourage full utilization of the features provided by the system. Futhermore, by fully understanding how the system works, enhancements to accommodate unforseen situations are more easily made.

Within this goal the complexity of each of the major system components are viewed independently and then aggregated. Thus, the goal is defined based on the complexity of the master, communications, and local hardware components.

Goal 5 - Reliability

Reliability is an item of major concern in any traffic control system. As long as the system is operational it may fulfill the traffic operations goal very well. However, this may be overshadowed if the system is inoperative much of the time. Reliability can therefore be expressed in terms of the amount of time the entire system, or major components of the system, are inoperative. As above, the reliability of each of the major system components are assessed and aggregated to determine the candidates ability to achieve the performance goal.

Goal 6 - Maintainability

This goal has as its primary objective to minimize the level of preventative and emergency maintenance required to operate the system. To some extent the goal is in harmony with the complexity and reliability performance goals in that satisfying two of these goals generally results in satisfying the third. However, this is not necessarily the case as the system could be easily understood and very reliable provided that a high level of preventative maintenance is maintained.

Goal 7 - Flexibility

This goal requires that the traffic control system has sufficient reserve capabilities to accommodate future conditions anticipated in the Study Area. This includes the ability to add additional signals, to permit new timing plans to be easily implemented as traffic conditions change, and to have the ability to interface with an areawide system at some future date. This latter objective is of particular importance in view of the current energy crisis and the proven ability of an areawide control system to result in substantial reductions in fuel usage.

Goal 8 - Equipment Monitoring

Current traffic control system technology has proven that major benefits to the public can be realized if the system has self monitoring capabilities. Although it would be very desirable if the Fleur Drive/Army Post Road system could monitor all components (e.g., controllers, etc.) a reduced level has been established that is necessary for efficient operation as the performance goal. The goal is therefore defined as the systems ability to recognize improper system detector data and the ability to recognize a master or communications failure such that signals are returned to isolated control.

GOAL WEIGHTING

Based on the analysis of existing and future conditions and on discussions held with City personnel, each of the performance goals were weighted as to their relative importance in the decision process.

In addition, where the goal was further described by elements within the goal, the importance of the element was also established. These were then discussed with the Technical Advisory Committee and formed the criteria against which each candidate system was evaluated. The results are presented in Table 7.

TABLE 7

Performance Goal Weighting

Number	Goal		Points
1	Section Considerations		100
	° Configuration	(20%)	
	° Signal Reassignment	(30%)	
	° Section Coordination	(50%)	
2	Timing Plans		300
	° Repetitive	(40%)	
	° Inclement	(20%)	
	° Traffic Responsive	(30%)	
	° TOD/DOW	(10%)	
3	Local Control		300
	° Reassign Cord. Phase	(50%)	
	° Independent Phase Timing	(40%)	
	° Special Function	(10%)	
4	Complexity		60
	° Master	(33.3%)	
	° Communications	(33.3%)	
	° Controller	(33.3%)	
5	Reliability		60
	° Master	(33.3%)	
	° Communications	(33.3%)	
	° Controller	(33.3%)	
6	Maintainability		60
	° Master	(33.3%)	
	° Communications	(33.3%)	
	° Controller	(33.3%)	
7	Flexibility		70
8	Equipment Monitoring		50

As a result of the goal and element weighting procedure, over one half of the decision is based on the candidates ability to provide the local and system operational capabilities defined through analysis (Goals 2 and 3). As these goals relate directly to on-the-street operation and were rigorously defined, the relative importance of these goals are justified and consistant with the importance other jurisdictions have given them when performing similar studies.

However, almost one third of the decision is based on the candidates ability to satisfy the maintenance and operations objectives (Goals 4 through 8). This brings significant perspective into the decision process as the importance placed on traffic operations is tempered by the need to implement a system that can be operated and maintained.

To further investigate the decision process, each element was normalized and is shown in Table 8. From this it is seen that 39% of decision is based on the candidates ability to satisfy specific requirements--the ability to reassign the coordinated phase at Fleur Drive and Army Post Road, the ability to provide the required system timing plans, and the ability to independently time the phase green duration. All are important factors that were identified as necessary for effective system operation in the Study Area.

CANDIDATE SYSTEM RATING

Each of the candidate systems was rated as to its ability to meet each of the performance goals. This was performed by assigning up to the maximum number of points allocated to each element within the goal and then summing the element point values to obtain the performance goal value.

An important criteria observed during the candidate rating was the assignment of maximum allowable point values if the candidate just satisfied the requirement even though the other candidates

TABLE 8

Relative Importance of Decision Elements

ELEMENT	IMPORTANCE
Reassign Coordinated Phase	15
Repetitive Timing Plans	12
Independent Timing	12
Traffic Responsive Plan Selection	9
Flexibility	7
Inclement Weather Timing Plans	6
Section Coordination	5
Equipment Monitoring	5
Signal Reassignment	3
Special Function	3
TOD/DOW Plan Selection	3
Section Configuration	2
Master Complexity	2
Communications Complexity	2
Controller Complexity	2
Master Reliability	2
Communication Reliability	2
Controller Reliability	2
Master Maintainability	2
Communications Maintainability	2
Controller Maintainability	2
TOTAL	100%

may provide capabilities that far exceed the requirement. Thus, the candidate is rated only on how well it performs relative to the goal criteria and does not indicate a comparison of one candidate against another. The candidate comparison only occurs after the goal point values have been defined and the candidates total point value obtained.

The ratings of each of the candidate systems relative to the performance goals is presented in Table 9.

TABLE 9

Summary of Candidates Performance Values

PERFORMANCE GOAL	AVAILABLE	CANDIDATE 1	2	3	4	5	6
Section Considerations	100	10	10	0	60	0	100
Timing Plans	300	240	240	150	240	300	300
Local Control	300	0	0	30	270	300	240
Complexity	60	40	50	50	20	40	10
Reliability	60	50	50	20	20	40	20
Maintainability	60	30	40	40	20	30	20
Flexibility	70	30	30	30	60	60	70
Equipment Monitoring	50	20	20	0	30	30	50
TOTAL	1000	420	440	320	720	800	810

To permit the meaning of the resulting performance goal values to be more easily interpreted, the ability of each candidate to satisfy each of the performance goals were classified within the following categories and are presented in Table 10:

- <u>Excellent</u> - meets all or nearly all of the requirements
- <u>Goal</u> - provides two thirds of the required capability
- <u>Average</u> - satisfied approximately half of the requirement
- <u>Poor</u> - provides little or no satisfaction of the requirements

TABLE 10

Classification of Candidate's Ability to Achieve Goal

PERFORMANCE GOAL	CANDIDATE					
	1	2	3	4	5	6
Section Considerations	P	P	P	A	P	E
Timing Plans	G	G	A	G	E	E
Local Control	P	P	P	E	E	G
Complexity	G	G	G	P	G	P
Reliability	E	E	P	P	A	P
Maintainability	A	A	A	P	A	P
Flexibility	A	A	P	A	A	E
Equipment Monitoring	A	A	P	A	A	E

E = Excellent G = Good A = Average P = Poor

From this the following observations can be made:

- Candidate 1 and Candidate 2 provide reasonable capabilities in regards to meeting the timing plan and level of complexity goals. However, they are unable to provide the section consideration or local control requirements. Furthermore, there is very little benefit gained by Candidate 2 over Candidate 1.
- Candidate 3 is the poorist choice in terms of meeting the performance goals. In all areas of traffic control it only provides average capabilities in the goal of timing plans and is classified as poor in meeting the remaining traffic control requirements.

- Candidate 4 provides many of the features required for traffic control and provides a high level of flexibility. However, it does not satisfy the goals of complexity, maintainability, and reliability.
- Candidate 5 satisfied the traffic operations requirements with the exception of section considerations. It also satisfies the flexibility goal and received an average rating in the areas of maintenance and reliability.
- Candidate 6 provides the most capability in traffic operations and equipment monitoring. However, in the areas of complexity, reliability, and maintenance Candidate 6 is a poor choice.

SYSTEM COST

The performance characteristics of each candidate is one element of the evaluation. The other dimension is cost. A summary of comparative cost estimates is presented in Table 11.

TABLE 11

Estimated Cost
(thousands of dollars)

	CANDIDATE					
ITEM	1	2	3	4	5	6
Intersection Improvements	101.0	101.0	101.0	101.0	101.0	101.0
Master	17.8	17.8	-	20.1	24.7	149.5
System Detectors	36.2	36.3	-	15.6	36.3	15.6
Controller	73.6	108.7	92.8	119.6	64.4	23.0
Communications Hardware	83.4	83.4	-	12.7	90.9	60.4
Telephone	-	-	-	32.2	-	26.5
Signal Timing	10.6	10.6	10.6	11.7	11.7	12.9
Contingency	48.4	53.7	30.6	46.9	49.3	58.3
TOTAL	371.0	411.5	235.0	359.8	378.3	447.2

These costs represent capital cost and the ten year telephone rental cost for those candidates that do not utilize a city owned cable network. The following is a brief description of each cost category.

- Intersection Improvements - This consists of the intersection improvements required to provide the signal phasing and mode of signal operation required. The cost includes conduit, signal cable, handholes, detectors, mast arms, signal heads, signing, and other items of work that are intersection related. The cost does not include controller equipment as this is a candidate dependent cost.

  The cost also does not include the channelization and minor roadway construction required at the intersection of Fleur Drive with Bell Avenue, with Park Avenue and with, Army Post Road as these costs are non-system related. However, it is estimated that this work will cost approximately $39,000.00.

- Master - The items contained in this category include the master hardware, interface, and enclosure for candidates 1 through 5. As the environmental considerations for Candidate 6 do not permit it to be field located it was assumed the master would be located in existing space either in City Hall or a similar location.

- System Detectors - This category consists of the roadway loop and lead-in, conduit associated with the detectors, and detector sensor units.

- Controller - This consists of controller equipment, cabinet, and installation.

- Communications Hardware - This category consists of the communications electronics at each signal and at the master, if any, and the cost of cable, conduit, and other material necessary for installing a cable network for all candidates except Candidates 4 and 6.

- Telephone - This consists of the ten year telephone charges for interconnecting Candidates 4 and 6 by means of telephone provided lines. Telephone service was used for these candidates as their communications technique is well suited for this media and the cost of a city cable system would have overstated the optimal configuration cost. An analysis of telephone costs for the remaining candidates, however, indicated that they were the same or higher than the cost of a city owned cable network.

- Signal Timing - This consists of the cost to develop new signal timing, implementation of the timing, and fine tuning after the system is operational.
- Contingency - The contingency amount is to cover unforeseen events that occur during construction and to provide some allowance for inflation.

It should be noted that the estimated costs do not include final design or the costs incurred to the City and the State during implementation for inspection services, etc.

In addition, maintenance costs are not included in the analysis. Maintenance costs were omitted as the cost for all candidates, except Candidate 6, will be approximately the same as that currently experienced for maintenance of signals in the Study Area. In addition, the relative difference in maintenance costs for Candidates 1 through 5 is so small that it would have been negligible in the decision process.

Candidate 6 will require an additional maintenance cost as portions of the maintenance must be performed under a service contract with the manufacturer of the master equipment. Therefore, it was decided to consider the maintenance costs of Candidate 6 as a separate element of the analysis only if it appeared to be the best choice so that all candidates could be evaluated initially within a consistant framework.

CANDIDATE PERFORMANCE EVALUATION

Using the candidate performance values and the estimated cost, a performance/cost ratio was developed. The ratio provides an indicator of the performance or value received on total investment. It is analogous to the results of a benefit/cost ratio in that it indicates a return on investment justifies the expenditure. Therefore, it is necessary to subject the alternative providing the greater effectiveness per dollar investment to a Benefit/Cost Analysis to determine whether the expenditure is justified. The Benefit/Cost Analysis is performed only on the selected alternative and is presented in a later section of this report.

The performance/cost ratios for each of the candidates are presented in Table 12. By comparing the ratios of each candidate system, it can be seen that Candidate 5 provides the greatest performance per dollar invested, closely followed by Candidate 4. Candidate 2 provides the least value per dollar with Candidate 1 being only slightly better.

TABLE 12

Performance/Cost Comparison

Candidate	Performance Value	Estimated Cost (Thousands)	Ratio
1	420	371.0	1.13
2	440	411.5	1.07
3	320	235.0	1.36
4	720	359.8	2.00
5	800	378.3	2.11
6	810	447.2	1.81

Although Candidate 5 has a superior performance ratio, it is more costly than Candidate 4. Confirmation that Candidate 5 is clearly the best choice was obtained by investigating the incremental performance ratio that results by implementing Candidate 5 instead of Candidate 4. Although Candidate 5 is $18,500 more, it provides an 80 point higher performance value. This translates into an incremental performance/cost of 4.32 which indicates that the return per additional dollar invested to implement Candidate 5 is almost two times as great as the return on the investment to implement Candidate 4.

BENEFITS

The previous analysis has shown that Candidate System 5 represents the best investment alternative to meet the system requirements. However, implementation of Candidate System 5 requires an expenditure of $378,300.00. It is, therefore, necessary to determine whether the expenditure is justified from an economic viewpoint. This requires a comparison of estimated cost to the potential benefits to the motorists.

Benefits to be realized from a modernized traffic signal system will accrue from many sources. Direct benefits include reduced fuel consumption, improved air quality, increased safety, increased motorist comfort, reduced travel time, and others. Indirect benefits include such items as managing traffic to meet community objectives, increased maintenance efficiency, and postponing major roadway improvement projects by increasing the transportation network efficiency.

As several of these benefits are not easily translated into monetary terms, the economic evaluation performed considered only the factors of reduced travel time, accidents and fuel consumption reductions that are anticipated by implementing Candidate System 5.

Travel Time

In an urban environment travel time generally represents the major transportation cost component. Reducing the time spent in transportation activities provides a direct benefit to the community as the time can be spent in more profitable activities such as work, recreation, etc.

A conservative approach was used to estimate travel time benefits to be realized by the installation of Candidate System 5. The analysis considers the savings resulting during the weekday. In addition, an improvement of only 10 percent is used to compute time savings. Before and after evaluations of similar systems in other cities have shown improvements greatly in excess of 10 percent.

The value of time used was based on the findings of a study performed by Stanford Research Institute in 1967 which established $2.82 per person per hour as the value of travel time.* The 1967 per person value of time was adjusted to a 1980 equivalent using the cost of living index. The value of time per vehicle hour to reflect vehicle usage was developed by multiplying the value of time per person per hour by the average vehicle occupancy of 1.2 persons.

The time savings resulting from the installation of Candidate System 5 was computed by estimating the number of vehicle miles traveled in the network during a typical day. The number of vehicle hours was then computed based on the average speed of 27.7 miles per hour obtained from travel time runs. The number of vehicle hours was then recomputed based on the improvement expected by implementing Candidate System 5. The difference in vehicle hours represented the user savings. This was then converted to an annual savings by computing the daily savings and using 250 work days per year. From this it is estimated that Candidate System 5 will result in a yearly savings in travel time of $483,800.00.

Accident Reduction

Although improved signal system operation will tend to reduce all types of accidents involving a non-erratic signalized intersection conflict (e.g., right angle, left turn, etc.) only those accidents involving rear-end collisions and left turns were considered in estimating benefits.

Although there is a direct relationship between stops and rear-end accidents, it was conservatively estimated that only two-thirds of the stops resulted in a situation that contributed to rear-end collisions. It is therefore anticipated that rear-end and right angle collisions will be reduced by approximately five (5) accidents per year.

---

* Thomas T. Thomas, Final Report, Volume II, The Value of Time For Passenger Cars: An Experimental Study of Commuters Values, SRI, May 1967.

To establish the benefits resulting from the accident reduction, the Iowa Department of Transportation developed, for the Sioux City Signal System Study, an estimate of the cost associated with a rear-end collision based on data from the National Safety Council (1975) and data from 1974-75 rural and urban accidents experienced in Iowa. As the cost derived included rural accidents, it was reduced by 15 percent to reflect the reduction in severity of urban accidents.

From this an average cost of $1,500.00 per accident was estimated. This results in an estimated yearly savings of $7,500.00 by the installation of Candidate System 5.

Fuel Consumption

By providing for the progressive movement of traffic, a signal system improves traffic flow quality. These improvements consist of fewer stops, shorter stopped time, and fewer changes in vehicle speed. All of these improvements have a positive benefit in reducing fuel comsumption.

To estimate the effects on fuel consumption by implementating Candidate 5, the computer program RUNCOST was used. RUNCOST was developed by the Federal Highway Administration to provide an analytical tool for analyzing data obtained from travel time studies. From this data the program calculates, among other parameters,an estimate of the total fuel consumption and pollutants for the network under study.

To estimate the benefits expected for the Fleur Drive/ Army Post Road System, data were used from the travel time and delay studies conducted during this study to establish the "before" condition. The "after" condition was then computed by RUNCOST based on a 10 percent improvement resulting from the implementation of Candidate 5. The "benefit" was then determined by comparing the before condition to the after condition.

From this it was determined that air quality would be improved by reducing Hydrocarbons by 5.3 percent and CO by 16 percent. To put this into a more meaningful perspective, a 16 percent reduction in CO is almost 150 tons of pollutants that will not enter the air--about the same as 34 average size adult elephants.

By improving traffic flow quality, Candidate 5 will also reduce fuel consumption by 110,900 gallons per year. At current market prices this is $144,170.00. Thus, the savings in fuel alone will pay for the system in slightly over 2 1/2 years.

BENEFIT/COST

A benefit/cost ratio was computed by comparing the estimated benefits from reduced travel time, accidents and fuel consumption to the estimated cost required to implement Candidate System 5. The following is a summary of the estimated annual benefits:

Delay Savings	$ 483,800.00
Accident Reduction	7,500.00
Reduced Fuel Consumption	144,170.00
Total Annual Benefit	$ 635,470.00

The first year benefit cost ratio was then determined by dividing the annual benefit by the estimated cost to implement Candidate 5 as follows:

$$\frac{\text{Annual Benefit}}{\text{Estimated Cost}} = \frac{\$\ 635,470.00}{\$\ 378,300.00} = 1.68$$

Therefore, the system pays for itself and also provides a return of 68 cents for every dollar invested in the first year of operation. As the system has a minimum design life of 10 years, the economic justification for implementing Candidate 5 is very positive.

VII RECOMMENDATIONS

The findings of this study have established the need to provide improved signal operation to promote safety and to increase the efficiency of the transportation network. The study has also proven that coordination of signals within the Study Area is feasible and will satisfy the project objectives. Furthermore, the systems evaluation and economic analysis have shown that implementation of Candidate 5 is the most cost-effective option available to the City. Therefore, JHK & Associates recommends that the City actively undertake a program to implement Candidate 5.

Viewed from an economic sense, Candidate 5 represents an excellent investment in the community. The investment required to implement the system is returned by savings to the motoring public in less then eight months. Of more importance, implementation of the system complements the Nation's policy to reduce fuel consumption. In one year the system will result in a reduction of fuel consumption of at least 110,900 gallons. This is equivalent to the average annual fuel consumed by 220 motorists.

Operation and maintenance of Candidate 5 can be accomplished within the City's existing resources. Controller hardware will be similar to equipment already in use by the City. Maintenance training will be required for the master as the device has not been used previously in the City. However, the master technology is familiar to maintenance personnel and it can be maintained with minimal inpact on current operations. As the communications network will be installed underground in telephone duct, little if any maintenance is expected.

Components of Candidate 5 will be directly compatible with an areawide traffic control system. The master could either be left in place to serve as a standby for the areawide system or could be relocated for effective control of signals outside the coverage of the areawide system. This would be determined during design of the areawide system.

The major features of Candidate 5 are described as follows:

- The Fleur Drive/Army Post Road System will operate as a single section with the master and cabinet field located at the intersection of Fleur Drive and Army Post Road.
- The master will provide nine timing plans for recurrent conditions and three timing plans for inclement weather conditions.
- The master will directly supervise the controllers and will permit independent timing of each controller phase.
- Recurring timing plans will be selected on a traffic responsive basis from traffic data at 12 system detectors. The master will also provide Time-of-day/day-of-week override capabilities.
- Inclement weather timing plans will be manually selected at the master. Consideration should be given to providing the capability of selecting these plans remotely, (e.g., the signal shop, by telephone lines after the effectiveness of the initial selection technique can be evaluated).
- The master will provide the ability, by means of a special function command issued as a function of the timing plan in effect, to alter the controller operation (e.g., grounding of detectors to simulate a pretimed controller).
- The master will have the ability to place any or all controllers in "free" or isolated operation as a function of the timing plan in effect.
- The master provides the ability to reassign the coordinated phase at Fleur Drive and Army Post Road.
- Updating of the timing plan cycle, split and offset as well as the plan selection thresholds is performed by programming at the master.
- The master and communications facilities provide sufficient capacity for the system expansion required.
- Controller equipment will be replaced at six locations. This will result in all controller equipment in the system conforming to NEMA interface standards.
- Signal phasing will be changed at Fleur Drive at Bell Avenue, Park Avenue, and Army Post Road, and protective/permissive left turn phasing (including "screening" of low volume movements) will be provided at all multi-phase locations.

- Existing intersection vehicle detection will be disabled during system operation. However, it will be retained for use when the signal is operating in the isolated mode. This ensures that the vehicle detection is not compromised for either type of operation.
- The master monitors system sampling operation and reverts to time-of-day plan selection if the number of failed detectors exceeds a specified number.

One exception to the proposed presence detector scheme is the intersection of Fleur Drive and Army Post Road. Presence detection similar to that used elsewhere in the system will be used on the westbound and northbound approaches. Small area detection to provide detection of vehicles further back from the stop bar will be used on the other two approaches. In this case, the existing eastbound magnetic detector will be retained during system operation to detect high speed vehicles and new small area detectors will be installed closer to the stop bar to keep the allowable vehicle gap settings to a minimum.

GEOMETRIC REVISIONS

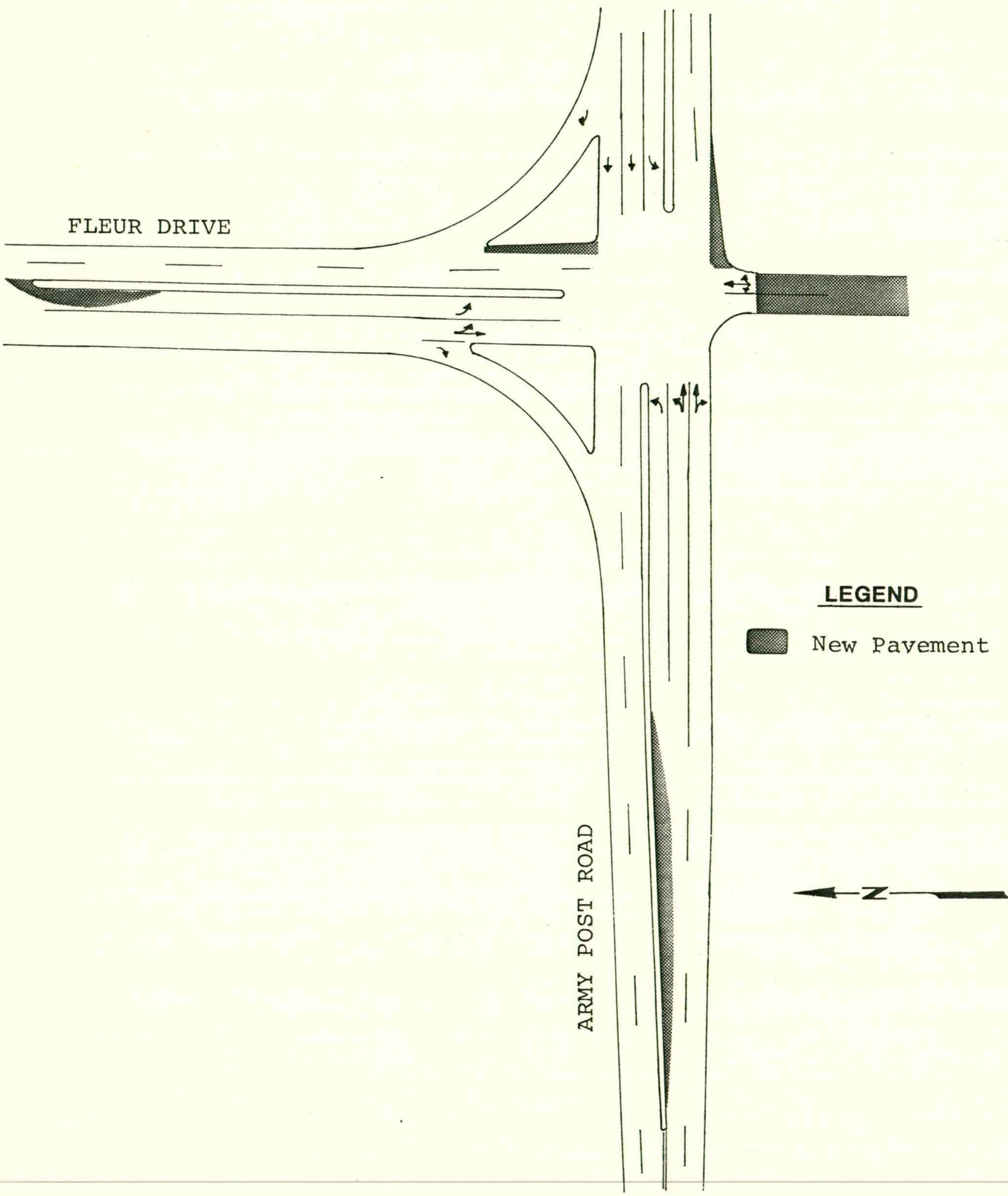
As a result of the intersection phasing analysis, it became evident that several geometric revisions were required to accommodate the system operation. These consist of revisions required to permit double left turns to be made or to increase the length of left turn storage for more effective lane usage.

The geometric revisions required at Army Post Road and Fleur Drive are shown in Figure 22. The improvements include increasing the dual left turn receiving roadway width to provide at least a 30 foot throat. The median modifications will improve left turn operation by increasing storage area and, on the west approach of the intersection, provide a smoother transition taper for both directions. It is also recommended that the southern approach of Fleur Drive be paved to a point approximately 100 feet south of the curb line of Army Post Road. This will provide a suitable pavement for the vehicle detectors to be installed and will eliminate the slowing of southbound vehicles while still in the intersection.

FIGURE 22

INTERSECTION IMPROVEMENTS

FLEUR DRIVE/ARMY POST ROAD



Geometric modifications are also recommended for the eastbound approach on Bell Avenue at Fleur Drive, as shown in Figure 23. By relocating the median three approach lanes can be provided which will allow for a detectorized left turn lane.

DISPLAY MODIFICATIONS

To provide the uniformity desired along Fleur Drive and Army Post Road it is recommended that all intersection displays be similar. The use of five indications (red ball, yellow ball, green ball, yellow arrow, and green arrow) is required for the protected/permissive left turn indications. The City has expressed a desire to reduce the number of signal sections by the use of dual-indication programmed visibility signal sections for the protected left turn green and yellow display. Therefore, modifications of left-turn signals will be required to provide three conventional twelve-inch signal sections and one dual indication signal section as shown in Figure 24.

At Army Post Road and Fleur Drive modifications of signal display are required to reflect the dual left turn operation.

LEFT TURN SCREENING DETECTORS

A detector strategy has been developed for use in left turn lanes that allows a leading protected left turn phase to be skipped, with the left turn controller phase set in the "non-lock" mode, when the vehicles waiting will be able to turn left on the permissive circular green. Figure 25 shows the detector configuration, consisting of four hexagonal loops. The three loops closest to the intersection are connected together to a detector amplifier channel set on presence but provides an input to the controller only when the left turn arrow is being displayed. The fourth loop is connected to a different detector amplifier channel and provides an input to the controller only when the left turn phase is red.

FIGURE 23
INTERSECTION IMPROVEMENTS
FLEUR DRIVE/BELL AVENUE

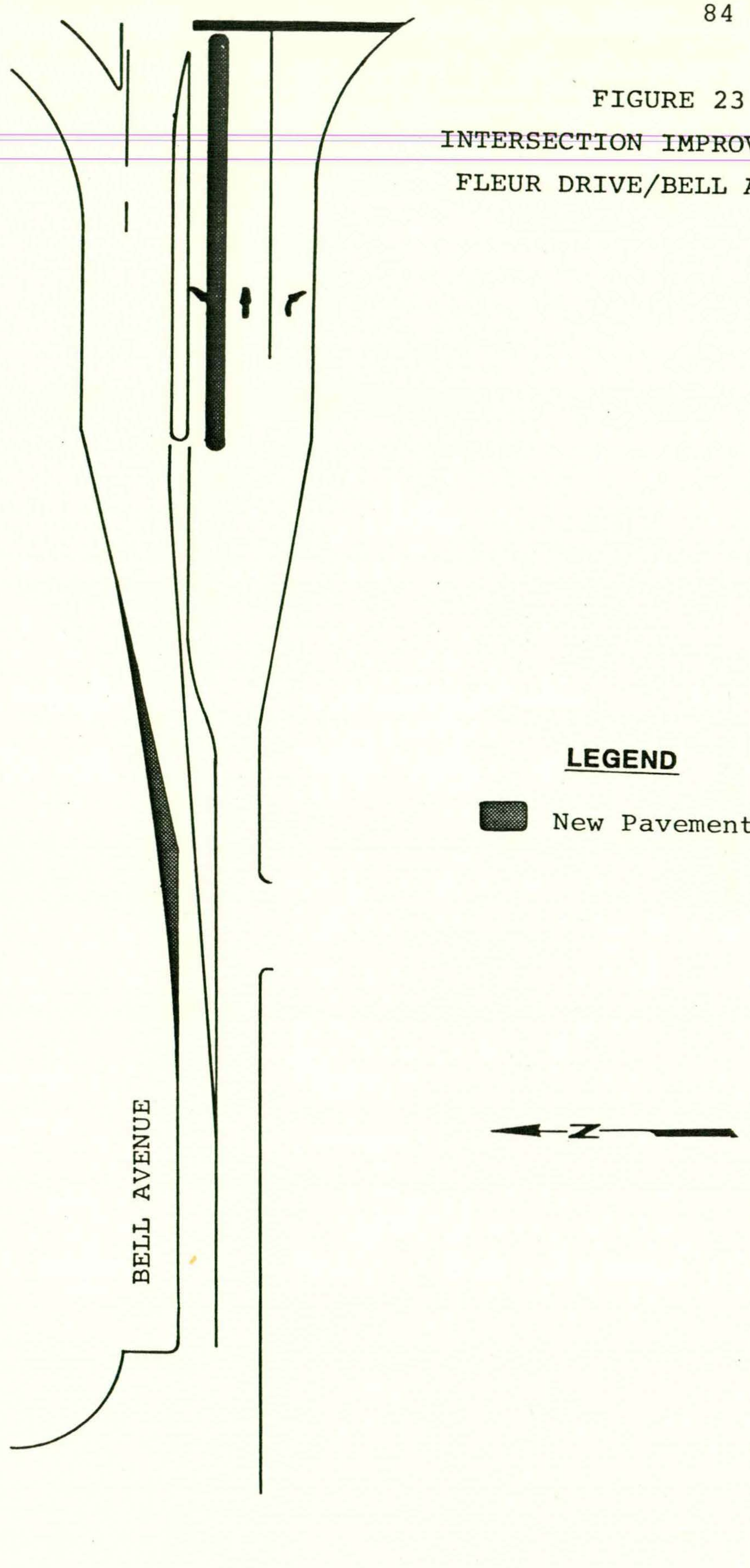


FIGURE 24

LEFT TURN SIGNAL DISPLAY
(TYPICAL)

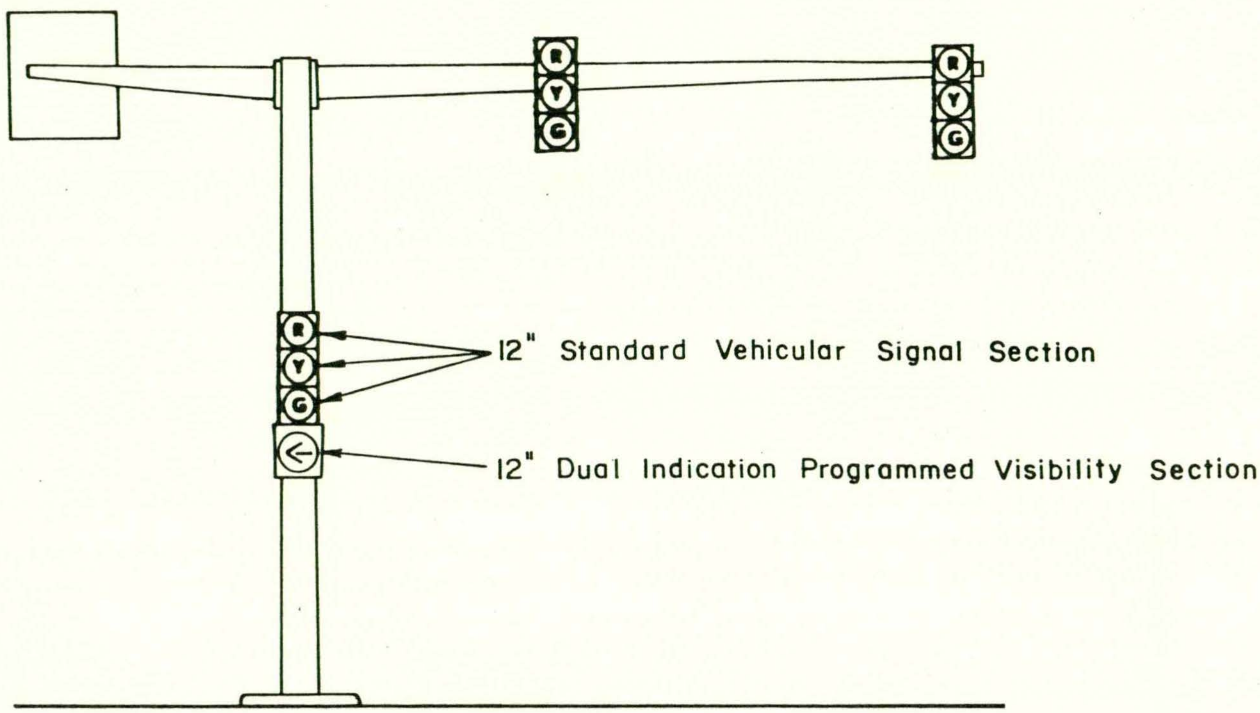
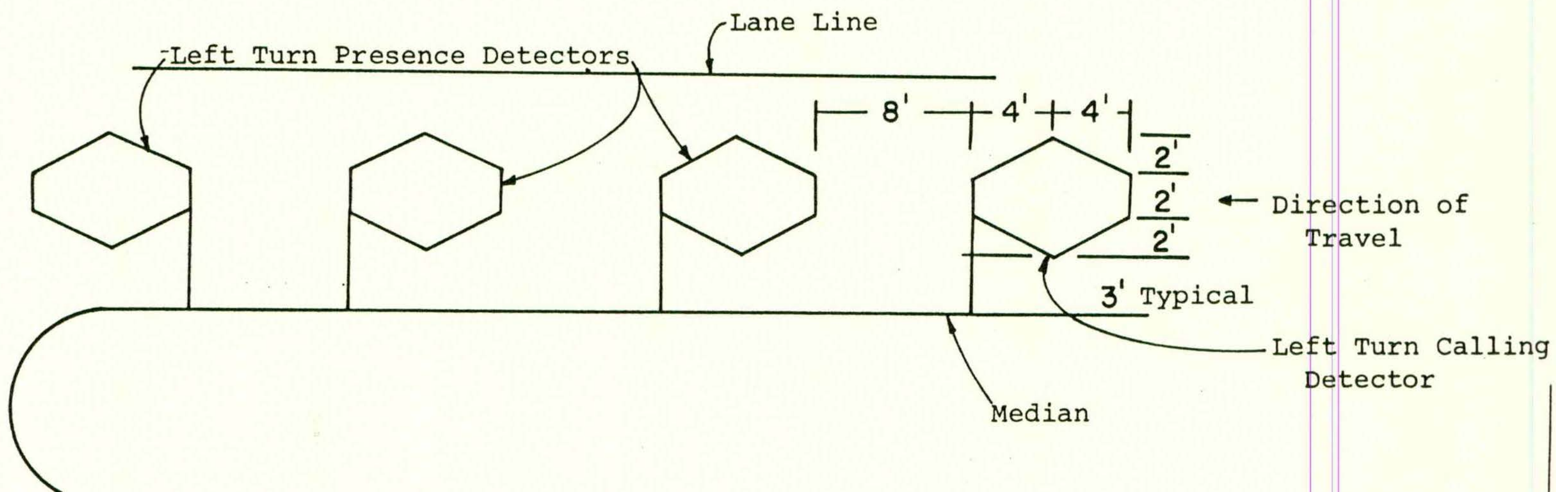


FIGURE 25

LEFT TURN LANE DETECTION
(TYPICAL)



If one or two cars are waiting to turn left on the red, no call is placed in the controller as the input from the first three loops is inhibited. However, if there are three or more cars waiting to turn left, then the queue is detected by the fourth loop and a call is placed to the controller. When the green arrow is displayed, the front three loops provide presence detection until the queue clears the intersection. During this time, the output from the fourth loop is inhibited to maintain "snappy" operation by controlling the vehicle gap.