RF Project 760736/710540
Final Report

the ohio state university
research foundation
1314 kinnear road
columbus, ohio
43212

A METHODOLOGY FOR THE ALLOCATION OF POLICE PATROL VEHICLES

Brooke Allen Saladin and Lawrence D. Vitt
Department of Management Sciences

For the Period
May 27, 1977 - February 26, 1980

U.S. DEPARTMENT OF JUSTICE
Office of Criminal Justice, Education and Training
Washington, D.C. 20531

Grant No. 77NI-99-0054

March 7, 1980

66435 c.1

Memorandum

66435

Subject : The Attached Dissertation	Date : April 2, 1980

To : David Farmer, Police Division, ORP/NIJ
Charles Sorrentino, Police Division, OCJP/LEAA

From : Annesley K. Schmidt
Graduate Research Fellowships

THRU: W. Robert Burkhart WB
Director, ORP

Attached is a copy of the dissertation of Brooke Saladin, Ohio State University. This dissertation entitled "A Methodology for the Allocation of Police Patrol Vehicles" was supported by Graduate Research Fellowship 77-NI-99-0054.

NCJRS

A METHODOLOGY FOR THE ALLOCATION OF POLICE PATROL VEHICLES

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Brooke Allen Saladin, B.S., M.B.A.

* * * * * *

The Ohio State University
1980

Reading Committee:

Dr. LeRoy Krajewski
Dr. Larry Ritzman
Dr. Lawrence D. Vitt
Dr. David Schilling

Approved By

Lee Krajewski

Advisor
Department of Management Sciences

VITA

Brooke Allen Saladin

October 28, 1947 .... Born - Lorain, Ohio

1969 .... B.S., The Ohio State University, Columbus, Ohio

1974 .... M.B.A., Bowling Green State University Bowling Green, Ohio

1974-1975 .... Instructor, Department of Management Bowling Green State University, Bowling Green, Ohio

1975-1978 .... Teaching Associate, Department of Management Science, The Ohio State University, Columbus, Ohio

FIELDS OF STUDY

Major Field: Production/Operations Management

Studies in Inventory Control and Scheduling - Professor LeRoy Krajewski

Studies in Capacity Planning, Location, and Layout - Professor Larry Ritzman

Studies in Service Organizations - Professors LeRoy Krajewski and Lawrence D. Vitt

Second Field: Transportation and Logistics

ACKNOWLEDGMENTS

As with any large research project, there have been many things which have contributed to the successful completion of this research effort. Foremost has been the time, effort, and guidance my committee has been willing to put forth throughout the course of this research, along with the patience, understanding, and support my lovely wife, Debra, has endlessly shown.

I also wish to thank Dr. Roscoe Davis, The University of Georgia, for his aid as I struggled through writing the Fortran program for the matrix generator. Finally, this research would not have been possible without the support of the Department of Justice, Law Enforcement Assistance Administration, which funded this research under grant number 77-NI-99-0054.

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INTRODUCTION

Production/Operations Management is a discipline comprised of a collection of concepts, principles, and methodologies that has as a general goal the effective utilization of available resources in providing a product or service. Traditionally, this discipline has been oriented toward the manufacturing sector. One only has to review the literature or examine the textbooks which have been written in the past dealing with Production/Operations Management to validate this claim. Recently, however, there has been a growing awareness of the service sector and its importance in the Production/Operations Management discipline. This is evidenced by both new textbooks being published; Sasser et al. [69], and research being conducted, Bodin [7], Henderson and Berry [48], Chaiken [13], Chaiken and Dormont [15], and Krajewski and Henderson [54], all of which have recently addressed problems in the service sector.

The service sector poses, for the decision-maker, a unique and complex decision-making environment. Much of this complexity can be attributed to the variability which is present in both the demand that is placed on various public and private services, and the service times associated with these demands. Many demand patterns for particular services vary seasonally, weekly, daily, and in such cases as fire and police service, hourly.

In the manufacturing sector, much of this demand variability can be tempered by using such alternatives as inventory accumulation, subcontracting, or back-ordering. For example, inventory can be accumulated in periods of low demand and depleted in periods of peak demand. The use of such alternatives leads to a smoothing of the impact of a variable demand pattern. In the service sector, however, an organization typically is unable to inventory its "services rendered" for future use. The service provided must usually be made available when demanded. This is especially true in the case of emergency services such as ambulance, fire-fighting, and police services. This requirement of matching available services with the demand for those services on a spacial and temporal basis is what makes decision-making in the service sector such a unique and complex problem area. The decision-making environment is one of multiple criteria and conflicting objectives with the key to making sound decisions lying in the ability to recognize, understand, and model the criteria, the objectives, and their interrelationships.

This research investigates one facet of the decision-making process in the public service sector, namely the area of police patrol allocation. The police patrol allocation problem presents a very special case of decision-making in the service sector. First, the demand for police service is a twenty-four hour a day seven day a week demand. Second, it is difficult to place specific values on many of the services provided by the police patrol function. For instance, how does one measure the value of having a patrol vehicle cruise a particular area? Or, what are the benefits of responding quickly to various calls-for-service? Finally, it is difficult to identify appropriate levels at which to set the multiple objectives. How frequently should a patrol vehicle pass a certain point? And, what is an optimum response time for calls-for-service?

1.1 Disaggregation in Police Patrol Allocation

Krajewski and Ritzman [55] have structured the problems of going from aggregate plans to detailed plans and have termed this process disaggregation. Within the disaggregation process, for both manufacturing and service sector problems, there are three planning levels. The planning process is then characterized by a top-down approach with each level exhibiting appropriate feedback loops throughout the process. One of their major contentions is that the effectiveness of any methodology employed in the disaggregation process can be eroded due to the lack of appropriate interfacing mechanisms between planning levels.

Using the conceptual framework provided by Krajewski and Ritzman [55] as a guide, the police patrol allocation problem can be modeled as a disaggregation process with three identifiable levels.

The First Level of Disaggregation

The first level of the disaggregation structure is concerned with the staff sizing decision. The staff sizing problem occurs after an aggregate plan has been established for the police department as a whole. The aggregate plan takes the total amount available of a particular resource and apportions this amount out to the various functional areas within the police department that compete for it. For example, the traffic division, the detective division, and the patrol division all compete for a given number of police vehicles. The aggregate plan indicates the number of police vehicles to be allocated to each functional area. After the number of police vehicles, and other resources, allocated to the patrol function has been established, the staff sizing problem emerges. In other words, the staff sizing problem begins where the aggregate plan leaves off.

The staff sizing problem is one of apportioning the total amount of manpower and vehicles allocated to the patrol function across each precinct in such a manner that conforms to the existing variable demand pattern. The patrol function itself consists primarily of two activities: (1) response to calls-for-service and (2) administrative and crime prevention activities. The latter category includes the presence of patrol units as a crime deterrence and the availability of emergency units to provide reasonable response times for high priority calls-for-service. The demand for services provided by the patrol function varies among districts as a result of the geographic and demographic factors that are particular to each district. A major contribution to the decision-making process at this first level of disaggregation would be an investigation of the relationships that are present between these geographic and demographic factors and the resulting demand for service they place on the patrol function.

The Second Level of Disaggregation

In the second level of disaggregation, as shown in Figure 1, manpower and vehicle tour schedules are developed. A tour represents a time period during which a patrol officer can be on duty during a twenty-four hour period. A tour schedule represents a set of on-duty periods which extend over some planning horizon. Synonyms commonly used in lieu of the term tour are shift or watch. The term "watch" will be used throughout the remainder of this research in keeping with the terminology utilized by the Columbus, Ohio Police Department.

The problem at this level of disaggregation is to systematically vary manpower and vehicle levels to meet demand over some planning horizon. Allocations will vary in terms of the particular watch per day and day per week. The allocation decisions made here are done so in an

LEVEL 1 STAFF SIZING OF EACH DISTRICT

GIVEN ALLOCATION OF RESOURCES TO PATROL FUNCTION, ASSIGNMENTS MUST BE MADE ON PRECINCT-BY-PRECINCT BASIS.

LEVEL 2 VEHICLE AND MANPOWER TOUR SCHEDULE

RESOURCES ASSIGNED TO EACH PRECINCT MUST BE SCHEDULED ACROSS WATCHES OF THE DAY AND DAYS OF THE WEEK.

LEVEL 3 DESIGN OF PATROL BEATS

WITHIN EACH PRECINCT, MUST DESIGN AREAS OF RESPONSIBILITY FOR INDIVIDUAL PATROL UNITS.

FIGURE 1 THE PATROL ALLOCATION PROBLEM A: DISAGGREGATION PROBLEM environment characterized by multiple objectives which in many instances conflict with one another. Krajewski and Ritzman [55] have identified a sample of various criteria that may affect the allocation decision: (a) bounds imposed by the staff sizing decisions, (b) service standards, (c) wage costs, (d) legal constraints, (e) labor contracts, (f) departmental policies, (g) amount of departure from previous plans, (h) administrative convenience, (i) attitudinal differentials caused by transfers between watches, and (j) workload imbalances.

The services provided by patrol vehicles are characteristic of a single stage scheduling environment. The customer, placing a demand on a patrol vehicle, typically passes through only one phase of service, meaning that only one operation is performed to satisfy the demand. This is in contrast to the manufacturing sector where a product may flow through many phases of production before completion and ultimate satisfaction of demand. There are, however, a number of decisions inherent to the allocation process across time periods which complicate decisions at this level of disaggregation.

The patrol planner must decide on the use of fixed or rotating schedules. In a fixed schedule the patrol officer would work the same watch per day and days of the week throughout the planning horizon. Rotating schedules, as developed by Heller [47], would systematically vary the watch worked each day and the days of the week over the time horizon. A second decision area is concerned with the number of watch options available. This includes the number of watches fielded per day, their individual starting times, and the use of overlay watches. Finally, there is the question of permanent versus variable assignments. With regard to the patrol allocation problem, an officer and his vehicle can either be permanently assigned to a cruiser district or beat, or he can be assigned to different districts depending upon the varying demand criteria. This last point leads us into the final level of disaggregation.

The Third Level of Disaggregation

The third and lowest level of disaggregation in the patrol allocation decision hierarchy addresses the issue of designing specific patrol beats. A patrol beat is an area of specific geographical bounds that is assigned to a particular patrol officer or vehicle. It is the responsibility of that vehicle to patrol the beat and provide the necessary services rendered by the patrol function.

In designing patrol beats, also known as cruiser districts, two types of information dominate the decision process, geographic and demographic data. These are the same parameters that dictate the workload levels placed on patrol vehicles. Therefore, the investigation of these geographic and demographic factors, which was mentioned in the first level of disaggregation, not only will aid in the staff sizing decision but also will provide information to be used in beat design decisions.

1.2 Research Objectives

The police patrol system, like all other emergency service systems, has the basic mission of providing the proper level of resources, at the proper time, and at the proper place. With regard to the police patrol function, the resources provided to fulfill this mission concern the level of vehicles and manpower which are made available. The number of vehicles and the amount of manpower available are largely restricted by the amount of capital allocated to the patrol function. Therefore, like any other productive system, either manufacturing or service, a major problem facing the patrol planner is the efficient utilization of scarce resources. The police patrol planner must effectively manipulate his factors of service, which are the vehicles and manpower levels available, to accomplish his mission. An important objective of this research is to provide some decision aids that will aid the patrol planner in the accomplishment of this mission.

In surveying the tradeoff between the objectives of minimizing costs and maximizing service, the major issues encountered by the patrol planner are determining what constitutes service and what are the appropriate levels of service to provide. With regard to the first issue, "What is service?", patrol planners tend to view service as being described by various performance measures. Some such measures include response times, queue statistics for calls-for-service waiting for a response, patrol frequencies, service times, and utilization measures. The specific number and type of performance measure used to describe service will certainly vary among patrol planners. Once, however, specific performance measures have been chosen by a patrol planner, the problem remains of having to establish appropriate target levels for each performance measure. This problem is compounded by the interrelationships that are present between performance measures. One performance measure, the utilization ratio, is a comparison between the amount of time patrol units spend on calls-for-service and the total time they are on duty. Mathematically the utilization ratio is represented by the following:

$$\text{Utilization Ratio} = \frac{\text{Call-for-Service Workload}}{\text{Total amount of time on duty}} .$$

One specific objective of this research is to establish the utilization ratio as a key decision variable in the patrol allocation problem. This seems to be a natural action since the utilization ratio not only delineates the two primary activities of the patrol function, but it also portrays the relationship between the major factors influencing the allocation decision, workload and available resource levels. Furthermore, the utilization ratio is one performance measure where all other measures can be directly related back to it. Finally, other patrol allocation methodologies, such as the Patrol Car Allocation Model [15], use the utilization ratio as a major measure of performance without really knowing if a reasonable level has been attained or not. This tends to lead to variation in the utilization rates exhibited by patrol vehicles assigned to different areas which, in turn, causes other measures of performance to vary. An objective of this research is to help alleviate this problem of performance measure variation while at the same time provide a comparative measure with which the relative effectiveness of various methodologies can be judged.

In striving to establish the utilization ratio as a major decision variable, two subobjectives must be accomplished. The first of these subobjectives is the specification of the relationships that exist between the utilization ratio and district-watch workload factors.

Patrol resource allocations are not directly proportional to computed vehicle workloads. If they were the planning environment would be far less complex. However, the desired utilization ratio will certainly vary by watch with the night watch utilization ratio typically being lower than the day or afternoon watch ratios. This may be due to the fewer number of calls-for-service received during the night watch and the faster response time permitted since traffic is lighter. It may be that patrol planners wish to have lower utilization ratios because calls-for-service at night seem to be of a more serious nature and require longer service times.

For similar reasons, utilization ratios also vary between districts. Previous research at The Ohio State University by Professor Lawrence D. Vitt [77] has found utilization ratios for districts to vary between ten and fifty percent. Several causes of these deviations are: (a) the workload per citizen by district, (b) the preventive requirements of the area, (c) the population density, (d) the square miles per patrol unit, (e) the street miles per district, and (f) the percent two-man vehicles employed. The first subobjective is to investigate these and other relationships present between workload factors and utilization ratios. This will enable the utilization ratio to be estimated for any set of workload factors.

The second subobjective is concerned with investigating the relationships present between the utilization ratio level and levels of other performance measures. If these relationships can be expressed, then they will act as a mechanism for both modeling and specifying constraints which in turn will act as a guide in allocating patrol vehicles. Furthermore, by knowing how the utilization ratio reacts to various workload factors, the patrol planner will be able to estimate the reaction of other performance measures.

A second major objective of this research is the development of a decision-making methodology which will aid the patrol planner in the patrol allocation problem at all three levels of the disaggregation hierarchy explained in Figure 1. The methodology is to be flexible enough to allow adoption by any police department while at the same time providing structure to the decision process. As a result of using this methodology the patrol planner will be provided with a schedule of required vehicle hours on a per watch, per day, per precinct basis. This schedule, coupled with the information processed to derive it, should aid the patrol planner in establishing the appropriate staff sizes and designing the patrol beats.

Present resource allocation techniques being employed typically confine themselves to solving only one phase of the total allocation problem. For example, I.B.M.'s LEMRAS program [56] was mainly concerned with the staff sizing problem where other techniques proposed by Capaul et al [12], Vitt [77], Heller [47], and Chaiken and Dormont [15] are primarily interested in the second level of disaggregation, manpower and vehicle scheduling. Finally, the Hypercube model [14] deals with designing response districts for ambulances, police patrol vehicles, and fire-fighting units.

What each of these techniques lacks individually is the recognition that interactions are present between the levels of disaggregation. Each of the forementioned techniques does generate information for the patrol planners use; however, this information is not being fully utilized. Information generated at one level in the disaggregation hierarchy should not be limited in its use to decision-making at that one level only.

Levels of the disaggregation scheme should be linked together by these information flows thus providing the opportunity to develop iterative problem solving techniques whereby the output of one level contributes to the solution of problems found at other levels in the structure. This type of problem solving approach should result in the efficient use of available information and is similar to the approach taken by Krajewski and Henderson [54] in Post Office staff sizing research.

1.3 Scope, Assumptions, and Limitations of This Research

The problem of specifying the appropriate number of patrol vehicles to schedule across both spacial and temporal bounds is the focal point of this research. The primary output provided the patrol planner will be the required amount of patrol vehicle hours to be allocated to each watch, day, and precinct in order to attain designated performance measure levels. Although the use of both one-man and two-man vehicles is taken into consideration, the scheduling of individual patrol officers is not addressed in this research. This excludes the need to consider micro level scheduling decisions, one of which is the choice between permanent and variable assignments. Likewise, the issue of establishing rotating versus fixed schedules is of no concern in this research.

The specification of patrol vehicle allocations is accomplished through the use of a three stage methodology. A statistical analysis provides information concerning the relationships that exist between geographic and demographic factors and the workload that is exhibited in a particular area. The modeling of these relationships enables estimates of workload levels to be made for any combination of geographic and demographic factors. Given these estimates, expected utilization ratios can be derived. The second stage models the trade-off relationships existing between the utilization ratio levels and the resulting levels of other measures of performance. The final stage of the research applies the information provided in the first and second stages toward the development of a goal program model which generates an allocation of patrol vehicle hours on both a spacial and temporal basis. Information derived from the modeling of the trade-off relationships is used to construct the constraint sets of the goal program model while the information from the first stage concerning workload estimation is used to establish appropriate goal levels for each constraint set modeled.

All relationships which are modeled, decisions which are made, and vehicle hours which are allocated are done so based on data collected with respect to the Columbus, Ohio Police Department. The data base reflects actual data pertaining to the third quarter of 1975. Columbus, Ohio at this time was comprised of two-hundred and twelve census tracts. The Columbus, Ohio Police Department was structured into fifteen precincts and sixty-three cruiser districts. For reasons described later, this research is eventually limited to allocating vehicle hours across only eight precincts.

The assumptions made that are not specifically validated throughout the course of this research primarily pertain to the use of the Patrol Car Allocation Model [15]. The Patrol Car Allocation Model (PCAM) is a queuing based simulation model requiring certain technical assumptions to be made. These assumptions permit PCAM to estimate the fraction of calls that will have to be placed in a queue to await an available patrol vehicle and the average length of time that calls in each priority level will have to wait in queue. The assumptions are [15, p. 29]:

(1) Incidents occur according to a poisson process.

(2) All incidents have the same exponential distribution of service time.

(3) The system is in steady state in each hour.

Besides the assumptions inherent in queuing based simulation models, the use of PCAM places a number of limitations on modeling the decision environment. To begin, PCAM allows only three priority levels of calls-for-service. The Columbus, Ohio Police Department has their calls-for-service broken down into over seventy different ten-codes. Each ten-code designates a different type of call-for-service. For example, a 10-28 call designates a homicide whereas a 10-45 call indicates a stolen auto. Therefore, the patrol planner is forced to aggregate the ten-codes into three priority levels.

Other limitations are concerned with the manner in which calls-for-service are serviced. PCAM makes no provision for intersector travel of patrol vehicles. Each patrol unit is assumed to remain within its assigned area of responsibility. Furthermore, each call-for-service is responded to by only one vehicle, regardless of the severity of the call. Finally, there is no mechanism for the preemption of calls-for-service. This means that if a high priority call-for-service is received while all patrol vehicles responsible for the area in which the call originated are busy, the high priority call will be placed in queue. This will occur even if the incoming call-for-service has a much higher priority than any other call presently being serviced.

The limitations present in this research each represent new research thrust for the future. The elimination of each limitation brings the decision model one step closer to reality and thus opens up many new avenues of research. It is hoped that this research, by providing both vehicle allocation decisions and the resulting interactions of these decisions with the other levels of the disaggregation structure, will open some new areas of research.

However, even though there are a number of limitations and simplifying assumptions present that restrict the scope of this research, they should not detract from it's significance. The patrol allocation decision is a complex one characterized by a perplexity of multiple objectives and interactions. This research not only models some of the important interactions that exist but, it also results in the development of a structured approach for using the multiple objectives that are present to arrive at patrol vehicle allocations across time and space. To ensure the continued propagation of research in any particular area, a firm foundation must be established from which to build. It is hoped that the information and decision aids resulting from this research will contribute to the establishment of a firm foundation for future research concerning the patrol allocation problem.

1.4 Outline of Research Presentation

In this introductory chapter a general framework was described for structuring the patrol allocation problem. That discussion helps provide some perspective as to how this research fits into the overall allocation of patrol resources problem. Specific research objectives were then presented followed by a discussion of the scope of this research, the limitations present, and the assumptions under which this research is being performed.

Chapter II reviews the existing literature that is pertinent to the research effort. Among the areas covered are police patrol allocation theory, utility and multiple objective criteria theory, and goal programming. Each of these areas has a major influence on this study.

Due to the nature of this particular study, it is conveniently structured into three stages. Chapter III describes the first stage which is a statistical analysis of the relationships present between existing district-watch-workload levels and respective geographic and demographic factors. Chapter IV discusses the second stage of this research which pertains to the use of PCAM to model the trade-offs found between utilization ratio levels and levels of other performance measures. And, Chapter V describes the development and use of a goal programming model to derive patrol vehicle allocations.

Chapter VI presents an analysis of the results of this research. Included in this analysis is a comparison of the existing and the derived vehicle allocations along with the levels of performance each exhibits. Chapter VII concludes this research by providing a brief summary of the research and it's results, a discussion of the contributions that have been made by this research effort, and a statement concerning possible extensions to this research.

CHAPTER II

A REVIEW OF PERTINENT LITERATURE

The literature pertaining to this research falls into three distinct categories. First, attention must be given to the development of current police patrol allocation theory and the techniques being proposed. Then, since the decision-maker utilizing the methodology proposed in this research must deal with tradeoff curves and make value judgements, a review of the literature concerning utility theory is appropriate. Finally, due to the use of goal programming in this research, it is essential to include a review of the literature in this area.

2.1 POLICE PATROL ALLOCATION THEORY

2.1.1 Hazard Formula

The foundation for the development of police patrol allocation theory was constructed by O.W. Wilson [78]. In the 1930's Wilson developed what is typically thought of as the "Traditional Allocation Approach". In this approach virtually all factors which are thought to be relevant to the allocation of patrol units are combined in a subjective manner to create a workload or hazard formula. These formulas attempted to balance the workload between patrol districts. Wilson combined such factors as:

(a) number of arrests
(b) number of calls-for-service of particular types
(c) number of doors and windows to be checked
(d) number of street miles
(e) number of crimes
(f) number of licensed premises.

The workload or hazard score was computed by taking a weighted sum of the fractions of each of the factors used by each district. The weights were subjective indications of each factor's relative importance. Then the total number of men available were distributed to each district in proportion to the workload or hazard score. See Figure 2 for examples of hazard and workload formulas.

In a recent application of this approach, the Los Angeles Police Department [75] used the following factors to arrive at a hazard score:

Factor	Weight
Selected Crimes and Attempts	5/19
Radio Calls Handled by Car	4/19
Felony Arrest	3/19
Misdemeanor Arrest	1/19
Property Loss	1/19
Injury Traffic Accident	1/19
Vehicles Recovered	1/19
Population	1/19
Street Miles	1/19
Population Density	1/19

Although at first glance this approach seems to accurately portray the patrol allocation problem, there are a number of flaws present. The use of hazard and workload formulas is a deterministic approach to what is essentially a probabilistic system. Another drawback in using these formulas is their inability to demonstrate a direct relationship to various performance measures. Measures such as response times, patrol frequencies, and queue statistics can not be specified in the formulas so there is no assurance that such measures will meet certain levels. Furthermore, one can not predict the affects that a reallocation of resources will have on various performance measures.

Factor	Precinct A	Precinct B	Precinct C	Total
1. Violent Crimes	250	475	850	1575
2. Felony Arrests	725	1500	2200	4425
3. Other Calls-for-Service	5500	22000	59000	86500

Hazard Formula

h_1 = hazard weight for violent crimes

h_2 = hazard weight for felony arrests

h_3 = hazard weight for other calls-for-service

H_A = hazard index for Precinct A = $h_1 \frac{250}{1575} + h_2 \frac{725}{4425} + h_3 \frac{5500}{86500}$

Assignment to Precinct A = (Total Number of Officers) x $H_A/(h_1+h_2+h_3)$

Workload Formula

w_1 = workload weight for violent crimes

w_2 = workload weight for felony arrests

w_3 = workload weight for other calls-for-service

W_A = workload index for Precinct A = $(w_1 \times 250) + (w_2 \times 725) + (w_3 \times 5500)$

W = total workload = $(w_1 \times 1575) + (w_2 \times 4425) + (w_3 \times 86500)$

Assignment to Precinct A = (Total Number of Officers) x W_A/W

FIGURE 2 HAZARD AND WORKLOAD FORMULAS

Finally, due to the subjectivity of the weights which are assigned to the different factors, the final allocation may be contrary to the results initially desired. For an example of this situation see Figure 3 where presumably the decision-maker, weighing Violent Crimes more heavily, wishes more officers be allocated to his district to counteract this factor. As can be seen, this is not the case.

2.1.2 LEMRAS

In the late 1960's I.B.M. developed a computerized version of the workload formula approach which they called, "Law Enforcement Manpower Resource Allocation System", (LEMRAS) [16]. The basic features of this I.B.M. package included the capability to predict the call-for-service rate, travel time, and service time on an hourly, daily, and weekly basis using historical data. Note that this program distinguishes between travel time and service time. Also, formulas similar to Wilson's workload formulas were used to weight various patrol related factors. Finally, the allocation of patrol units among precincts was based on two criteria. First, patrol units were assigned to equalize the amount of time spent on dispatches. Secondly, allocations were made to precincts to ensure that there was a sufficient number of patrol units present to respond to 85% of the calls-for-service within a specified time period. The time periods were established by the decision-maker by priority level. For instance, when used by the Saint Louis Police Department, a three minute time limit was established for high priority calls.

LEMRAS alleviated one of the major flaws associated with workload formulas by allocating patrol units to meet specified performance

PRECINCT C: (FROM FIGURE 2.)

CASE 1

$h_1 = 1$

$$H_C = (1 \times \frac{850}{1575}) + (1 \times \frac{2200}{4425}) + (1 \times \frac{59000}{86500})$$

$h_2 = 1$

$h_3 = 1$

$$H_C = 1.71894$$

$$\text{HAZARD ASSIGNMENT} = \text{Total Number of Officers} \times \frac{H_C}{1+1+1}$$

HAZARD ASSIGNMENT = Total Number of Officers x .57298

THEREFORE, PRECINCT C RECEIVES 57.298 PERCENT OF THE TOTAL WORKFORCE USING EQUAL WEIGHTS.

CASE 2

$h_1 = 7$

$$H_C = (7 \times \frac{850}{1575}) + (2 \times \frac{2200}{4425}) + (1 \times \frac{59000}{86500})$$

$h_2 = 2$

$h_3 = 1$

$$H_C = 5.4542$$

$$\text{HAZARD ASSIGNMENT} = \text{Total Number of Officers} \times \frac{H_C}{7+2+1}$$

HAZARD ASSIGNMENT = Total Number of Officers x .54542

THEREFORE, PRECINCT C RECEIVES 54.542 PERCENT OF THE TOTAL WORKFORCE. A SMALLER PERCENTAGE EVEN THOUGH VIOLENT CRIMES AND FELONY ARRESTS ARE WEIGHTED MORE HEAVILY.

FIGURE 3 HAZARD FORMULA INEQUITIES

standards for response times. However, a number of shortcomings remained. As mentioned earlier, one of the basic features of the LEMRAS package is the ability to predict future calls-for-service using exponential smoothing techniques. However, it was found that the calls-for-service could not be predicted with accuracy on a day-to-day basis which led to overstaffing in the districts. Furthermore, LEMRAS operated in a batch mode only and there was little actual customer use due to their desire to have an on-line capability. A final point that should be mentioned is that LEMRAS, along with the hazard and workload formulas, addresses only one level in the patrol allocation problem's disaggregation scheme explained in Chapter I. This is the first level dealing with the staff sizing of each district.

2.1.3 Queuing Theory

"The primary objective of all urban emergency systems is to reduce to a low level the possibility that an urgent call will have to be placed in queue for more than a few seconds" [16, p.66]. The queuing theory approach has as its main objective minimizing the response time such that the probability of an important call encountering a queue is less than a specified threshold level.

A queuing model has been used by the City of Saint Louis Police Department [62]. In this queuing model the city is divided into nine districts and a call-for-service is assumed to enter a queue when all cars in a district are busy and cannot respond. The Police Department estimates, using a multiserver queuing model, the number of cars needed so at most only fifteen percent of any district's calls are placed in a queue. This is done on a four hour time period. The major problem here is that allocations are made using the minimization of queue delay but these allocations do not insure that specified levels of other performance measures are met. For instance, performance levels concerning total response time, which is composed of both queue delays and travel times, and patrol frequency are not considered.

The most advanced allocation model to date, which is gaining widespread use, is the Patrol Car Allocation Model (PCAM) developed by Chaiken and Dormont [15] for the RAND institute in New York. It is a queuing model which allocates patrol units to satisfy various performance standards. PCAM is capable of operating in either a batch or interactive mode. It does not estimate call rates or service times as the LEMRAS package did. Here the past averages can be used or call rates and service times can be determined using outside programs.

PCAM can be used as either a descriptive or a prescriptive program. Used as a descriptive program, PCAM will display quantitative information about various allocations of patrol units which are read into the program. This permits the user to compare various alternative allocation schemes.

Utilized in the prescriptive mode, PCAM will determine the number of patrol units necessary to meet certain standards of performance. It will also indicate to the user the "best" allocation of his existing resources over either districts and/or time. "Best", of course, is a relative measure which is dependent upon the amount of resources available for the allocation procedure. "Best" with respect to PCAM can be defined in one of three ways:

(1) The average percentage of calls placed in queue is as small as possible.

(2) The average length of time calls of a given priority must wait in queue is as small as possible.

(3) The average total response time is as small as possible.

There are, however, some criticisms to be levied against PCAM which for the most part concern simplifying assumptions. PCAM does not consider the differing demographic structure of the various districts and seems to be insensitive to the location of the patrol unit within the district when gathering information or allocating patrol units. Only three levels of priority are specified for calls-for-service while the dispatching practices on which the performance statistics are based are unrealistic. Examples of these practices include only one car ever being dispatched to any call-for-service, no dispatching across district boundaries even for high priority calls, and no preemption of service on low priority calls for high priority calls, or the placing of low priority calls in queue to await the availability of a local beat car.

As with other methodologies, PCAM deals primarily with one level of the patrol allocation disaggregation scheme. In this case attention is focused on vehicle and manpower scheduling.

There has been an attempt to bridge the gap between stochastic queuing models and hazard formulas by Capaul, Heller, and Meisenheimer [12]. Their work pertains to the allocation of police call-for-service units to police districts in a manner reflecting the rate of physical injury, property loss, and fear that is related to each incident in conjunction with stochastic response times. They attempt to show that the demand for police service is multidimensional and that fairly reliable operational measures of each dimensional component can be developed to assist in the allocation of police units.

Capaul et al [12] have proposed an interesting approach trying to combine the best of both worlds. The major stumbling block the authors face is the subjective nature of the development of the measures of seriousness pertaining to injury, property loss, and fear. These seriousness measures are based only on the incidents reported and eventually lead to an average measure for all districts. Furthermore, there may be present upper class residential areas that have the ability to apply pressure for more service even though the seriousness measures are low for that particular area. Once again this approach caters to one level in the disaggregation framework, the staff sizing of each district.

2.1.4 Mathematical Programming

Larson [56] has developed a policy oriented dynamic programming algorithm in which the allocation of patrol units is based on a set of objectives to be fulfilled, rather than on some weighted workload or hazard formula. It is structured such that police policy, in terms of objective functions and constraints, can be input directly into the algorithm and these constraints are permitted to vary between districts. The algorithm supplies each district with enough units to satisfy the set of specified constraints while using a queuing delay equation as the objective function to minimize the use of any additional vehicles beyond the minimum number required to satisfy the constraints. The actual list of objectives (constraints) is supplied by police administrators; however, examples of such constraints are the average travel time, crime rate criteria, minimum number of units to be assigned to any one district, and preventive patrol frequencies. If the specified constraints are too restrictive in that they are unobtainable with the given resources, the algorithm will indicate the number of additional vehicles required.

Larson's model does not predict calls-for-service or service times. They must be input to the algorithm. It does, however, use a priority system to rank important calls-for-service which permits each priority level to have its own service time distribution. The program also allows the service time to vary with the number of units busy.

Along with allocating patrol units on a district-by-district basis, given hourly data the algorithm is capable of providing information pertaining to the scheduling of personnel.

Vitt [77] has approached the patrol resource allocation problem through the use of linear programming to develop manpower and/or vehicle schedules of tour assignments by watch, day of the week, and quarter. A set of technical constraints are specified which establishes the relationship between on-duty working time, recreational time, and vacation time. Given the workload requirements for each day and watch and the relationships specified in the constraints, the linear program determines the manpower level necessary to satisfy the workload. The objective function is the minimization of the sum of the penalties that are assigned to each unit of recreation and demand overload. There is a small penalty placed on recreation and a large penalty placed on demand overloads. In this respect, the program is very similar to a goal programming formulation.

Using a linear programming approach, the author quickly runs into a combinatorial problem which limits the degree of disaggregation that can be obtained. The major problem, however, seems to be the determination of the percentage of time patrol units should spend servicing calls-for-service. Therefore, what is necessary to make this approach more efficient is the determination of appropriate utilization ratios for each district to be scheduled.

It is evident that many varied attempts have been made to solve the police patrol allocation problems of staff sizing and manpower scheduling. However, most of these approaches have concentrated on a single stage in the disaggregation flow. This research attempts to alleviate that short-coming.

2.2 UTILITY AND MULTIPLE OBJECTIVE CRITERIA

2.2.1 Utility Theory

Fishburn [38], in his book, identifies the two most popular decision-value theories as first the von Neumann and Morgenstern (1947) theory of games and second Wald's (1950) statistical decision theory. Neither of these theories have enjoyed much success in terms of practical application. Wald has attempted to develop statistics into a science of decision-making under uncertainty. Brownlee [9, p. 64] describes the difficulty in applying Wald's approach in this excerpt:

> "Statistics is frequently defined as the science of making wise decisions in the presence of uncertainty. To cite Savage's example in his review (1951) of Wald's book (1950), the decision to be made may be whether to take an umbrella on one's trip to the office. This approach requires a knowledge of the relative

costs of carrying an umbrella when the day turns out to be fine and of getting wet through failing to carry an umbrella when the day turns out to be wet. The practical usefulness of this approach has been severely hindered by the rareness with which one can actually estimate with any confidence the cost functions. Whether this obstacle can be circumvented sufficiently to bring this decision-theory approach into common use remains to be seen."

Both of these decision-value theories are dependent on utility functions to measure "gains" or "losses". A utility function is taken here to be "a real-valued function whose domain of definition is a specific set and whose range lies in the real numbers, where the functional values are unique except for an origin and unit measure," [38, p. 6]. One basis for obtaining utility was developed by von Neumann and Morgenstern utilizing a system of axioms of rational behavior, which, if satisfied, would guarantee the existence of a utility function.

Fisburn [38] has developed a decision model related to the von Neumann-Morgenstern postulates that relies on the expected relative value of a strategy as it's basis, where a stragegy is a course of action. The expected relative value of a strategy is a weighted sum of the relative values of the consequences. A consequence is an outcome brought about by choosing a particular strategy. The weights are the respective probabilities of the consequences occurring if a particular strategy is adopted. As seen symbolically [38, p. 12];

$$E(S_i) = P_{i1}V_1 + P_{i2}V_2 + . . . + P_{ir}V_r. \quad (1)$$

where $E(S_i)$ = expected relative value of strategy S_i.

P_{ij} = probability that the jth consequence in a set of r consequences will occur if strategy S_i is adopted with $\sum_{j=1}^{r} P_{ij} = 1$.

V_j = relative value of the jth consequence j = 1, . . ., r.

The decision maker's total expected relative value is defined by

$$EV(I) = \sum_{i=1}^{t} C_i \, E(S_i) \qquad (2)$$

where EV(I) = decision maker's total expected relative value,

C_i = probability that the decision maker will adopt strategy S_i, and

t = the total number of possible strategies that could be adopted,

where $\sum_{i=1}^{t} C_i = 1$, $C_i \geq 0$, i = 1, . . ., t.

The major advantage of this additive utility function is its simplicity since the assessment of an n-attribute utility function can be reduced to an assessment of n one-attribute utility functions. This additive utility function is based on Fishburn's additive independence condition [51, p. 295]:

> "Attributes $x_1, x_2, \ldots, x_n$ are additive independent if preferences over lotteries on $x_1, x_2, \ldots, x_n$ depend only on their marginal probability distributions and not on their joint probability distributions."

Then the simplification to the assessment of n one-attribute utility functions is performed by using the concepts of preferential and utility independence [51, p. 284].

> "Attribute y, where $y \subset x$ is preferentially independent of its complement $\bar{y}$ if the preference order of consequences involving only changes in the levels of y does not depend on the levels at which attributes of $\bar{y}$ are held fixed."

> "Attribute y is utility independent of its complement $\bar{y}$ if the conditional preference order for lotteries involving only changes in the levels of attributes in y does not depend on the levels at which the attributes in $\bar{y}$ are held fixed."

With this simplification, the key to the usefulness of this decision model is determining the V_j's, the relative values of the jth consequences. In order to accomplish this, a measure of the decision-maker's preferences must be obtained.

It should be noted that an additive decision model as presented above assumes that the decision-maker has knowledge of the true probabilities present in the model. Also, the decision-maker is assumed to possess exceptional and consistent judgmental capabilities.

Fisburn [39] has reviewed twenty-four methods of estimating additive utility formulations for risky and nonrisky multiple-factor decision situations. The general case has n factors of interest where X is the set of all vectors $(x_1, x_2, \ldots, x_n)$ and x_i' is a level of the ith factor, i = 1, 2, ..., n. To be consistent, elements in X will be referred to as consequences. The additive utility model for X is: if $x = (x_1', x_2', \ldots, x_n')$ and y are any two consequences in X. then

(1) x is not preferred to y if and only if $u(x) \leq u(y)$,

(2) $u(x_1', x_2', \ldots, x_n') = u_1(x_1') + u_2(x_2') + \ldots + u_n(x_n')$ for all x in X;

where u is a numerical utility function on X and u_i is a numerical utility function for the ith factor, i = 1, 2, ..., n, [39, p. 436].

2.2.2 Multiple Objective Criteria

There has been a number of attempts to synthesize the approaches to multiple objective criteria decision-making [32], [42], [51], [52], [61], [67]. Keeney and Raiffa [51] and Easton [32] begin their ordering by describing the dominance approach. Dominance only exploits the ordinal character of the relationships of the multiple criteria and does not formalize the preference structure of the decision-maker. If x represents a consequence then x' dominates x" whenever [51, p. 69]

(a) $x'_i \geq x''_i$ for all i

(b) $x'_i > x''_i$ for some i.

Truly dominant alternatives are superior to all others in the set no matter what system of ordering is used or what criterion weights are assigned [32, p. 169]. However, the situation rarely arises where the ordering of alternatives can be accomplished by dominance alone.

A second choice procedure that also does not formalize the preference structure of the decision-maker is the concept of an efficient frontier [51], [67]. Quite simply, the efficient frontier is a set of consequences that are not dominated, also known as the "Pareto Optimal set". Keeney and Raiffa describe two ways to explore the efficient frontier. The first is by the use of artificial constraints where various aspiration levels are set and evaluated iteratively. The procedure requires a series of creative judgments from the decision-maker pertaining to first the arbitrarily imposed constraints and second deciding when he is satisfied. The probing procedure involves interaction between analyzing the "achievable" versus the "desirable" [51, p. 74].

Methods which attempt to formalize the decision-maker's preferences are also described by Keeney and Raiffa [51]. Lexicographic ordering is a very simple and easily administered technique which is very similar to ordering in a dictionary. Act a' is preferred to act a" if it merely has a higher score on consequence x_1 regardless of how well it compares against other x_1 evaluators. In other words, consequence x_2 is only evaluated if the x_1 scores are tied. This approach is actually too simple and rarely appropriate.

Indifference curves are a second approach to formalizing the decision-maker's preferences. An act a' is preferred to an act a" if the consequences of a' lie on a higher indifference curve. A major prerequisite in using indifference curves is comparability among consequences.

Keeney and Raiffa [51] propose the use of value functions as a third alternative to specifying the preferences of decision-makers. If a real number can be associated with each point x in the evaluation space, then a value function representing the decision-maker's preferences can be obtained. With a value function reflecting the preferences, the problem can be put into a standard optimization problem and solved.

Find $a \in A$ to max $v\,[X\,(a)]$,

where A - the set of all feasible acts,

a - one feasible act or alternative

$v\,[X\,(a)]$ - the value function for the X vector of consequences associated with alternative a.

Easton [32] proposes the use of a vector to scalar transformation to arrive at the value function of available alternatives. This procedure requires the amalgamation of the elements of each alternative's valuation score set of consequences into a single index number used as a figure-of-merit (FOM). This procedure is useful because we do not know how to compare multi-valued alternatives directly unless, accidently, they appear in a dominance, contradominance, or equality relationship [32, p. 171]. Problems arise in deciding which particular mathematical operation to use in arriving at the FOM. "We cannot properly state that one of a pair of unequal, nondominant alternatives is superior, inferior, or equivalent to a second unless we first specify the method for transforming the vector score-set into a scalar (method of amalgamation) because under one mathematical ordering system, a particular alternative may be superior while under another system, it may prove inferior," [32, p. 173]. Alternative amalgamation approaches consist of summation where an arithmetic mean is used to arrive at average utility, multiplication which is similar to the use of a geometric mean, and lengths of vectors which leads to a composite utility of the alternative.

Mac Crimmon [61] in "An Overview of Multiple Objective Decision Making" describes various multiple objective decision models. By interrelating some of the major approaches into four categories he indicates the characteristics of decision problems to which each approach is most applicable.

The first category deals with Weighting Methods where the goal is to determine the decision-maker's preference structure. Techniques found in this category range from linear regression and analysis of variance which are used to infer preferences from past choices to directly assessing preferences by the use of trade-offs and additive weightings.

A second category of multiple objective decision-making methods is the Sequential Elimination approaches. The techniques comprising this category utilize a standard comparison in the decision making process. Popular techniques surveyed include dominance, lexicography, elimination by aspects, and the use of disjunctive/conjunctive constraints.

Dominance is usually used as an initial filter after which successive attributes can be compared across alternatives using lexicography. Elimination by aspects is similar to lexicography in that it examines only one attribute at a time for each alternative. However, alternatives are eliminated that do not satisfy some standard until only one alternative remains.

In using disjunctive/conjunctive constraints, the decision-maker sets standards which are applied to the values of the attributes of each alternative. If the constraints are conjunctive all the standards must be met and if the constraints are disjunctive only one standard has to be met.

A third category pertains to the use of mathematical programming methodology. Techniques representative of this approach include linear programming, goal programming, and interactive multi-criterion programming. The use of interactive multi-criterion programming does not assume a global objective function but requires the decision-maker to provide local trade-offs in the neighborhood of feasible alternatives. These trade-offs are then used in local objective functions to generate optimal solutions for that objective. Given the solution, the decision-maker is then free to provide a new set of trade-offs and the procedure continues until a satisfactory solution is reached.

An interactive multi-criterion approach has been described by Dyer [30] and used by Geoffrion, Dyer, and Feinberg [43]. Dyer describes the approach as a time sharing computer system which is programmed to query the decision maker with a series of paired comparisons to which he is to indicate his preference or indifference. The process continues until the point of indifference is reached. This trade-off procedure is used to determine weights which are used in approximating the decision-maker's utility function which in turn provides a direction of movement from an initial point. The decision-maker then determines the optimal step size with which to move in the chosen direction. The mathematical programming technique used in this research was the Frank-Wolfe method which is a large step gradient ascent algorithm. The procedure is being used to help schedule teaching assignments for the academic faculty at the Graduate School of Management at the University of California at Los Angeles.

Klahr [52] expounds on the problems faced when using mathematical programming procedures when multiple objectives are involved. He states that mathematical programming requires, before anything else, an abstraction from a real situation to a model suitable for computation. Furthermore, the most difficult aspect of the model development, in many applications, is the choice of the objective function, not because it is too hard, but because it is too easy [52, p. 849]. This is because mathematical programming requires that a unique objective must be chosen to specify the problem and in many real situations a number of economic quantities suggest themselves. To choose only one is often restrictive and arbitrary.

To help alleviate this problem Klahr describes some approaches for using mathematical programming techniques. First, one can attempt to bound the problem by formulating a variety of problems concerning the real situation, each of which is extreme in some sense. Then each problem is solved individually and the solutions compared to help guide the decisions. The trouble with this approach is that the real problem is never solved.

Klahr also mentions the use of weighted averages where the weighted average of the distinct individual objectives is used as the objective function [52, p. 850]. This approach, however, imposes the requirement of commensurability. A common denominator must be found and this often times is not possible.

Mac Crimmon's final category groups techniques utilizing spatial proximity for decision making purposes when multiple objectives are present. Approaches described within this category include indifference mapping which is a more explicit form of trade-off graphs, graphical overlays which can be used for location decisions such as where to put a highway, and multi-dimensional scaling with ideal points. In the last approach, alternatives are represented by points in a multi-dimensional solution space.

Gearing [42] extends the procedures of Mac Crimmon by using an eclectic methodology to eliminate alternatives. In his procedure he first eliminates alternatives using dominance, then he uses the principles of bounding to further reduce the number of feasible alternatives. Finally, a quasi-lexicography procedure is used to determine a score for each remaining alternative to derive the optimum.

Benayoun, Tergny, and Keuneman [5] have developed the Progressive Orientation Procedure (POP) which treats the case in multiple objective functions where the various criteria are not interconnected. The technique is a two phase approach where in the Choice Phase, the decision-maker examines a pay-off table that is associated with the efficient solution for each criteria. There is no interaction and the objective criteria are treated independently. The second phase, the Reoptimization Phase, uses the decision-maker's input to find new efficient solutions within the individual subsets. More constraints can then be added and the decision-maker returns to step one. This technique only considers subsets of efficient solutions.

Benayoun, Montgolfier, Tergny, and Laritchev [6] have developed an approach similar to POP called STEM. STEM is useful if the decision-maker is unable to give enough information about the relative importance of the objective function to specify an ordering. It is an iterative exploration procedure which strives to reach a compromise. There are basically three stages in its development the first being the construction of a pay-off table using the optimum solution with respect to each objective. Then a calculation stage seeks feasible solutions from the pay-off table data. Finally, in a decision stage the solution from the calculation stage is examined and new information is developed in terms of various trade-offs and relaxations of certain objectives until a compromise solution is obtained.

2.3 GOAL PROGRAMMING

"In his eagerness to use some quantitative methods, the decision-maker often ignores the limitations of these techniques. He conveniently derives an arbitrary estimate of intangible outcomes in terms of costs or profits and solves the problem," [57, p. 173]. This statement in many instances is indicative of linear programming. The primary difficulty with using general linear programming is that it requires cost and/or profit information which is often very hard to obtain. Goal programming is a modification and extension of linear programming. The goal programming approach allows the simultaneous solution of a system of complex objectives rather than concentrating on a single cost or profit objective. The user may also specify non-homogeneous units of measure in the goal programming objective function.

Goal programming, as an approach itself, was developed by Charnes and Cooper and named as such in their test on linear programming in 1961 [58, p. 16]. When using goal programming, the objective function tends to cause the deviational variable to "drive" the values of the choice variables as opposed to a regular linear programming approach where the choice variables "drive" the slack variables [58, p. 22].

Ijiri's study of goal programming techniques presented a definition of "preemptive priority factors" to treat multiple goals according to their importance and to weight the goals within the same priority level [58]. These preemptive factors and differential weights take the place of the objective function coefficients, C_j's, as used in linear programming. The preemptive priority factors are multi-dimensional, being ordinal rather than cardinal values, which means these priority factors at different levels are not commensurable. Therefore, the simplex criterion can not be expressed as a single row. Rather, a m x n matrix must be employed where m refers to the number of priority levels and n refers to the number of variables, both choice and deviational [58, p. 48].

The most important advantage of goal programming is its great flexibility, which allows model simulation with numerous variations of constraints and goal priorities. The biggest disadvantage is that the goal programming model simply provides the best solution under a given set of constraints and priority structure; therefore, the decision-maker must be careful to assure that the priority structure is in accordance with the organizational objectives.

Because goal programming is an extension of linear programming there are a number of limitations imposed on the use of the technique. Four key limitations are concerned with the principles of proportionality, additivity, divisibility, and determinism [58, p. 32]. Proportionality requires that the measure of goal attainment and resource utilization be proportional to the level of each activity conducted individually. Additivity ensures linearity by requiring the activities to be additive in the objective function and constraints. Divisibility relaxes the integer requirements for decision variables while determinism places the burden of assuming constant and known-for-certain coefficients and goal levels on the goal programming approach. Charnes and Cooper [17] engage in a general discussion of goal programming explaining the progression from the use of absolute priorities through the development of both relative and preemptive weights. The absolute value format is as follows [17, p. 8]:

$$\underset{x \varepsilon X}{\text{Min}} \sum_{i \varepsilon I} \sum_{j=1}^{n} \left| a_{ij} x_j - g_i \right| \tag{3}$$

where:

a_{ij} represents the constraint matrix coefficients for row i column j.

x_j represents the decision variable associated with column j in the constraint matrix.

g_i represents the goal level one wishes to attain for the ith goal.

The absolute value format can then be quickly converted to a format using deviational variables which more closely resembles a linear programming formulation.

$$\text{Min} \sum_{i \varepsilon I} (d_i^+ + d_i^-) \tag{4}$$

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = g_i \tag{5}$$

$d_i^+, d_i^- \geq 0$ for $i \varepsilon I$,

where:

g_i represents the specified level of the goal.

d_i^+ represents the positive (average) deviation from the specified level.

d_i^- represents the negative (shortage) deviation from the specified level.

In Equation (4) the discrepancy relative to the ith goal is being minimized and then the total deviation is arrived at by summing the individual discrepancies. The next logical progression is the desire to weight these discrepancies within each goal differently. For instance, if the goal is to respond to eighty-five percent of all police calls-for-service immediately, then it may be more important to minimize the negative deviation where we would be responding to less than eighty-five percent than to minimize the positive deviation where we would respond to better than eighty-five percent. Charnes and Cooper [17, p. 10] show this formulation as the following:

$$\text{Min} \sum_{i \varepsilon I} (w_i^+ d_i^+ + w_i^- d_i^-) \tag{6}$$

Subject to:

$$\sum_{j=i}^{n} a_{ij} x_j - d_i^+ + d_i^- = g_i \tag{7}$$

$$d_i^+, d_i^- \geq 0 \text{ for } i \varepsilon I$$

where:

w_i^+ and w_i^- represent the relative weights for the respective positive and negative deviations.

The final step is to allow for the use of preemptive weights, M_i, which are defined by the decision-maker to produce the desired preemptive properties. These constants, M_i, set up a priority structure such that the group of goals contained in the highest priority category are satisfied first and there is no substitutions across categories. This property is represented by [17, p. 11]:

$$M_i >> M_{i+S} \tag{8}$$

to mean that no real number y, however large, can produce

$$yM_{i+S} \geq M_i. \tag{9}$$

The model is mathematically represented as follows [17, p. 11]:

$$\text{Min} \sum_{i \epsilon I} M_i \sum_{K=1}^{n_j} (w_i^+ (K)\ d_i^+ (K) + w_i^- (K)\ d_i^- (K) \tag{10}$$

Subject to:

$$\sum_{j=1}^{m} a_{ij} (K)\ x_j - d_i^+ (K) + d_i^- (K) = g_i (K) \tag{11}$$

$$d_i^+ (K),\ d_i^- (K) \geq 0 \text{ for } i \epsilon I$$

where:

$w_i^+ (K)$, $w_i^- (K)$ represent the relative weights associated with each of the K goals within each preemptive category.

Equation (10) is the final model incorporating the possible use of both relative and preemptive weights.

Dyer [31] discusses recent developments in multi-attribute utility theory and approximation theory in mathematical programming which have implications for applications of goal programming to problems involving multiple objectives. It is his contention that the current attention focused on goal programming is not warranted and that it should be viewed as a useful and special case of several more general concepts. The discussion is limited in that only problems with multiple, compensatory objectives are considered for the goal programming methodology. Non-compensatory models involve the use of non-Archimedian, or "preemptive priority," weights.

Dyer shows, through the use of a simple example, how a goal programming formulation is actually equivalent to an additive separable nonlinear objective function. Since the choice of the goals and goal intervals reflect the decision-maker's preferences, the goal programming formulations of multiattribute mathematical programming problems implicitly assume the existence of an additive separable utility function. This conclusion poses two questions regarding the use of goal programming formulations [31, p. 7]:

(1) Is the implicit assumption of the existence of an additive separable utility function valid in a particular application?
   (a) Are the conditions for its existence satisfied?
   (b) If these conditions are not satisfied, how much error is likely to occur if we use the additive separable form as an approximation?
(2) How should the piecewise linear approximations to the non-linear conditional utility functions be selected in order to minimize errors?

In addressing the first set of questions, Dyer reminds us that goal programming applications generally allow the decision-maker to select each goal independent of any consideration of the values for other criteria. This, in turn, implies the existence of a cardinal additive utility function under certainty [31, p. 8]. The key condition then that must be satisfied is called "difference independence." "Difference independence" can be summarized by the following: The preference differences between two pairs of alternatives that differ in only one component should not depend on the fixed values of the other components [31, p. 8].

Dyer goes on to conclude that the additive separable form is a robust approximation that will give satisfactory results in many applications; however, one should be very careful in his choice of criteria in order to avoid violating the difference independence condition.

Given that one has chosen his criteria so that the additive separable form serves as a reasonable approximation, Dyer proceeds to provide some guidelines for approximating the conditional utility functions. The two cases presented consider monotonic functions exhibiting decreasing marginal utility and nonmonotonic functions also exhibiting decreasing marginal utility. The optimal approximation occurs when the maximum "undershoots" of each linear component from the utility functions are equal. In summary, Dyer concludes that a goal programming formulation of a multiple objective mathematical programming problem is equivalent to the use of a piecewise linear approximation to an additive separable utility function [31, p. 19].

2.3.1 Applications

Goal programming formulations have been applied to a wide array of problem situations. The area of application, which specifically relates to the research presently being conducted in this text, concerns the problems associated with manpower planning. Price and Piskor [65] have applied goal programming to manpower planning problems found in the military personnel system for officers in the Canadian

Forces. The formulation is part of a control system for fixing promotion quotas and strengths for the various rank levels in occupational classifications of the military for a three year planning horizon.

Goal levels are specified in terms of the number of personnel who can be supported for promotion for each classification. In this research a computer program was developed called UPDATE which was designed to be used in conjunction with I.B.M.'s MPSX program. The model then uses a series of cascaded one-period models for the preparation of a multi-period forecast which specifies the number of personnel to be promoted. The process must be repeated for each period in the planning horizon.

Price and Piskor identify three sources of improvement gained by using a goal programming formulation as opposed to a regular linear programming model [65, p. 230]:

(1) All policies which are considered in the decision making process must be formalized and clearly stated.

(2) The rapid response time of the automated model permits the evaluation of a larger number of policies.

(3) All the information available to the decision-maker is actually used in the calculation of the solution.

Krajewski and Henderson [54] present a goal interval programming model to address the problem of aggregate manpower planning of postal clerks in a Sectional Center post office. This problem entails selecting optimal employee complements, where an employee complement is the number of employees of a particular type employed for sorting mail, over a horizon of one year. The model is used to analyze fixed versus variable complement size policies [54, p. 254].

The goal constraint set specified by Krajewski and Henderson contained two goals, [54, p. 256]:

(1) Do not exceed a certain annual budget commitment,

(2) Do not fall below certain stated service levels.

The service level was expressed in terms of average working-in-process inventory levels. By analyzing the trade-offs in service and employee complement sizes at various mail volume levels, it was found that a nonlinear relationship existed which necessitated the use of goal interval programming.

Krajewski and Henderson concluded, "that interval goal programming models are capable of providing relevant information for policy formulation and therefore should be considered as an important management tool in the Public Sector," [54, p. 259]. Specific information gained in employing this approach include:

(a) By solving a series of programs in which the goal level for the budget constraint is increased, the cost/service relationship can be developed.

(b) The model can be used to evaluate the effect of various management policies on both the cost and service goals.

(c) By solving the model for a series of upper limits, information relative to the "most appropriate" limit management should impose would be provided [54, p. 258-259].

Dyer [29] provides an extension to goal programming in the form of an algorithm which requires interaction with the relevant decision-maker. In this research, he is attempting to bridge the gap between goal programming and other proposed interactive strategies used for the optimization of the multiple criteria problem. Although the procedure requires interaction with the decision-maker to obtain information regarding his utility functions, it does not require the explicit representation of those functions.

The procedure is a six step algorithm that leads to the formulation of a one-sided goal program with multiple criteria which is equivalent to the piece-wise linear approximation of an additive separable utility function which was discussed earlier in this text.

2.4 Concluding Remarks

Chapter II has summarized the research efforts, in four major areas, that are related to and affect the research described in this document. Other solution methodologies which have been used to address the police patrol allocation problem were reviewed. By studying these past attempts to solve the patrol allocation problem, the strengths and weaknesses of each methodology were identified. This information is then to be used to develop an integrative solution methodology. Literature concerning multiple objective criteria was reviewed because it accurately depicts the environment in which the patrol allocation decision must be made. The basic principles of utility theory were summarized due to their importance in weighting the multiple objective criteria. And finally, literature pertaining to the goal programming approach of solving multiple criteria problems was reviewed, which established it's appropriateness for use in the solution of the patrol allocation problem.

Chapter II has provided a foundation from which to build a solution methodology for the police patrol allocation problem. The remainder of this document, beginning with Chapter III, presents the development and results of such a methodology.

CHAPTER III

STATISTICAL ANALYSIS

This research is structured into three distinct stages. The first stage, described here in Chapter III, is a statistical analysis of geographic and demographic factors thought to influence the demand placed on the patrol function. By studying the interrelationships present between these factors and the resulting level of demand exhibited by a particular area, an equation can be modelled which will enable one to predict the level of demand expected to occur as a result of a particular set of factors.

The importance of this statistical analysis is centered in the predictive capabilities which are acquired with respect to the call-for-service workload of a particular area. The statistical analysis allows for the estimation of workload levels. Since the utilization ratio is the call-for-service workload over the total amount of time a patrol vehicle spends on-duty, the ability to estimate workload translates into the ability to estimate utilization ratios for any set of geographic and demographic factors, given the total amount of patrol vehicle hours spent on-duty. In this research, the ability to estimate utilization ratios leads directly to the modeling of relationships which exist between utilization levels and other measures of performance and the establishment of target goals for these measures.

In cases where redistricting is not an issue the statistical analysis step may not be necessary. In such cases historical demand of the existing districts may be used to estimate utilization ratios. The statistical analyses is important, however, when the redesign of precincts is being considered, since historical workload levels will, most likely, not be available with respect to the new district boundaries. The statistical analysis is also an important step in that it could be used to project workload levels for the future to aid in planning for various factor changes such as population increases.

A specific objective of this research is the establishment of the utilization ratio as a key decision variable to be used in the patrol allocation problem. The statistical analysis helps achieve this objective because of the direct relationship existing between workload and utilization. Due to this relationship, the statistical analysis should provide insights as to the causes of utilization variation between patrol districts and, in turn, help establish appropriate staff sizes for each district. Furthermore, a knowledge of the causes of utilization variation will enable the patrol planner to design equitable patrol districts. Therefore, the patrol planner is aided at the first and third levels of the patrol allocation problem, as structured in Figure 1, Chapter I.

3.1 Data Collection

Working closely with the research and planning division of the Columbus Police Department in Columbus, Ohio, sixteen geographic and demographic factors thought to influence the call-for-service workload were identified. The following is a list of all sixteen factors:

(1) the total population of the area

(2) the percentage of growth of the population which occurred between census

(3) the population density

(4) the acreage of the area involved

(5) the percentage of the population that were black

(6) the total number of houses

(7) the housing density

(8) the number of vacant houses

(9) the number of owner occupied houses

(10) the median rent payment

(11) the median value per house

(12) the number of substandard houses as judged by the city housing codes

(13) the number of part one offenses committed within the area

(14) the total number of offenses committed within the area

(15) the number of persons charged with part one offenses

(16) the total number of persons charged with any offenses

For the most part these sixteen factors are self explanatory except for the term 'part one offenses.' The Columbus Police Department identifies 'part one offenses' as major crimes which would include such things as murder, robbery, assault, and rape.

Data were collected which reflect the level of each of the sixteen factors with respect to the two-hundred and twelve census tracts that comprise Columbus, Ohio. Also corresponding to each census tract, the call-for-service workload was derived. This was achieved by processing call rate and service time data for the City of Columbus as a whole with the Patrol Data Analysis Program, which was developed by Dr. L.D. Vitt of The Ohio State University. The Patrol Data Analysis Program is an information processing computer program which transforms aggregated call-for-service workload into smaller spacial and temporal units.

The use of census tracts is a convenient unit for collecting data concerning the geographic and demographic factors listed previously. The census tract is a stable unit of reference and acts as a building block in identifying larger geographic areas. However, it is not a good geographic unit upon which to perform a statistical analysis for this research. This research revolves around the use of the utilization ratio as a key measure of service performance. If the statistical analysis was performed using census tracts, the utilization ratio of each tract would be very difficult to estimate. This is because the denominator, reflecting the total amount of time a patrol vehicle is on duty within each census tract, would be difficult to measure. The difficulty arises because each patrol vehicle patrols an area composed of a number of census tracts and the amount of time spent in each census tract can vary considerably depending on demand and service time variability.

Therefore, the statistical analysis should be conducted with respect to a geographic unit that will facilitate the estimation of utilization ratios. The logical choice then becomes the use of cruiser districts. For this reason the data collected concerning factor levels for each of the two-hundred and twelve census tracts was aggregated into sixty-three cruiser districts for purposes of statistical analysis. The use of cruiser districts provides a constant value for the denominator of the utilization ratio; eight vehicle hours per watch or twenty-four vehicle hours per day. Therefore, by estimating call-for-service workload the utilization ratio is also being estimated.

It should be understood that, although the objective of the statistical analysis is the development of a predicting equation for the call-for-service workload for a particular district, it is also important to study the factors themselves to gain some insight into existing relationships and interactions which may aid in the decision process. If all that was needed was the equation itself, a stepwise regression procedure alone could have provided it. The use of a factor analysis, however, helps provide these insights.

3.2 Factor Analysis

Upon completion of the data collection task, the statistical analysis progresses toward the development of a workload predicting equation based on the previously identified factors. However, the very nature of these factors suggests the presence of strong relationships between the factors themselves. For this reason a correlation analysis was performed on the sixteen factors with the resulting matrix of correlation coefficients being displayed in Table 1. This matrix substantiates the fact that certain factors are highly intercorrelated. For instance, the population factor is highly correlated with the number of total houses, exhibiting a correlation coefficient of .96603. The population density and housing density are correlated at the rate of .80625, median rent and median value register a .85026 correlation coefficient, and the number of part one offenses are correlated with the number of total offenses at a .99487 level.

TABLE 1

CORRELATION COEFFICIENT MATRIX FOR GEOGRAPHIC AND DEMOGRAPHIC FACTORS

	Population	Growth	Population Density	Acreage	Percentage Black	Total Housing	Housing Density	Vacant Housing
Population	1.0000	.245	.0131	.2359	-.2504	.9660	-.0192	-.0317
Growth	.2456	1.0000	-.4993	.7215	-.3144	.1351	-.5044	-.3083
Population Density	.0131	-.4993	1.0000	-.3997	.1578	.0771	.8063	.2578
Acreage	.2359	.7215	-.3997	1.0000	-.4020	.1395	-.5926	-.3921
Percentage Black	-.2504	-.3144	.1578	-.4020	1.0000	-.2608	.2236	.4679
Total Housing	.9660	.1351	.0771	.1395	-.2608	1.0000	.0955	-.2201
Housing Density	-.0192	-.5044	.8063	-.5926	.2236	.0955	1.0000	.4269
Vacant Housing	-.3017	-.3083	.2478	-.3921	.4679	-.2201	.4269	1.0000

TABLE 1, (continued)

	Population	Growth	Population Density	Acreage	Percentage Black	Total Housing	Housing Density	Vacant Housing
Owner Occupied Housing	.2278	.4965	-.4723	.6106	-.2648	.1076	-.6299	-.7036
Substandard Housing	-.2525	-.4948	.3969	-.5010	.3105	-.2507	.3997	.3852
Median Value	.1549	.5962	-.4357	.6484	-.4108	.1117	-.4784	-.3478
Median Rent	.2655	.5996	-.3529	.5416	-.4499	.2056	-.4113	-.3199
Part One Offenses	.7415	.1401	.1795	.0318	-.1007	.7256	.1991	.0604
Total Offenses	.7769	.1475	.1739	.0485	-.1273	.7548	.1772	.0232
Persons Charged Part One	.3999	.0474	.0972	-.0412	-.0076	.3804	.1086	.1736
Total Persons Charged	.1031	-.2393	.2493	-.3100	.0989	.1304	.3164	.3710

TABLE 1, (continued)

	Owner Occupied Housing	Substandard Housing	Median Value	Median Rent	Part One Offenses	Total Offenses	Persons Charged Part One Offenses	Total Persons Charged
Population	.2278	-.2525	.1549	.2655	.7415	.7760	.3999	.1031
Growth	.4965	-.4948	.5962	.5996	.1401	.1475	.0474	-.2393
Population Density	-.4723	.3969	-.4357	-.3529	.1795	.1739	.0972	.2493
Acreage	.6106	-.5010	.6484	.5416	.0318	.0485	-.0412	-.3100
Percentage Black	-.2698	.3105	-.4108	-.4499	-.1007	-.1273	-.0076	.0989
Total Housing	.1076	-.2507	.1117	.2056	.7256	.7548	.3804	.1304
Housing Density	-.6299	.3997	-.4784	-.4113	.1991	.1772	.1086	.3164
Vacant Housing	-.7036	.3852	-.3478	-.3199	.0604	.0232	.1736	.3710
Owner Occupied Housing	1.0000	-.6080	.5883	.5552	-.2212	0.1886	-.2680	-.5806

TABLE 1, (continued)

	Owner Occupied Housing	Substandard Housing	Median Value	Median Rent	Part One Offenses	Total Offenses	Persons Charged Part One Offenses	Total Persons Charged
Substandard Housing	-.6080	1.0000	-.6265	-.6499	.0314	.0333	.0111	.4583
Median Value	.5883	-.6265	1.0000	.8503	-.1508	-.1457	-.1618	-.4072
Median Rent	.5552	-.6499	.8503	1.0000	.0020	.0031	-.0738	-.4560
Part One Offenses	-.2212	.0314	-.1508	.0020	1.0000	.9949	.7056	.5251
Total Offenses	-.1886	.0333	-.1457	.0031	.9949	1.0000	.6866	.5107
Persons Charged Part One	-.2680	.0111	-.1618	-.0738	.7056	.6866	1.0000	.6559
Total Persons Charged	-.5806	.4583	-.4072	-.4560	.5251	.5107	.6559	1.0000

The high degree of correlation indicated by the geographic and demographic factors lead to the problem of multicollinearity in estimating a multiple regression equation to predict call-for-service workload. When extreme multicollinearity exist, the initial set of independent factors can not be used to perform a regression analysis for the following reasons:

(1) Extreme collinearity may make it impossible to invert the correlation matrix of independent variables.

(2) The regression coefficients that are derived will be statistically different from sample to sample.

(3) The reliability of the interpretation of the independent variables is in question.[1]

To overcome the problems imposed by multicollinearity two solutions are suggested:

(1) The creation of a new set of independent variables with each new variable being a composite scale of a set of highly intercorrelated variables.

(2) Using only one variable out of a set of highly correlated variables to represent that one particular dimension.[1]

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[1]Nie, Norman H., SPSS: Statistical Package For the Social Sciences, Second Edition, McGraw-Hill Book Company, New York, New York, 1975, p. 341

The approach taken in this research concerns solution alternative number one which refers to a factor analysis technique. The second alternative was not chosen because at this point the actual relationships existing between variables was not known and the researcher did not want to discard any relevant data.

Factor analysis is most widely noted for its data-reduction capabilities. Given a set of variables and the corresponding correlation coefficient matrix, factor analysis attempts to identify underlying patterns in the relationships between the variables. This enables the data to be consolidated and reduced so that a smaller set of factors emerges that represent the observed interrelations. These resulting factors are independent of each other and therefore may serve as input into a regression analysis without incurring the problems associated with multicollinearity.

Factor analysis is a generic term which encompasses a number of factor-analytic techniques. The various classifications of techniques usually are associated with the three primary steps involved in a factor analysis and the alternatives available at each step. The three steps include:

(1) The preparation of the correlation matrix.

(2) An extraction of the initial factors which is the data reduction step.

(3) And, the achievement of simple and theoretically meaningful factor patterns.

For this research the SPSS Factor Analysis Program [64, p.468] was employed due to its general acceptance and wide spread use on various types of computing equipment. The SPSS Factor Analysis Program [64] provides the user with two major options at each of the three primary steps in the factor analysis. In preparing the correlation matrix in the first step the user has the choice of employing a R-factor analysis or a Q-factor analysis. The Q-factor analysis is based on associations between individuals or objects. For instance, the association between two objects may be the correlation between cruiser districts themselves. The R-factor analysis refers to correlations between variables, for example, the characteristics of the cruiser districts. Therefore, the R-factor analysis option was chosen for this research.

The second step of the factor analysis, extraction of initial factors, is afforded the option of utilizing either defined or inferred factors. The use of defined factors is called principle-component analysis.[2] This is a relatively straightforward approach in which a new set of independent (orthogonal) factors is formed by creating

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[2] Nie, Norman H., SPSS: Statistical Package For The Social Sciences, Second Edition, McGraw-Hill Book Company, New York, New York, 1975, p. 470

linear combinations of the original factors in such a way as to account for as much of the variance present in the data as a whole as possible. In order to maintain independence between each newly formed factor, each successive linear combination of original factors accounts for variation in the residual variance only.

Classical-factor analysis refers to the use of inferred factors. This approach is based on the belief that the correlations present are mainly due to some underlying regularity in the data. Here it is assumed each variable can be broken into a common part and a unique part. It is the common part of the variable that contributes to the relationships present between other variables. Therefore, the factor analysis tries to identify the common elements which account for all the observed relations and transform these common elements into a set of new factors. By using the inferred factor analysis approach one is betting that the common variance will not only account for all the observed relations in the data but will also lead to a smaller number of variables. The inferred factor approach was used in this research which replaces the main diagonal of the correlation matrix with communality estimates before factoring begins.

Finally, the third step of the factor analysis procedure has the option of employing either orthogonal or oblique rotation procedures. The orthogonal rotation procedures were used because of the requirement of having independent factors as input to a regression analysis.

3.2.1 Procedural Description

The factoring procedure began by using the principal factoring with iterations (PA2) method[3] of factoring with an minimum eigenvalue set equal to one. The eigenvalue is a measure of the variance accounted for between variables in the data by a particular factor. Since all the variables were standardized, each had a variance of one and the total variance was equal to sixteen. This preliminary factoring run settled on four factors each having eigenvalues greater than or equal to one. The amount of variance accounted for by these four factors was 78.3% of the total variance. The extracted factors were then rotated orthogonally using three different rotation procedures. The varimax rotation centers on simplifying the columns of the factor matrix, quartimax the rows, and equimax combines the previous two methods together. The purpose of rotating the factors is to improve the interpretability of the set of factors.

In this research the varimax rotation procedure proved to exhibit the best results. It defines a simple factor as having only zeros or ones in the column, meaning it attempts to maximize the variance of squared loadings in each column. Results of the preliminary factoring run with each rotation procedure can be examined in Appendix A.

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[3] Nie, Norman H., SPSS: Statistical Package For the Social Sciences, Second Edition, McGraw-Hill Book Company, New York, New York, 1975, p. 480

With the four factor results established as a point of reference, additional factoring runs were performed which specified the extraction of three, five, and six factors. Each of these follow-up runs were performed using the PA2 method of factoring, as previously described, and encompassed all three orthogonal rotation procedures. The aim was to determine the best set of factors in terms of both the amount of variance accounted for by the factors and their interpretability.

The factoring run in which five factors were extracted exhibited the best results with respect to the percent of variation accounted for and the interpretability of the loadings. The factors accounted for 83.7% of the variability. The varimax rotation procedure resulted in a logical load pattern which was easily interpreted into the following factors: population, density, affluence, arrest, and vacancy. The factor names were derived in an attempt to describe the types of variables which loaded on each particular factor. The results of the five factor analysis are displayed in Appendix A.

In an attempt to clean up the data and strengthen the loadings of the five factor results so that the variability accounted for by the factors could be increased, Pearson Correlation Coefficients were calculated to measure the association between call-for-service workload of each cruiser district and the sixteen geographic and demographic variables. As seen in Table 2, the percentage black coefficient of .0544 and the growth coefficient of -.1337 exhibited low significance levels of association of .336 and .148 respectively. These results led to the conclusion that perhaps the percentage black and growth variables were predominately unique variables in that they did not contribute much

TABLE 2

Pearson Correlation Coefficients: Workload Versus Variables

		Population	Growth	Population Density	Acreage	Percentage Black	Total Housing	Housing Density	Vacant Housing
Workload	(coefficient)	.5991	-.1337	.2754	-.1744	.0544	.5904	.2542	.1764
	(cases)	63	63	63	63	63	63	63	63
	(significance)	.001	.148	.014	.086	.336	.001	.022	.083

		Owner Occupied Housing	Substandard Housing	Median Value	Median Rent	Part One Offenses	Total Offenses	Persons Charged Part One Offenses	Total Persons Charged
Workload	(coefficient)	-.4168	.3475	-.3621	-.2639	.8475	.8559	.6188	.6787
	(cases)	63	63	63	63	63	63	63	63
	(significance)	.001	.003	.002	.018	.001	.001	.001	.001

to the overall variability present between the variables. Therefore, the factor analysis was performed again deleting the percentage black and growth variables from consideration. The results, shown in Appendix A, led to 87.1% of the variability being explained by five factors which also exhibited logical and easily interpretable loadings.

3.3 Regression Analysis

The purpose of the factor analysis was to reduce the sixteen inter-correlated demographic and geographic variables thought to influence workload into a smaller number of independent factors which could be used as input for a regression analysis. The regression analysis, in turn, leads to the development of a predicting equation for workload levels and thus utilization ratios for any set of geographic and demographic variable levels. Regression analysis is a general statistical technique whereby the relationships between a dependent variable, in this case workload, and a set of independent or prediction variables, the set of five extracted factors from the factor analysis, can be analyzed. Specifically, factor scores are used as input for the independent set of factors. A factor score is derived by multiplying the factor-score coefficient matrix times the standardized value of the original geographic and demographic variables. In this manner a set of factor scores are calculated for each cruiser district. The factor score coefficient matrix is a matrix of regression weights that specify the relationship between the factors and the original geographic and demographic variables.

The SPSS Multiple Regression Analysis; Subprogram Regression [64, p.321] was employed in this research to perform the regression analysis. A preliminary analysis was performed which entailed a regression analysis of the dependent variable, workload, with each of the five extracted independent factors individually. The results and accompanying scattergrams indicated that nonlinearities were not present. The results can be examined in Appendix B. They indicate population as having the most significant relationship to workload followed closely by the arrest factor. Affluence displayed a high degree of significance with vacancy being marginally significant and density exhibiting an insignificant relationship.

Satisfied with the assumptions of independent factors and the lack of nonlinearities, a forward inclusion regression analysis was performed between the call-for-service workload levels of the sixty-three cruiser districts and the corresponding factor scores of the five independent extracted factors. A forward inclusion methodology permits independent factors to enter the regression equation only if they meet certain statistical criteria. The order of inclusion is determined by each factors relative contribution to the explained variance in the workload.

Three statistical criteria are used as a basis for judging the appropriateness of each factor for inclusion into the regression equation. The first criteria limits the number of independent variables allowed to enter into the regression equation. The standard default level is eighty and, therefore, has no bearing on this research. The second criteria is an F-ratio test for significance of the regression coefficient. For this criteria, the F-ratio is computed for each factor which has not already entered the regression equation. Only those independent variables whose F-ratio conforms to a specified significance level are permitted to enter the equation. The default level, which is used in this research, is a significance level of .01. The final parameter refers to the tolerance of an independent factor. The tolerance of a factor is defined as the proportion of variance of that factor not explained by the other factors already entered in the regression equation. On a tolerance index of 0 to 1, where 0 is indicative of a perfect linear combination with respect to the other factors in the equation and 1 indicates no correlation whatsoever, the default level is equal to .001. Given these default levels for each of the inclusion criteria, the stepwise regression analysis entered the factors in the following order:

(1) Population

(2) Arrest

(3) Affluence

(4) Vacancy

(5) Density.

The results of the regression analysis are displayed in Table 3.

A residual analysis was performed to substantiate the assumptions of homogenity of the variances and normality of the standard error. A chi-square goodness-of-fit test shows a 98% probability that the probability distribution observed for the standard residual is a normal distribution. A Spearman rank correlation test for the consistency of variance does not reject the null hypothesis of no association at a probability level of .4238. This implies that the residuals are homogeneous; the level the residual displays is not associated with the value of the predicted workload. The calculations and results of each of these tests can be examined in Appendix B.

TABLE 3

Regression Analysis Results for Determining Call-for-Service Workloads

Factor	R	R^2	R^2 Change	B
Population	.63084	.39796	.39796	1.779654
Arrest	.85211	.72609	.32813	1.731860
Affluence	.90397	.81716	.09107	-.894288
Vacancy	.91790	.84255	.02539	.484436
Density	.91922	.84497	.00242	.147832
			Constant	5.348573

3.4 Concluding Remarks

The first stage of this research has been concerned with the identification of geographic and demographic factors which influence call-for-service workload levels within cruiser districts and the modelling of the existing relationships in the form of a regression equation. The ability to predict workload levels, which in turn leads to the derivation of utilization ratios, is important in designing patrol districts, in setting staff sizes for precincts, and in scheduling vehicles and manpower across tours. Since the focus of this research is on the development of vehicle tour schedules, stage two of this research, explained in Chapter IV, demonstrates the significance that being able to estimate workload levels has upon the development of these schedules.

CHAPTER IV

STRUCTURING OF PERFORMANCE MEASURES

The statistical analysis described in Chapter III resulted in the specification of the relationships between a set of geographic and demographic factors present in a particular area and the workload. The forecasting of workload in this manner is particularly useful when new districts are being established or existing districts are be restructured. In situations such as this, historical demands of previously defined districts are inappropriate for use in forecasting demands for newly defined districts.

Although the statistical analysis, stage one of this research, provided a means of reducing the variability in the patrol planner's decisions concerning the structuring of cruiser districts by allowing him to compare the utilization ratios between districts, the structuring of cruiser districts is not the major issue in this research. The major concern is the scheduling of vehicles and manpower among the cruiser districts. The utilization ratio, whether estimated for a set of characteristic factors or from past demand, is a key measure of performance used in determining those schedules. However, it is not the only measure of performance. As utilization ratios change within cruiser districts the levels of other performance measures are in turn affected. It is the purpose of stage two of this research to identify other appropriate performance measures to be used in the scheduling decision and to structure the relationship between them and the utilization ratio. Therefore, stage one and stage two of this research are linked together in that the statistical analysis provides the opportunity to predict workload and thus estimate utilization ratios while stage two provides a means of determining the expected levels of performance associated with those utilization ratios.

4.1 Patrol Car Allocation Model

In order to identify relevant performance measures and structure their relationship to the utilization ratio, a simulation technique was employed. The simulation vehicle used was the Patrol Car Allocation Model (PCAM) which was developed by Chaiken and Dormont [15]. PCAM is a queuing based simulation model. Because of this, certain technical assumptions must be made in order to estimate the fraction of calls-for-service that have to be placed in a queue to await an available patrol vehicle and the average length of time a call-for-service in each priority level has to wait in the queue. The assumptions are as follows [15, p. 29]:

(1) Incidents occur according to a poisson process.

(2) All incidents have the same exponential distribution of service time.

(3) The system is in steady state.

PCAM has the capability of being operated in either the prescriptive or the descriptive mode. Since the aim of this stage of the research is to structure relationships between the utilization ratio and other performance measures, the descriptive mode is the appropriate choice for this research. While operated in the descriptive mode, PCAM provides facilities for displaying both the data items which are input and the performance measure outputs derived from these inputs. Information provided to the user include the following [15, p. 7]:

(1) The number of patrol vehicles assigned to each geographical command at each time of day.

(2) Information concerning the call-for-service workload of the patrol cars.

(3) Information about the amount of preventive patrol in which the patrol vehicles are engaged.

(4) The average length of time from the dispatch of a patrol vehicle to the arrival of the vehicle at the scene of the incident.

(5) The percentage of calls-for-service that have to wait in queue until a patrol vehicle is available to be dispatched to the incident.

(6) The average length of time (minutes) that calls-for-service of various priority levels have to wait in the queue.

(7) The average total response time.

In order to implement PCAM into this research three categories of input data are required and can be classified under the general headings of geographical control data, time of day data in terms of call-for-service rates and service times for each of the twenty-four hours in a day, and patrol car operational data. The necessary data concerning each category was acquired from the Columbus Police Department, Columbus, Ohio and is described in the next section.

4.2 Input Data For PCAM

The data required for the operation of the PCAM simulation originates solely from the Division of Police, Columbus, Ohio. It is a result of extensive personal interviews with the Planning and Research Division, the Annual Report, Division of Police, Columbus, Ohio 1975 and 1976

Statistical Summaries, and actual call-for-service workload data collected by the Division of Police and processed by the Patrol Data Analysis Program which was developed by Dr. L. D. Vitt and described in Chapter III.

4.2.1 Geographical Control Data

The Columbus, Ohio Division of Police is structured into three decision-making levels; the division, the precinct, and the watch. At the time of this research there was one division, fifteen precincts, and three watches. Each watch is a consecutive eight hour tour with the first watch beginning at 7:00 A.M. There were no overlay watches being utilized at this time. An overlay watch is one that begins during one watch and is completed during another watch.

For each precinct it is necessary to input the area in square miles and the number of street miles contained within this area. Also, for each precinct certain "unavailability parameters" must be specified. These unavailability parameters, labeled B1 and B2, are constraints which are used to estimate the fraction of time that a patrol vehicle will spend on non-call-for service activities and therefore, are unavailable to respond to calls-for-service. This fraction of time is estimated by the following equation [15, p. 27]:

$$\text{(fraction of time on non-CFS work)} = B1 \times \text{(fraction of time on CFS work)} + B2$$

To calculate the values of B1 and B2 data must be available that reflect both the fraction of time a patrol vehicle spends on non-call-for-service work and the fraction of time it spends on call-for-service work during each eight hour watch. Non-call-for-service work includes such activities as roll call, meals, court time, activity sheet paperwork, and the filing of reports. If such data were available, the non-call-for-service value for a particular watch, day, and precinct could be graphed against the corresponding call-for-service value. Letting non-call-for-service fractions represent the y-axis and call-for-service fractions the x-axis, a straight line could be drawn through the data, the slope of which would equal the B1 parameter. The intercept of this line would then be the B2 parameter. Unfortunately, the data necessary to perform these estimates were not available for this research. Therefore, a second option was used which sets B1, the slope, equal to zero and establishes B2 equal to the average fraction of time a patrol vehicle spends on non-call-for-service work during each watch. A value of thirty percent was estimated, by the Planning and Research Division, to be a representative value for B2 and was incorporated in this research across all watches, days, and precincts. The level which is specified for the B2 parameter does influence the levels displayed by other measures of performance in the PCAM simulation results; however, the relationships which exist between these measures should not be affected. Since it is the modeling of these relationships that is the primary concern at this stage of the research, the thirty percent estimate of the B2 parameter should not affect the simulation results pertinent at this time.

4.2.2 Time of Day Data

The time of day data is concerned with both call-for-service rates and service times. For each category a daily per hour average must be derived followed by a breakdown of the hourly percentage variation from this overall daily per hour average for each of the twenty-four hours in every day. The average call-for-service rates were calculated on a daily basis for every precinct by dividing the total daily frequency count of calls-for-service by twenty-four hours. The average service time was calculated by dividing the average workload per hour for each day and precinct by the average frequency of calls-for-service per hour and multiplying by sixty minutes per hour. Finally, the breakdown of the hourly percentage variations exhibited by the call-for-service rate and the service time were calculated by dividing the hourly averages by the overall daily per hour average. For purposes of this research a PCAM week begins on day Sun.-Mon. at 7:00 A.M. and each day runs from 7:00 A.M. to 7:00 A.M.

4.2.3 Patrol Car Operational Data

The last set of data necessary to operate PCAM must be input on a per watch basis. This data set describes the activity taking place during each watch and the parameters under which patrol vehicles operate. For each watch the average number of vehicles on duty, their average response speed, and their average preventive patrol speed must be specified. This data was obtained directly from the Planning and Research Division and reflects the situation during the third quarter of 1975.

PCAM allows calls-for-service to be sectioned into three priority levels. As part of the operational data, the fraction of priority one and the fraction of priority two calls-for-service received must be specified. This information was obtained from the Patrol Data Analysis Program output.

CONTINUED

1 OF 5

Finally, statistics concerning the number of suppressible crimes which occurred need to be supplied. A suppressible crime is one that has the possibility of being detected, and thus suppressed, by a patrolling vehicle. The total number of suppressible crimes on a per watch per precinct basis was obtained from the Division of Police Statistical Summary. The yearly totals were divided by 365 days to arrive at a daily average which was, in turn, adjusted to reflect the per watch percentage breakdown.

This concludes the input data necessary to operate PCAM. Table 4 displays the data for one day, Sun.-Mon., for precinct one. Due to space limitations the entire input data for each day in each precinct is not displayed. With fifteen precincts and seven days of data required for each precinct, there would be 105 different daily data sets displayed.

4.3 Operation of the Patrol Car Allocation Model

Operation and control of the Patrol Car Allocation Model (PCAM) is achieved through the use of a set of user commands. The simulation can be carried out in either a batch or interactive mode. This research utilized both the batch and the interactive mode interchangeably. The user commands are used to initiate three types of actions. The first type of user command initiates a data selection and/or modification action. Examples of this type of user command are the READ and the SET command. The READ command causes PCAM to select a specific part of the input data upon which to operate the simulation. For example, data concerning a specific precinct can be retrieved. If this is done then all other user commands will result in actions taken with respect to that one

TABLE 4

PCAM Input Data for Sun.-Mon. Precinct One

[a]ONE	[b]COLUMBUS	[c]4.96	[d]94.0	[e]0	[f].30
[g]2.78	[h]25.7	[i]0			
[j]074050106060067152115095074083110106117066092105140170141143131094069026					
[k]110110111108111102105106114112109096094097089095092095090101097095101100					
[l]5.0	[m]30.0	[n]25.0	[o].0308	[p].3725	
[q]7.0	30.0	25.0	.0689	.4459	
[r]7.0	35.0	25.0	.0836	.5283	
[s]020038020					

TABLE 4 (continued)

a. Precinct designation, refers to Precinct One.
b. Division name, Columbus, Ohio only has one division.
c. Area in square miles.
d. Number of street miles.
e. B1 unavailability parameter, slope.
f. B2 unavailability parameter, intercept.
g. Average daily call-for-service rate.
h. Average service time per call-for-service.
i. Overlay watch designation, zero indicates no overlay watches, one indicates presence of overlay watch.
j. Percentage deviation in call-for-service rate on an hourly basis, 24 three digit values beginning at 7:00 A.M.
k. Percentage deviation in service time on an hourly basis, 24 three digit values beginning at 7:00 A.M.
l. Number of cars assigned to the first watch.
m. Response speed for first watch vehicles.
n. Patrol speed for first watch vehicles.
o. Percentage of calls-for-service during first watch that are priority one.
p. Percentage of calls-for-service during first watch that are priority two.
q. This line indicates corresponding values of number 12 through 16 for the second watch.
r. This line indicates corresponding values of number 12 through 16 for the third watch.
s. The number of suppressible crimes during each watch beginning with the first watch and reading across in three digit groups.

precinct only until another READ command is issued. The SET command allows original input data to be modified such as changing the call-for-service rate to another value.

A second set of user commands causes PCAM to operate in a descriptive manner. The LIST command is an example of this and its use causes the display of the input data. The DISP command refers to a display command and initiates the display of various performance measures calculated by PCAM from the input data provided.

Finally, there is a set of user commands which allow PCAM to operate in a prescriptive mode. This set of commands is composed of the MEET, ALOC, and ADD commands. The MEET command causes PCAM to allocate sufficient vehicle-hours to satisfy specified constraints such as an average travel time of five minutes. The ALOC command, representing an allocate command, causes PCAM to allocate a specified number of vehicle-hours in a manner which optimizes a specific measure of performance. One such measure of performance may be the average length of time calls-for-service are delayed in queue. The ADD command is very similar to the ALOC command except that the ADD command assigns vehicles to selected watches in addition to those already assigned, in order to optimize a specific measure of performance. A complete description of all available PCAM commands and their uses can be found in the Patrol Car Allocation Model: User's Manual written by Chaiken and Dormont [15, p. 41].

4.3.1 Structure of PCAM Simulation

The goal of the simulation stage of this research is the structuring of the relationships which exist between levels of utilization and other performance measure levels relevant to the patrol scheduling problem. Through the specification of these relationships, a patrol planner can transform an estimated utilization ratio, as derived in stage one, into expected levels of performance for an entire set of performance measures. The structure of the PCAM simulation is directed toward the development of a series of trade-off curves to display these relationships.

There are seven measures of performance calculated by PCAM which the Planning and Research Division of the Columbus, Ohio Police Department felt were relevant to the patrol scheduling function. They are as follows:

(1) Utilization.

(2) Probability of a call being delayed.

(3) Average travel time.

(4) Average Patrol frequency.

(5) Patrol hours per suppressible crime.

(6) Average number of cars available.

(7) Average total delay.

PCAM provides two measures of utilization. First, there is an actual average utilization ratio defined by the equation:

$$\text{actual average utilization} = \frac{\text{expected number of call-for-service work hours}}{\text{total number of vehicle-hours fielded}} .$$

The second utilization measure relates an effective average utilization ratio where the numerator is the same as in the actual utilization;

however, the denominator is changed to represent the total number of effective vehicle-hours fielded. The effective average utilization ratio reflects the influence of the unavailability parameters by depicting, in the denominator, only that fraction of the time a patrol vehicle is available to respond to call-for-service work. It is the effective utilization ratio figure that is used in this research. This is because PCAM's queuing calculations are all based on the average utilization of an effective car, and not on that of an actual car.

The probability of a call being delayed reflects the chance, that any call-for-service entering the system has, of being placed in a queue to await a response by a patrol vehicle that becomes available to respond. The average travel time covers the period of time from when a patrol vehicle is actually dispatched to respond to a call-for-service up to the point in time it arrives at the scene. The average total delay is then the amount of time a call-for-service spends in a queue awaiting a response plus the travel time needed to respond.

The final three measures of performance summarize the preventive patrol characteristics of the system. The average patrol frequency reflects the average number of times a patrol vehicle passes a particular point each hour throughout the course of its' watch. The patrol hours per suppressible crime represent the total number of hours a patrol vehicle spends on preventive patrol during the watch divided by the number of suppressible crimes which took place during the same period within that patrol vehicle's area of responsibility. A suppressible crime is one that is considered to be detectable by a patroling vehicle. Finally, the average number of cars available reflect the number of cars that will be available to respond immediately to calls-for-service, on the average, at any one point in time.

The simulation incorporates the actions of data selection and modification and that of description. It is run on a precinct-by-precinct basis using the READ command to specify each individual precinct. The entire system encompassing all fifteen precincts could have been run at one time; however, PCAM is structured such that all summary statistics are calculated and displayed by precinct. Statistics summarizing the system as a whole are not available. Once the precinct is selected, the SET command permits the number of vehicles assigned to each watch for each day to be systematically increased by one unit in every watch. This sequential procedure begins with a very small number of vehicles and progresses until the resulting performance measures, which were previously listed, reach the point where they level off. By monitoring the changes which take place in each performance measure, the trade-offs that occur between the utilization ratio and the other measures of performance as the utilization ratio changes can be structured.

After each iteration, when the number of vehicles assigned to each watch each day is increased by one unit, the descriptive action PCAM possesses is used to display the corresponding levels of the performance measures. This action is achieved by employing the DISP command to display two tables. Examples of these tables showing actual results are displayed in Table 5 and Table 6.

TABLE 5

TABLE 1 Display for PCAM Simulation

PRECINCT: One; Day: Mon.-Tue

WATCH	Avg. Util. (EFF)	Avg. Util. (ACT)	Avg. Trav. Time	Patrol Hrs. Per Supp. Cr.	Avg. Patrol Freq.	Avg. Pat. Freq. Times Supp. Cr. Per Hr.	Avg. Cars Avail.
FIRST	.646	.449	2.9	5.03	0.33	0.084	1.26
SECOND	.512	.358	2.5	4.31	0.54	0.259	2.05
THIRD	.247	.173	1.9	10.54	0.70	0.175	2.64
AVERAGE	.469	.329	2.6	6.09	0.53	0.173	1.98

TABLE 6

TABLE 2 Display for PCAM Simulation

PRECINCT: One; Day: Mon.-Tue.

WATCH	ACT. CARS	CAR HRS.	CALL RATE	SERV. TIME	PROB. CALL DELAYED	AVG. P2 DELAY	AVG. P3 DELAY	AVG. TOT. DELAY
FIRST	5.0	40.0	4.6	29.2	.460	5.56	23.00	18.84
SECOND	6.0	48.0	4.6	27.8	.271	3.08	10.66	9.19
THIRD	5.0	40.0	2.0	25.7	.132	1.44	2.97	3.94
AVERAGE	5.3	42.7	3.8	28.0	.323	3.59	15.48	12.19
TOTAL	16.0	128.0						

Table 5 and Table 6 show the results of a PCAM simulation run as they are actually displayed in the output. Not all the results shown are of concern to this research. Such measures as the average priority two call-for-service delay (Avg. P2 Delay) in Table 6 and the average patrol frequency times the number of suppressible crimes per hour (Avg. Pat. Freq. Times Supp. Cr. Per Hr.) were of no importance to the Planning and Research Division of the Columbus, Ohio Police Department and therefore, are disregarded here.

4.3.2 Results of PCAM Simulation

The PCAM simulation was performed for each of the fifteen precincts as described in Section 4.3.1 Structure of PCAM Simulation. The results of each iteration were collected from output exhibited in the form depicted in Table 5 and Table 6 and aggregated into one table. The actual results for Precinct One are shown in Table 7 through Table 14. Due to space limitations the results of only a single precinct are displayed. In order to display the entire set of results for every precinct, 120 tables would be required.

The analysis of the PCAM simulation results led to the elimination of seven precincts from further consideration. It was felt, by the Planning and Research Division, that Precincts 2, 3, 7, 9, 10, 14, and 15 posed only minor decision-making problems when it came to scheduling patrol vehicles. The geographic and demographic factors that comprised these precincts resulted in each precinct displaying a low and relatively stable workload. This caused the performance measure levels of these precincts to exhibit only minor variation and level-off quite rapidly as patrol vehicles were added. Since there was a managerially imposed

TABLE 7

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 4 Cars
Second Watch - 5 Cars
Third Watch - 4 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	4.3	5.3	4.7	5.0	5.3	5.3	4.7	5.0
Car Hours	34.7	42.7	37.3	40.0	42.7	42.7	37.3	39.6
Actual Utilization	27.5%	32.9%	32.5%	35.2%	31.4%	35.2%	34.5%	32.8%
Effective Utilization	39.2%	46.9%	46.5%	50.3%	44.8%	50.2%	49.2%	46.9%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	22.9%	32.3%	26.8%	30.7%	25.5%	33.9%	29.8%	29.2%
Average Total Delay	7.21	12.19	8.04	10.62	8.26	14.02	8.90	10.09
Average Travel Time	2.5	2.6	2.6	2.6	2.5	2.6	2.6	2.5
Patrol Hours/ Suppress Crime	5.67	6.09	5.38	5.36	6.34	5.72	5.10	5.67
Average Patrol Frequency	.49	.53	.46	.46	.55	.49	.44	.49
Average Cars Available	1.84	1.98	1.75	1.74	2.06	1.86	1.66	1.84

TABLE 8

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 5 Cars
Second Watch - 6 Cars
Third Watch - 5 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Car Hours	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7
Actual Utilization	22.3%	32.9%	28.5%	33.0%	31.4%	35.2%	30.2%	30.5%
Effective Utilization	31.9%	46.9%	40.7%	47.1%	44.8%	50.2%	43.1%	43.5%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	11.0%	32.3%	17.8%	28.3%	25.5%	33.9%	19.6%	24.8%
Average Total Delay	3.54	12.19	5.19	10.01	8.26	14.02	5.87	8.77
Average Travel Time	2.1	2.6	2.3	2.5	2.5	2.6	2.3	2.4
Patrol Hours/ Suppress Crime	7.83	6.09	6.82	6.08	6.34	5.72	6.54	6.49
Average Patrol Frequency	.68	.53	.59	.53	.55	.49	.57	.56
Average Cars Available	2.54	1.98	2.22	1.97	2.06	1.86	2.12	2.11

TABLE 9

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 6 Cars
Second Watch - 7 Cars
Third Watch - 6 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Car Hours	50.7	50.7	50.7	50.7	50.7	50.7	50.7	50.7
Actual Utilization	18.8%	27.7%	24.0%	27.8%	26.4%	29.6%	25.4%	25.7%
Effective Utilization	26.8%	39.5%	34.2%	39.7%	37.7%	42.3%	36.3%	36.7%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	4.6%	17.6%	8.3%	15.0%	13.2%	18.7%	9.4%	12.9%
Average Total Delay	2.27	5.19	2.95	4.59	4.04	5.66	3.12	4.08
Average Travel Time	1.8	2.2	2.0	2.1	2.1	2.2	2.0	2.1
Patrol Hours/ Suppress Crime	9.98	8.25	8.97	8.23	8.5	7.87	8.69	8.64
Average Patrol Frequency	.86	.71	.78	.71	.73	.68	.75	.75
Average Cars Available	3.24	2.68	2.92	2.67	2.76	2.56	2.82	2.81

TABLE 10

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 7 Cars
Second Watch - 8 Cars
Third Watch - 7 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Car Hours	58.7	58.7	58.7	58.7	58.7	58.7	58.7	58.7
Actual Utilization	16.2%	23.9%	20.7%	24.0%	22.8%	25.6%	21.9%	22.2%
Effective Utilization	23.2%	34.1%	29.6%	34.3%	32.6%	36.5%	31.3%	31.7%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	1.9%	9.5%	3.9%	8.0%	6.9%	10.4%	4.5%	6.7%
Average Total Delay	1.78	3.07	2.12	2.83	2.60	3.27	2.17	2.59
Average Travel Time	1.6	1.9	1.8	1.9	1.8	1.9	1.7	1.8
Patrol Hours/ Suppress Crime	12.13	10.40	11.12	10.38	10.65	10.03	10.84	10.79
Average Patrol Frequency	1.05	.90	.96	.90	.92	.87	.94	.93
Average Cars Available	3.94	3.38	3.62	3.37	3.46	3.26	3.52	3.51

TABLE 11

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 8 Cars
Second Watch - 9 Cars
Third Watch - 8 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Car Hours	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7
Actual Utilization	14.3%	21.0%	18.2%	21.1%	20.1%	22.5%	19.3%	19.5%
Effective Utilization	20.4%	30.0%	26.0%	30.2%	28.7%	32.1%	27.6%	27.9%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	.8%	5.0%	1.8%	4.1%	3.5%	5.6%	2.2%	3.4%
Average Total Delay	1.55	2.19	1.74	2.07	1.96	2.28	1.75	1.96
Average Travel Time	1.5	1.7	1.6	1.7	1.7	1.7	1.6	1.6
Patrol Hours/ Suppress Crime	14.29	12.56	13.28	12.54	12.80	12.18	13.00	12.95
Average Patrol Frequency	1.23	1.09	1.15	1.08	1.11	1.05	1.12	1.12
Average Cars Available	4.64	4.09	4.32	4.07	4.16	3.96	4.22	4.21

TABLE 12

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 9 Cars
Second Watch - 10 Cars
Third Watch - 9 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
Car Hours	74.7	74.7	74.7	74.7	74.7	74.7	74.7	74.7
Actual Utilization	12.7%	18.8%	16.3%	18.8%	17.9%	20.1%	17.2%	17.4%
Effective Utilization	18.2%	26.8%	23.2%	26.9%	25.6%	28.7%	24.6%	24.9%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	.3%	2.3%	.7%	1.9%	1.5%	2.7%	.9%	1.6%
Average Total Delay	1.41	1.75	1.52	1.69	1.64	1.79	1.52	1.63
Average Travel Time	1.4	1.6	1.5	1.5	1.5	1.6	1.5	1.5
Patrol Hours/ Suppress Crime	16.44	14.71	15.43	14.69	14.96	14.33	15.15	15.10
Average Patrol Frequency	1.42	1.27	1.33	1.27	1.29	1.24	1.31	1.31
Average Cars Available	5.34	4.78	5.02	4.77	4.86	4.66	4.92	4.91

TABLE 13

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 10 Cars
Second Watch - 11 Cars
Third Watch - 10 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
Car Hours	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7
Actual Utilization	11.5%	17.0%	14.7%	17.0%	16.2%	18.1%	15.6%	15.7%
Effective Utilization	16.4%	24.2%	21.0%	24.3%	23.1%	25.9%	22.2%	22.5%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	.1%	1.1%	.3%	.9%	.7%	1.4%	.4%	.7%
Average Total Delay	1.31	1.52	1.40	1.49	1.46	1.55	1.38	1.45
Average Travel Time	1.3	1.5	1.4	1.4	1.4	1.5	1.4	1.4
Patrol Hours/ Suppress Crime	18.60	16.86	17.58	16.84	17.11	16.49	17.31	17.26
Average Patrol Frequency	1.61	1.46	1.52	1.46	1.48	1.43	1.50	1.49
Average Cars Available	6.04	5.48	5.72	5.47	5.56	5.36	5.62	5.61

TABLE 14

PCAM SIMULATION RESULTS

PRECINCT 1

First Watch - 11 Cars
Second Watch - 12 Cars
Third Watch - 11 Cars

	SUN	MON	TUE	WED	THU	FRI	SAT	AVG
Average Actual Cars	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
Car Hours	90.7	90.7	90.7	90.7	90.7	90.7	90.7	90.7
Actual Utilization	10.5%	15.5%	13.4%	15.5%	14.8%	16.5%	14.2%	14.3%
Effective Utilization	15.0%	22.1%	19.1%	22.2%	21.1%	23.6%	20.3%	20.5%
Call Rate	2.8	3.8	3.2	3.7	3.6	4.0	3.6	3.5
Service Time	25.8	28.0	28.1	28.5	28.0	28.2	26.6	27.7
Probability Call Delayed	0	.5%	.1%	.4%	.3%	.7%	.2%	.3%
Average Total Delay	1.24	1.39	1.31	1.37	1.35	1.40	1.29	1.34
Average Travel Time	1.2	1.4	1.3	1.3	1.3	1.4	1.3	1.3
Patrol Hours/ Suppress Crime	20.75	19.02	19.74	19.00	19.27	18.64	19.46	19.41
Average Patrol Frequency	1.79	1.64	1.71	1.64	1.67	1.61	1.68	1.68
Average Cars Available	6.74	6.18	6.42	6.17	6.26	6.06	6.32	6.31

constraint requiring at least three vehicles to be assigned to each watch, the scheduling of patrol vehicles for the eliminated precincts was constrained not by performance levels but by management. This left Precincts 1, 4, 5, 6, 8, 11, 12, and 13 for this research to focus upon as its primary concern.

Using the results represented by those exhibited in Table 7 through Table 14, the relationships present between utilization levels and other performance levels can be structured for each precinct. This was done by graphing the weekly average value of the utilization ratio against the weekly average value of each of the other performance measures individually. The values exhibited at each iteration when graphed visually depict the trade-off relationship present between the utilization ratio and another performance measure. The relationships found to exist in Precinct One are presented in Figure 4 through Figure 10.

Each figure visually portrays the relationship between varying levels of utilization and the corresponding expected levels of another particular measure of performance. Although the results of Precinct One are the only results presented, an identical analysis was performed on each of the eight precincts designated earlier in this section as being of primary concern to this research. In order to present the tables and graphs associated with all eight precincts, 64 tables and 56 graphs would be required. It was felt the marginal value of presenting this massive amount of information would be relatively insignificant in so far as the research could be adequately explained with the use of the output from one representative precinct.

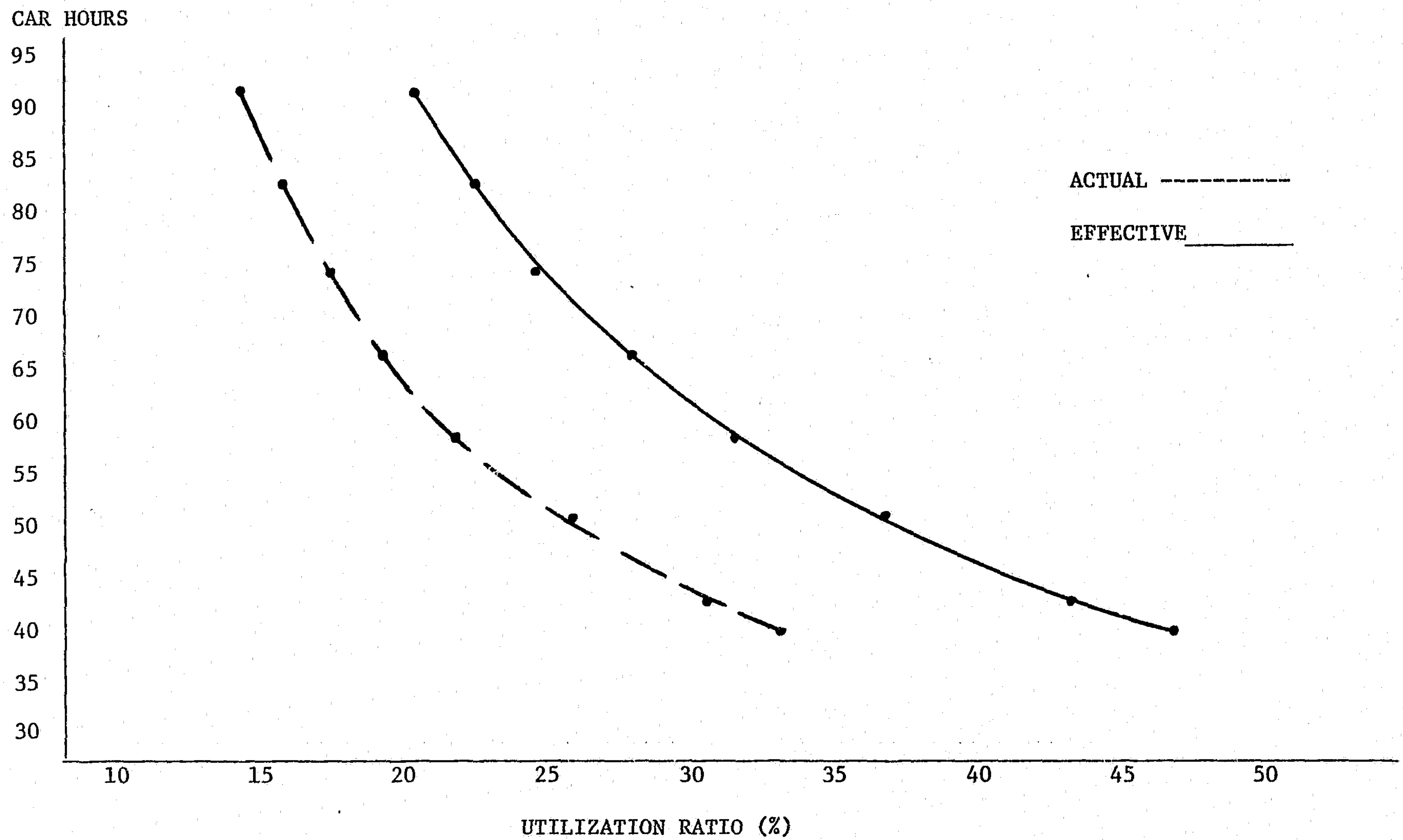

FIGURE 4 UTILIZATION VERSUS CAR HOURS FIELDED PER WATCH: PRECINCT 1

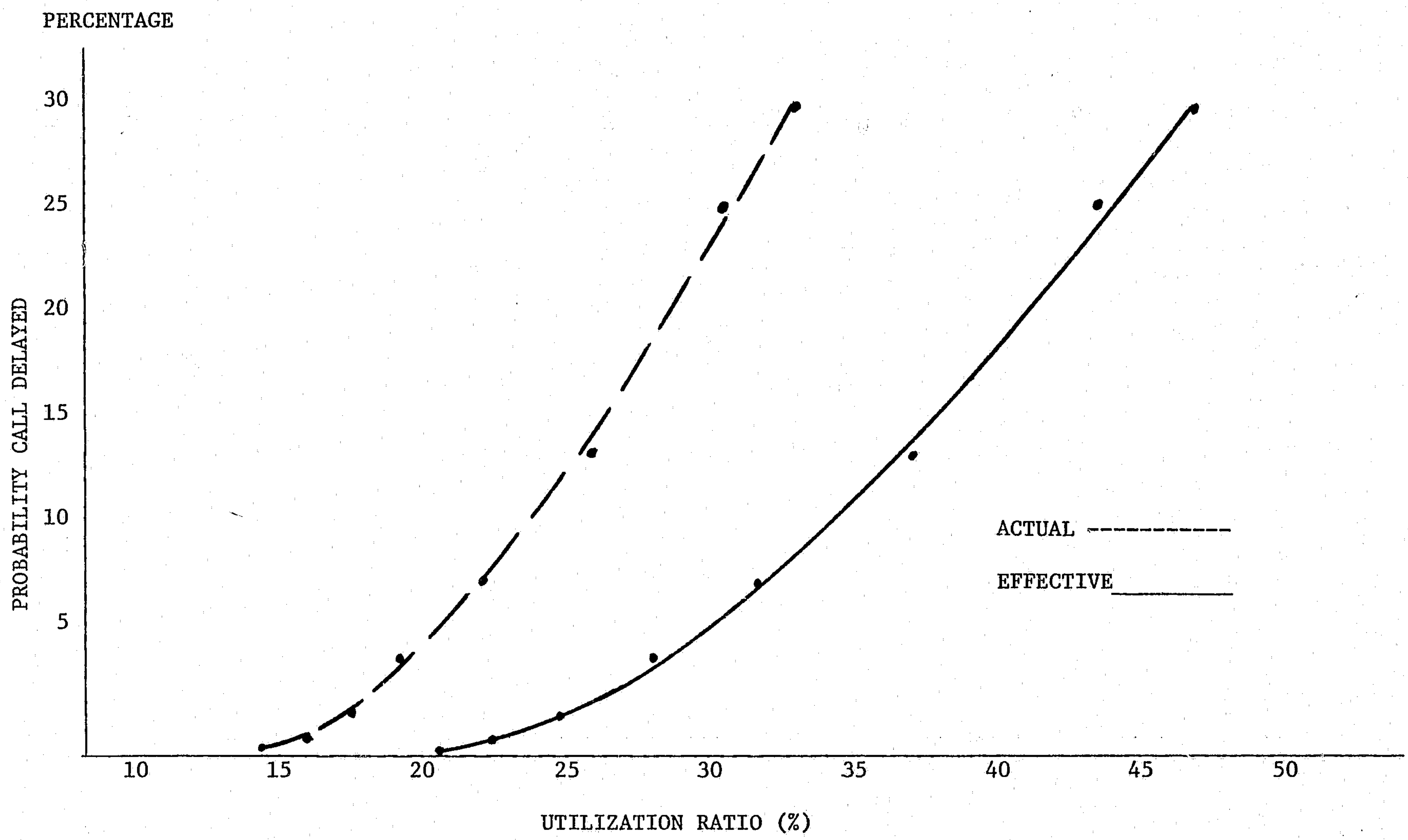

FIGURE 5 UTILIZATION VERSUS PROBABILITY CALL DELAYED: PRECINCT 1

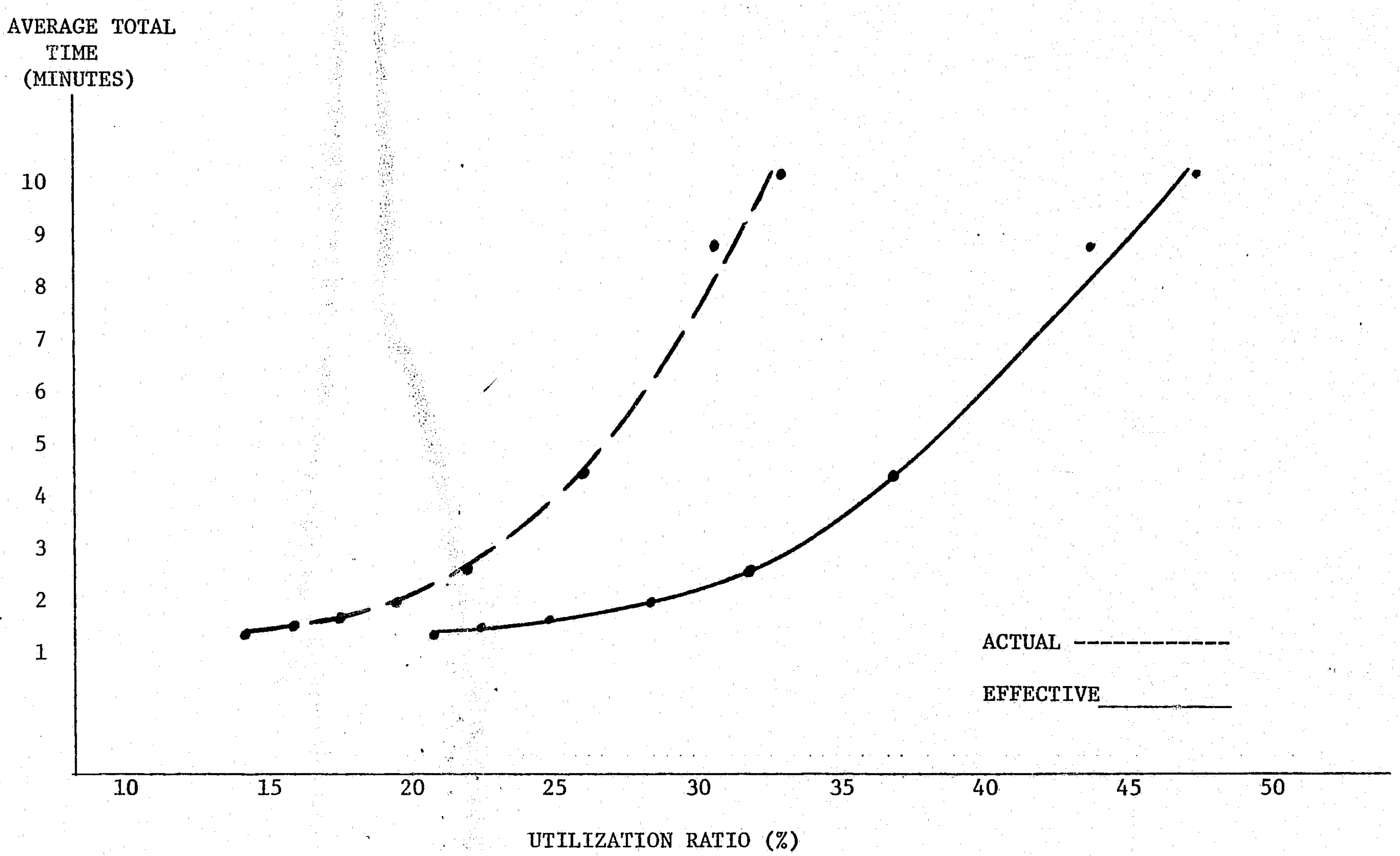

FIGURE 6 UTILIZATION VERSUS TOTAL AVERAGE DELAY: PRECINCT 1

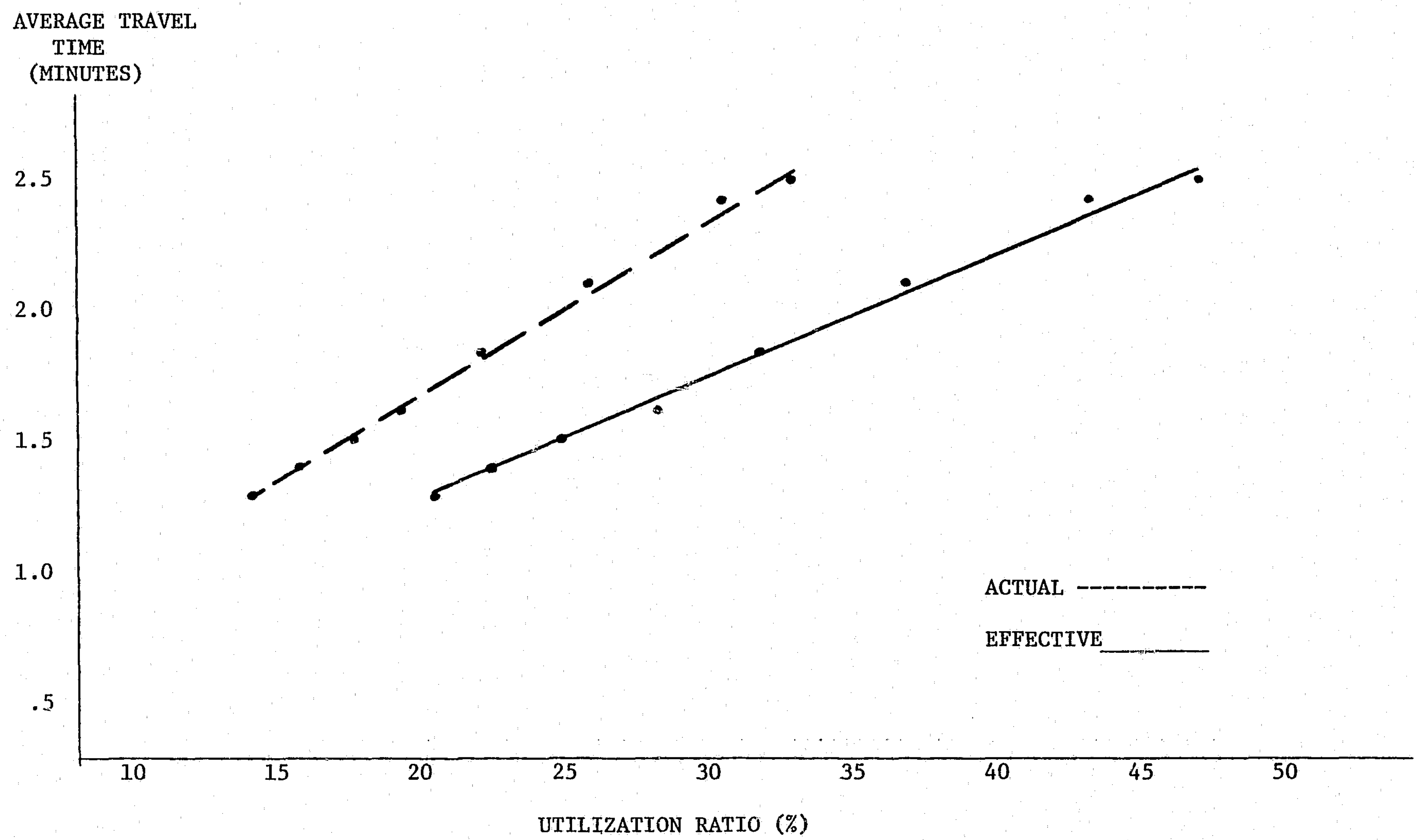

FIGURE 7 UTILIZATION VERSUS AVERAGE TRAVEL TIME: PRECINCT 1

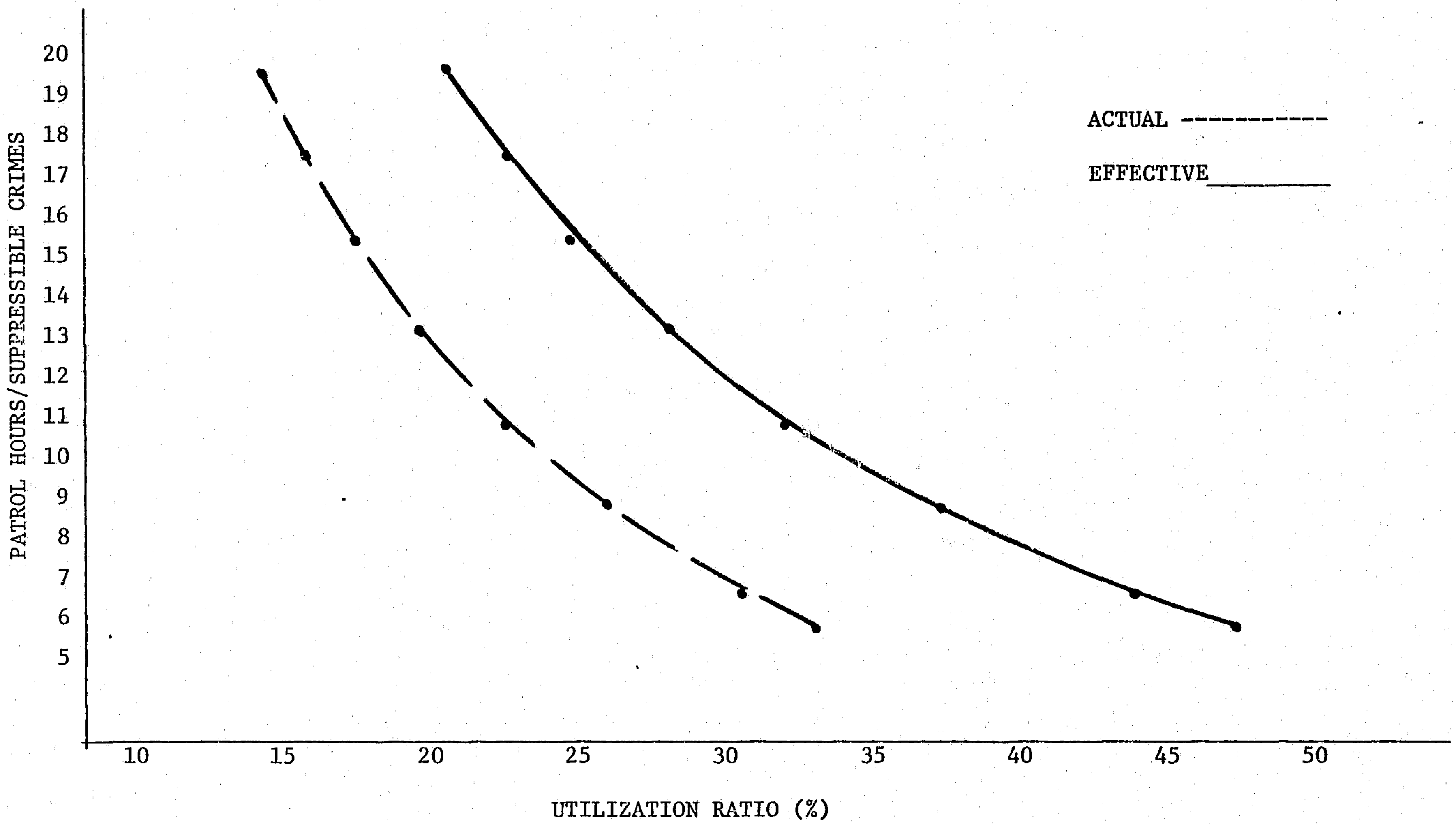

FIGURE 8 UTILIZATION VERSUS PATROL HOURS PER SUPPRESSIBLE CRIMES: PRECINCT 1

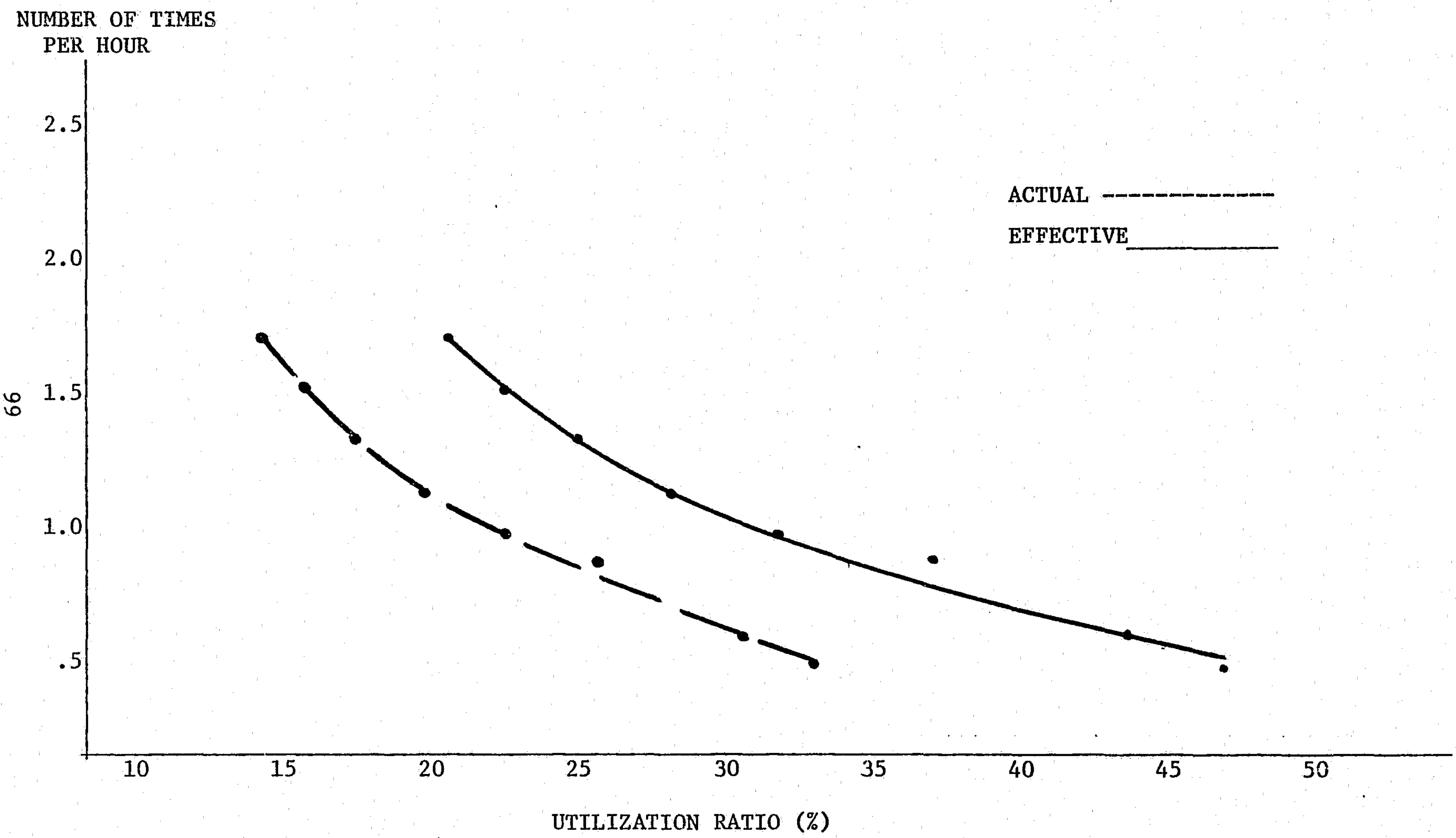

FIGURE 9 UTILIZATION VERSUS AVERAGE PATROL FREQUENCY: PRECINCT 1

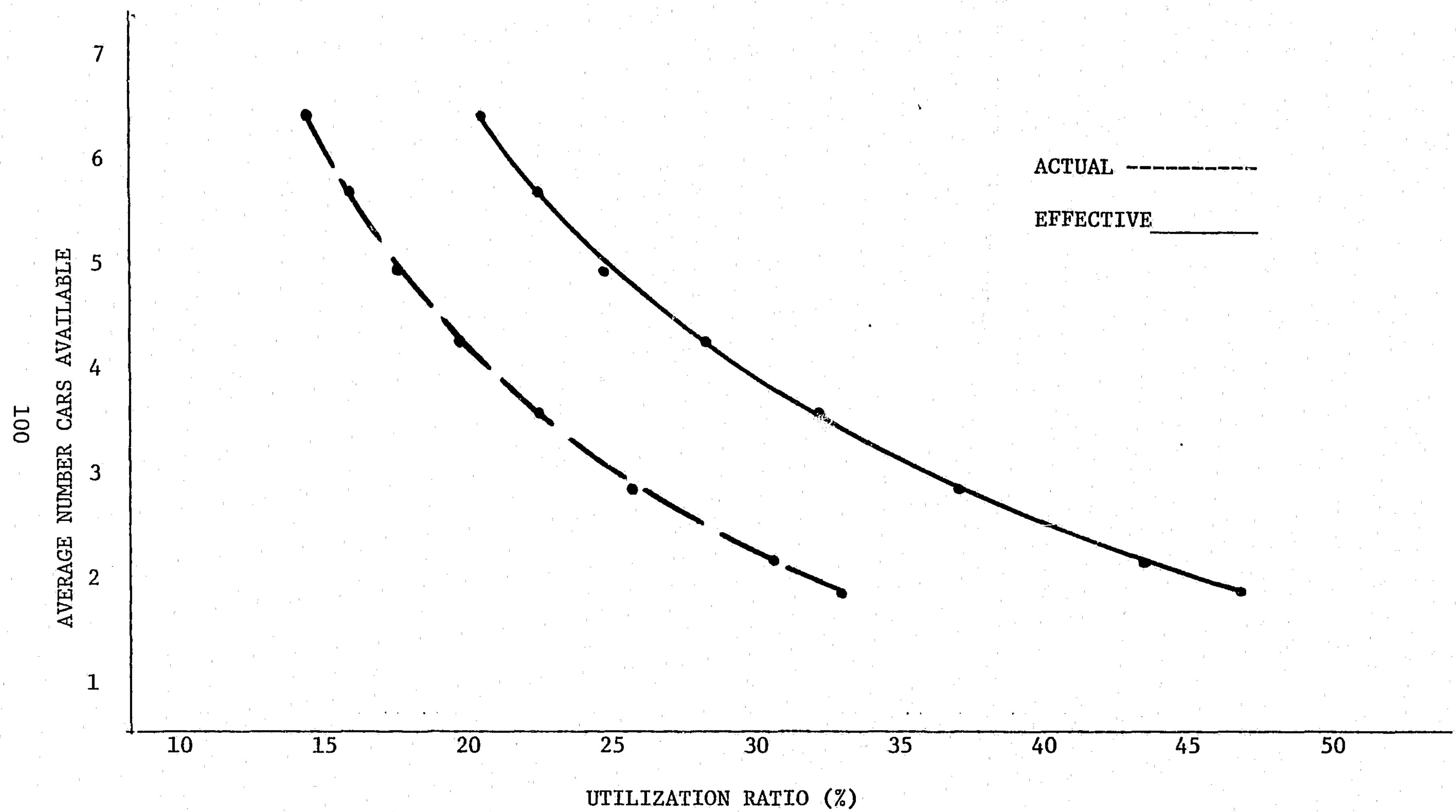

FIGURE 10 UTILIZATION VERSUS AVERAGE NUMBER OF CARS AVAILABLE: PRECINCT 1

The results of Precinct 1 are indeed representative of the relationships displayed in each of the other seven precincts. In each precinct, as the utilization ratio was decreased by increasing the car hours fielded per watch, the probability of a call being delayed, the average total delay, and the average travel time all decreased. However, at the same time, the patrol hours per suppressible crime, the average patrol frequency, and the average number of cars available were increased. The major conflict between these measures of performance seems to be between the desire to increase the utilization of patrol vehicles and to reach desirable levels for each of the performance measures.

4.4 Concluding Remarks

The results of the second stage of this research have provided the patrol planner with a vehicle whereby the expected level of a relevant performance measure could be determined given a specified utilization rate. This is valuable information to the patrol planner but it alone, in this form, is not enough to solve the vehicle scheduling problem. The trouble is that these performance measures conflict with one another. The move toward a desired level of one measure of performance may cause the levels of other measures to move away from their prescribed desired level. Therefore, the patrol planner must be able to arrive at the proper mix of performance attainment. The final stage of this research, described in Chapter V, begins with the trade-off relationships developed by the PCAM simulation to model a goal program. The goal programming model captures the conflicts among performance measures and ultimately arrives at a schedule for patrol vehicles.

CHAPTER V

GOAL PROGRAMMING MODEL

The aim of the final stage of this research is the specification of a patrol vehicle schedule whereby vehicle hours are assigned across all watches, days, and precincts in accordance with established requirements and performance levels. Up to this point this research has provided a means of establishing requirement levels through the ability to estimate call-for-service workload, and has related these workload estimates to various measures of performance by employing the utilization ratio as a key decision variable and structuring its relationships to other measures of performance. The ability to relate the utilization ratio, which is dependent not only upon the workload of a particular area but also the vehicle hours assigned to that area, to levels of other performance measures is a valuable aid to the patrol planner in assigning vehicle hours across watches, days, and precincts. At the same time, however, this ability complicates the patrol planner's decision-making environment. It creates a set of multiple criteria upon which the assignment of patrol vehicles can be based that directly conflict with one another. Therefore, in order to strive toward an optimum assignment of vehicle hours, a methodology must be found that can integrate the conflicting nature of the performance measure relationships with other managerially imposed constraints to derive vehicle schedules.

Following a decision-making process that parallels Mac Crimmon's Method Specification chart [61, p. 37], a goal programming methodology was arrived at an an appropriate methodology for the final stage of this research. The response to a series of six questions, related to the decision environment in which the methodology is to be used, led to this choice being made. The purpose of the method employed is normative rather than descriptive and an assessment of the decision-maker's preferences is valid and reliable, as evidenced by the presence of both difference and utility independence discussed in Section 5.3.2. The final results of the methodology will not be determined by only the best (or worst) performance measure values. Finally, the results are to be designated rather than chosen from a list of alternatives and the most valid kind of preference information concerns goal levels and their respective deviations, as opposed to a global objective. As Mac Crimmon [61] suggests, goal programming is the proper method to employ in the decision environment just described. It is a normative model that prescribes vehicle hour allocations through the solution of a system of complex objectives which may display nonhomogeneous units of measure. The problem then is the specification and structuring of the goal programming model itself.

5.1 General Structure of Goal Program Model

For this research a Charnes and Cooper [17] formulation was adopted due to its use of both relative and preemptive weights in the objective function and its flexibility in modelling nonlinear constraint relationships. The use of this type of formulation implies the existence of a cardinal additive utility function under certainty. The key condition of difference independence, necessary when making this assumption, will be addressed later in this chapter when the objective function is developed.

A generalized mathematical representation of the model is presented in Chapter II, equations (10) and (11). The decision variable for the goal programming model utilized in this research is designated as V_{ijp}. This represents the effective vehicle hours allocated to watch i, day j, precinct p where i goes from one to three watches, j goes from one to seven days, and p goes from one to eight precincts. The use of effective hours as the basic unit of measure for the decision variable is due to the PCAM simulation where it was assumed that thirty percent of the time patrol vehicles would be unavailable to respond to calls-for-service. This nonavailability parameter is used to translate actual vehicle hours fielded into effective vehicle hours available which, in turn are used by PCAM to calculate the values associated with the measures of performance. Since the performance measures are based on effective vehicle hours, it is appropriate that the decision variables follow suit. The use of effective vehicle hours poses no problem in scheduling vehicles since the value of V_{ijp} can be transformed easily into actual vehicle hours my multiplying by 1.4286. This value is equal to 1/.7 which is the reciprocal of the effective vehicle hour percentage.

The representation of three watches, seven days, and eight precincts totals 168 decision variables. The model in its final form contains eleven constraint sets totalling 1725 constraints. The model is structured to operate on a quarterly basis. In the sections that follow, a detailed description of the goal programming formulation will be presented along with the results obtained in running the model.

5.2 Formulation of the Goal Program Model

Goal programming, being a special form of linear programming, has the same basic structure with an objective function attempting to be optimized subject to a set of restricting constraints. In the case of goal programming, the objective is to minimize the total deviations from a set of specified goal levels.

As mentioned in the previous section there are eleven constraint sets associated with the goal program formulated for this research. They are a combination of technical, managerial, and goal constraints. A brief description of these constraint sets is presented in Table 15 along with the specified goal level where applicable. Each set will subsequently be discussed in greater detail.

5.2.1 Managerial and Technical Constraint Sets

The first set of constraints is a technical set representing the total number of aggregate patrol vehicle hours that are available to be allocated during any particular time period. There are 21 total constraints in this set reflecting three watches throughout seven days. Throughout the formulation of the model average quarter days were used. This is why only seven days need to be structured as opposed to all 91 days which comprise a quarterly based model.

In the time period represented by the data base used in this research, third quarter 1975, the Columbus Division of Police had a total of 128 patrol vehicles available. This number, multiplied by eight hours per watch, provided 1024 actual vehicle hours available to be assigned per watch. Converting actual hours to effective hours results in 716.8 effective vehicle hours available per watch.

TABLE 15

Goal Programming Constraint Sets

Set		
1	21 constraints	Represent total aggregate vehicle hours available at any one time.
2	168 constraints	Managerial imposed constraint of having at least three vehicles on duty in each precinct at all times.
3	21 constraints	Desired vehicle usage level.
4	3 constraints	Total available manpower levels for each shift.
5	168 constraints	45% utilization ratio.
6	168 constraints	Probability of 25% that a call is delayed.
7	168 constraints	Average travel time of 3 minutes.
8	168 constraints	Average patrol frequency of once per hour.
9	168 constraints	Patrol hours per suppressible crime, 5 hours.
10	168 constraints	Average of 3 cars available at any point in time.
11	504 constraints	Average total delay (piece-wise approximation using four line segments).

As described earlier, seven precincts have been eliminated from further consideration in this research. Due to a managerial constraint of allocating at least three vehicles to each precinct at all times, 168 actual hours, or 117.6 effective vehicle hours, have already been assigned. This leaves 599.2 effective vehicle hours per watch available to be allocated across the remaining eight precincts. This first technical constraint set then takes the following form:

$$\sum_{p=1}^{8} V_{ijp} \leq 599.2 \quad \forall_i, \forall_j. \tag{12}$$

The second constraint set reflects the managerially imposed constraint of requiring at least three patrol vehicles to be assigned to each of the eight precincts at all times. This three vehicle requirement translates into twenty-four actual and 16.8 effective vehicle hours allocated per watch per day per precinct. The constraint set then totals 168 constraints and is structured as follows:

$$V_{ijp} \geq 16.8 \quad \forall_i, \forall_j, \forall_p. \tag{13}$$

The third set of twenty-one constraints represent the desired vehicle usage level the Division of Police wished to maintain in the third quarter of 1975. Across all precincts during any particular watch, the goal was to assign no more than 85 patrol vehicles. These 85 patrol vehicles per watch at eight hours each made available 680 actual patrol vehicle hours per watch. When adjusted to reflect effective patrol vehicle hours, 476 hours were available. Finally, after subtracting the 117.6 effective vehicle hours already allocated to the seven precincts that are no longer involved in the decision-making analysis, 358.4 effective vehicle hours are available to be allocated to any one watch across the remaining eight precincts. Since this is a managerially imposed goal rather than a nonviolatable constraint, deviations may occur from the specified goal level. Therefore, the constraint set is structured as follows:

$$\sum_{p=1}^{8} V_{ijp} + d^-_{ij,1} - d^+_{ij,1} = 358.4 \quad \forall_i, \forall_j. \tag{14}$$

The terms $d^-_{ij,1}$ and $d^+_{ij,1}$ represent the positive and negative deviations that may occur during watch i and day j. The subscript number 1 indicates that this is the first set of deviational variables in the goal program model. All in all, there will eventually be 11 sets of deviational variables in the goal program model.

Constraint set four contains three constraints which relate to the manpower available to be allocated to each of the three watches. During the third quarter, 1975, the Division of Police had available for the patrol function, 118 men for the first watch, 177 men for the second watch, and 143 men for the third watch. When each of these manpower levels were multiplied by 40 hours per week and again by a factor of .7 to reduce the actual hours to effective hours, there are 3304, 4956, and 4004 effective manpower hours available per week respectively for the first, second, and third watch. This constraint set, as does the first set of constraints, establishes maximum available resource levels. These levels concern manpower in the fourth constraint set and patrol vehicles in the first constraint set. These ceilings were established to conform to the third quarter, 1975 levels in order to allow for a comparison of the vehicle allocations existing at that time to the vehicle allocations derived from this research. It was felt that a more valid comparison could be achieved if the resources available in each case were equal.

Once again remembering that seven precincts have already been allocated manpower levels, the total available manpower must be adjusted to reflect the level of manpower hours remaining for assignment to the eight precincts of concern. Table 16 shows the number of manhours that have been assigned per watch per week to the seven allocated precincts. Note that precincts 7 and 15 each only have two vehicles assigned, contradicting constraint set two. This is due to their very low population levels, about half the size of the next smallest precinct's level, and the low workload levels that, in turn, result. The workload levels average only 6.08 and 6.81 hours of workload, respectively, in a 24 hour day. After the 1344 manhours indicated in Table 16 have been adjusted to reflect effective manhours, it is found that a total of 940.8 effective manhours have already been allocated on a per watch per week basis. Therefore, the remaining effective manhours available to be assigned to each of the three shifts on a weekly basis are 2362.2, 4015.2, and 3063.2 effective manhours respectively.

TABLE 16

Patrolman Manhours Already Allocated Per Watch

Precinct	Number of Vehicles	x	8 Hours Per Watch	x	7 Days Per Week	=	Manhours	+	2-Man* Vehicle	=	Total Manhours Per Week
2	3	x	8	x	7	=	168	+	56	=	224
3	3	x	8	x	7	=	168			=	168
7	2	x	8	x	7	=	112			=	112
9	4	x	8	x	7	=	224	+	56	=	280
10	4	x	8	x	7	=	224	+	56	=	280
14	3	x	8	x	7	=	168			=	168
15	2	x	8	x	7	=	112			=	112
					Total Manhours Per Watch Per Week						1344

* Indicates precincts where one vehicle per watch is a 2-man vehicle.

A final consideration that must be made in structuring constraint set four is the percentage of two-man vehicles assigned to each watch throughout the remaining eight precincts. It was discovered that seventeen percent of the first watch vehicles, thirty percent of the second watch vehicles, and thirty-two percent of the third watch vehicles are two-man vehicles. Therefore, the three constraints associated with constraint set four are structured as follows:

$$\sum_{j=1}^{7} \sum_{p=1}^{8} 1.17 \quad V_{1jp} + d^{-}_{1,2} - d^{+}_{1,2} = 2363.2 \qquad (15)$$

$$\sum_{j=1}^{7} \sum_{p=1}^{8} 1.3 \quad V_{2jp} + d^{-}_{2,2} - d^{+}_{2,2} = 4015.2 \qquad (16)$$

$$\sum_{j=1}^{7} \sum_{p=1}^{8} 1.32 \quad V_{3jp} + d^{-}_{3,2} - d^{+}_{3,2} = 3063.2 \qquad (17)$$

The deviational variables $d^{-}_{i,2}$ and $d^{+}_{i,2}$ represent the negative and positive deviations that occur in the number of effective manhours assigned to watch i summed over all seven days and all eight precincts. They are the second set of deviation variables.

5.2.2 Performance Measure Constraint Sets

The last seven constraint sets, as displayed in Table 15, are concerned with the structuring of performance measure relationships and the establishment of appropriate goal levels for each measure. All goal levels were specified by the Planning and Research Department of the Columbus Police Department and represent target values.

Constraint set five, pertaining to the utilization ratio, evolves from within the PCAM simulation but is the only constraint set of the last seven that is not directly structured from its output. This set identifies target levels for the effective utilization ratio that occur during each watch, each day, and in each precinct. This requires 168 constraints, all of which were targeted for a forty-five percent effective utilization rate.

As described in Chapter IV, the effective utilization ratio is equal to the workload divided by the effective number of vehicle hours assigned. The general relationship can then be structured as:

$$\text{Effective Utilization Ratio} = \frac{\text{Workload/watch/day/precinct}}{V_{ijp}} \, . \qquad (18)$$

With the Columbus Division of Police interested in maintaining a forty-five percent utilization rate, the general relationship can be changed to read:

$$45\% = \frac{\text{Workload/watch/day/precinct}}{V_{ijp}} \, . \qquad (19)$$

And, with a minor mathematical transformation the relationship is changed to:

$$V_{ijp} = \frac{\text{Workload/watch/day/precinct}}{45\%} \, . \qquad (20)$$

By estimating the workload for each watch, day, and precinct the right-hand side of equation (20) becomes a scalar value and a set of goal constraints can be modeled by the addition of a third set of deviational variables. The resulting set of constraints are modeled as follows:

$$V_{ijp} + d^-_{ijp,3} - d^+_{ijp,3} = \frac{Workload/i/j/p}{.45} \quad \forall_i, \forall_j, \forall_p. \qquad (21)$$

Constraint sets six through ten representing five measures of performance, (see Table 15), were all modeled directly from the output obtained from the PCAM simulation iterations. The target levels of goal attainment were individually specified by the Planning and Research Department of each goal, but the formulation of each set of constraints is exactly the same. Using the utilization ratio as a standard of comparison, because of its direct relationship to each of the other measures of performance, a series of tradeoff curves were drawn which reflect the average change in each performance measure with respect to average changes in utilization ratio levels. Data from the PCAM simulation iterations, in which vehicles assigned to each precinct were systematically increased, were used as a basis for these curves. Examples of this output can be seen in Chapter IV, Table 7 through Table 14. The tradeoff curves were drawn on a precinct-by-precinct basis using average daily data, averaged over the seven days. The curves associated with the data in Table 7 through Table 14 are exhibited in Chapter IV, Figure 4 through Figure 10. Due to space requirements only Precinct One data are displayed.

A regression analysis was performed on each tradeoff relationship for each of the eight precincts. These equations were developed on a precinct-by-precinct basis because the different geographic and demographic factors exhibited in each precinct affects the performance measure relationships existing within each precinct. These factors do not change across watches or days; therefore, individual equations for each watch or day are not necessary. The results, exhibited in Table 17, indicate that for all but one performance measure, average total delay, the tradeoff curves could be very closely approximated by a straight line for each precinct. Therefore, mathematically these relationships can be modeled as follows:

$$P = a + b(\text{Effective Utilization Ratio}) \tag{22}$$

where P equals the value of the particular performance measure being modeled.

Since it has been established earlier that the utilization ratio is a measure of workload divided by vehicle hours, if W_{ijp} were to represent the call-for-service workload of watch i, day j, precinct p then equation (22) could be written as:

$$P = a + b(W_{ijp}/V_{ijp}). \tag{23}$$

Through a simple mathematical manipulation equation (23) becomes:

$$V_{ijp} = \frac{b \times W_{ijp}}{P - a}. \tag{24}$$

Because the term on the right-hand side of equation (24) is known; a and b are the derived regression coefficients of the tradeoff curves; P is determined by the Planning and Research Department and represents desired goal levels; and W_{ijp} is either predicted from the regression analysis of factor scores for a new district or derived from past data for an existing district; equation (24) simplifies into V_{ijp} being set equal to a known scalar value. Since V_{ijp} is the decision variable in the goal program model, the addition of deviational variables on the left-hand side of equation (24) causes the formulation

TABLE 17

REGRESSION ANALYSIS OF PERFORMANCE MEASURE CURVES

	Car Hours	Probability Call Delay	Total Average Delay	Average Travel Time	Patrol Hours Per Suppressible Crime	Average Patrol Frequency	Average Number Available Cars
Precinct 1							
R	.97554	.97749	.95048	.9979	.97533	.97537	.9755
R^2	.95167	.95548	.90341	.9958	.95127	.95135	.95161
B	-1.8653	1.13742	.33996	.04696	-.50178	-.04343	-.16318
Constant	122.6757	-26.2486	-6.8305	.3303	28.008	2.4235	9.1078
Precinct 4							
R	.97798	.9791	.96276	.99854	.97793	.97847	.97807
R^2	.95644	.95863	.9269	.99709	.95635	.9574	.95661
B	-1.771908	1.179166	.307166	.06551	-.243114	-.027696	-.155136
Constant	115.4111	-27.255	-5.44105	.469792	13.4257	1.523541	8.56466
Precinct 5							
R	.97272	.98049	.96972	.99827	.97289	.97212	.97299
R^2	.94619	.96137	.94036	.99655	.94651	.94502	.94671
B	-1.801524	1.166865	.33838	.088408	-.274338	-.02809	-.157885
Constant	117.1077	-26.09267	-5.22727	.69309	15.1749	1.5513	8.73325
Precinct 6							
R	.93675	.96316	.87065	.99362	.9366	.9371	.93646
R^2	.87751	.92768	.75804	.98728	.87722	.87816	.87696
B	-1.8475	1.142824	.504012	.05343	-.461612	-.0431127	-.161517
Constant	106.6762	-21.0091	-8.4537	.6301	23.38367	2.18015	8.181155
Precinct 8							
R	.95144	.97556	.91307	.99455	.9515	.95265	.9515
R^2	.90523	.95172	.8337	.98912	.90535	.90753	.90535
B	-1.64972	1.19321	.48956	.076038	-.46187	-.038525	-.144334
Constant	96.80265	-22.2723	-7.51055	.954565	23.6443	1.96757	7.3901
Precinct 11							
R	.96789	.98666	.89362	.99297	.96801	.96788	.96801
R^2	.93681	.97351	.79856	.98599	.93705	.93679	.93705
B	-1.60856	1.205574	.491263	.03858	-.33791	-.030199	-.140796
Constant	103.2938	-25.37829	-10.1946	.4131177	18.55478	1.65756	7.72949
Precinct 12							
R	.97049	.9848	.88987	.99773	.97054	.97216	.97034
R^2	.94186	.96983	.79187	.99547	.94154	.94509	.94156
B	-1.577858	1.19199	.431245	.0373539	-.318524	-.029498	-.137993
Constant	104.1334	-26.1077	-9.1604	.387035	17.88406	1.65802	7.749752
Precinct 13							
R	.95937	.98085	.9417	.9976	.95949	.95943	.95947
R^2	.9204	.96207	.88679	.99521	.92062	.9205	.92058
B	-1.74548	1.155179	.484127	.12068	-.3943	-.0403698	-.152713
Constant	90.95085	-19.51814	-5.26955	1.46399	18.1599	1.866425	7.03815

of constraint sets for each of the performance measures, except the average total delay. A general formulation of these constraints is as follows:

$$V_{ijp} + d^-_{ijp,n} - d^+_{ijp,n} = \frac{b \times W_{ijp}}{P - a} \quad \forall_i, \forall_j, \forall_p \tag{25}$$

where n = 4, 5, 6, 7, and 8 and designates the deviational variables associated with constraint sets 6 through 10.

The target levels for each performance measure, P, are specified in Table 15, Chapter V. The call-for-service workloads inputed for each watch, day, and precinct, W_{ijp}, were the actual values which occurred in the third quarter, 1975, derived from the Patrol Data Analysis Program discussed in Chapter III, Section 3.1. The use of actual workload levels enables the model to take into consideration the variation workload exhibits across watches and days.

The final constraint set, number eleven, is concerned with the modeling of the average total delay performance measure. The regression analysis results of this performance measure were the only ones to exhibit a R^2 value below the .8 level. Because of these low R^2 levels as compared to the other results, the decision was made to model this non-linear tendency by the use of a piecewise approximation method. The approach taken is described by Charnes and Cooper [17, p. 17]. To facilitate the approximation and since the decision variable V_{ijp}, is specified in units of effective vehicle hours, the average total delay in minutes was graphed against the effective vehicle hours assigned. An example of this graph for Precinct One is exhibited in Figure 11. The data points in Figure 11 represent the relationships displayed by

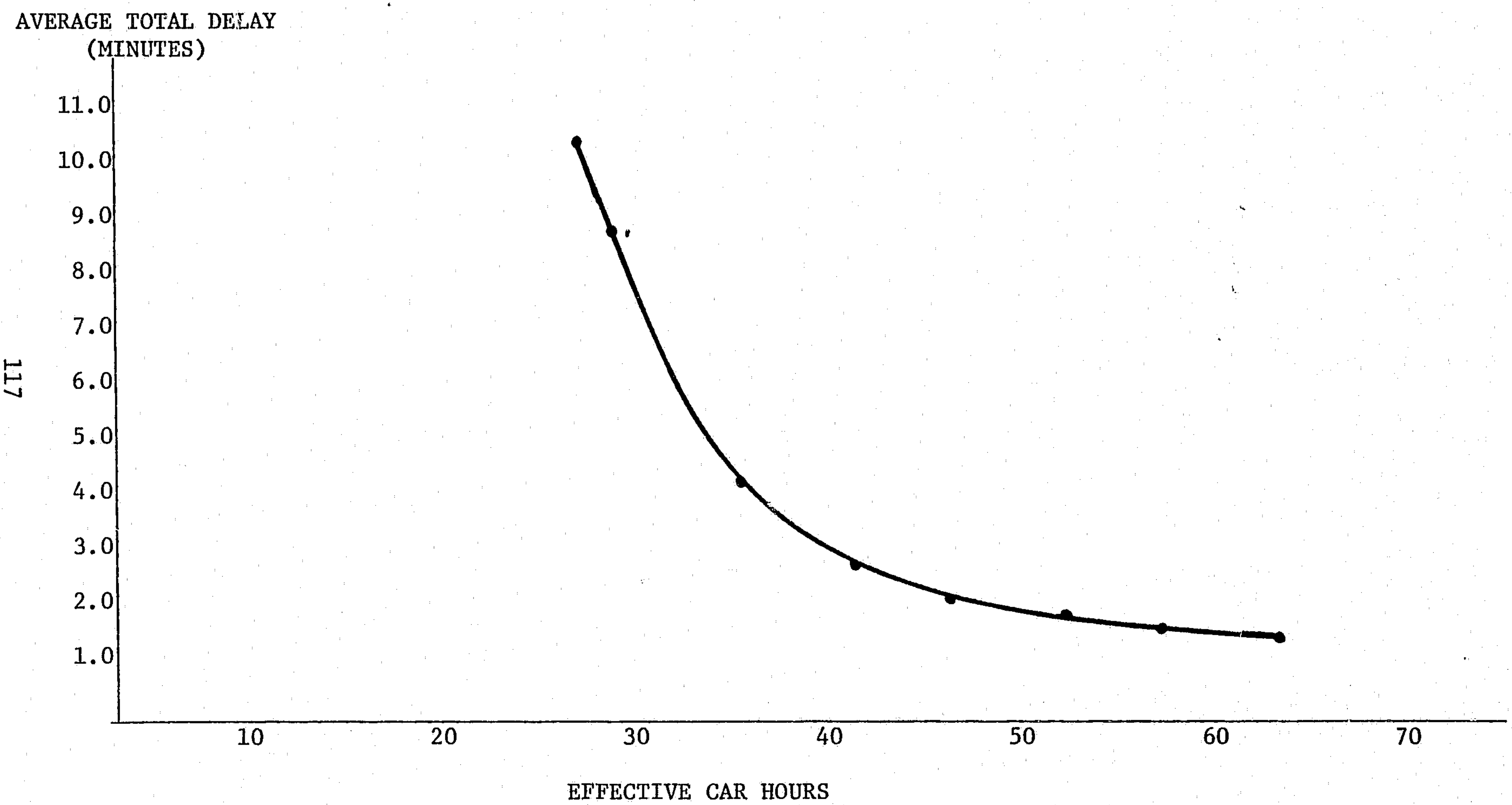

FIGURE 11 EFFECTIVE CAR HOURS VERSUS TOTAL AVERAGE DELAY: PRECINCT 1

the PCAM simulation iterations between the average minutes of delay and the average effective vehicle hours assigned to Precinct One. The values were averaged across both watches and days.

The functional relationship for each precinct was approximated using three goal levels which results in four linear line segments. The use of three goal levels, which are specified directly from the graphing of the functional relationships, result in a tripling of the necessary number of constraints needed to model the average total delay performance measure. Furthermore, the required number of deviational variable sets is increased to three for each precinct. This results in 504 individual constraints and 24 pairs of deviational variables. A generalized constraint is structured as follows:

$$V_{ijp} + d^{-}_{ijp,n} - d^{+}_{ijp,n} = G_m \qquad \forall_i, \forall_j, \forall_p, \forall_n \tag{26}$$

where: n = 9, 10, 11, and m = 1, 2, 3 .

In this formulation n, ranging from 9 to 11, represents the three pairs of deviational variables associated with each of the three goal levels, G_m, specified in the piecewise approximation.

This concludes the description of the eleven constraint sets formulated for the goal programming model. A summary of each of these sets can be found in Appendix C, Goal Program Model and Matrix Generator. The constraints presented in both this section and Appendix C represent the general structure of the constraints actually used in the goal program runs. Actually, before the deviational variables were added to any constraint, each constraint was divided through by its right-hand side value. This takes away the effects of the magnitude of each deviation and provides percentage deviations. Also, it was easier for the police personnel to think in these terms. The final step in the structuring of the goal program model is the formulation of the objective function, discussed in the next section.

5.3 Objective Function Formulation

The objective function of a goal programming model is generally comprised of the deviational variables specified in the goal constraint sets. The objective is to minimize the sum of all the deviational variables. The Charnes and Cooper [17] formulation allows the user to prescribe both relative and preemptive weights for the deviational variables in the objective function. Relative weights indicate the relative importance the user places on the positive versus negative deviations from within a particular goal. Preemptive weights, on the other hand, indicate the degree of importance the user perceives to be present between the different goals that have been established. The objective function formulated for this research contains a total of 3240 variables, of which 168 are the decision variable, V_{ijp}, with the other 3072 being deviational variables. The decision variable, V_{ijp}, is incorporated into the objective function due to the piecewise approximation of the average total delay constraint set. The formulation of the objective function, using a piecewise approximation technique, is discussed in the next section.

5.3.1 Formulation of the Objective Function for a Piecewise Approximation

Charnes and Cooper in their article, "Goal Programming and Multiple Objective Optimizations," articulate the following theorem [17, p. 17]:

Any polygonal (i.e., piecewise linear and continuous) function, f(x), may be represented

$$f(x) = \sum_{i=1}^{N} a_i |x - g_i| + Bx + E \qquad (27)$$

where:

$$a_i = \frac{K_{i+1} - K_i}{2} \qquad (28)$$

$$B = \frac{K_{N+1} + K_i}{2} \qquad (29)$$

and:

$$K_1 < K_2 < K_3 < K_4$$

$$g_1 < g_2 < g_3 \quad .$$

In this representation, x refers to the decision variable V_{ijp}, K_i equals the slope of the i^{th} linear line segment, and g_i equals the specific goals established at the intersection of the approximating linear line segments. Since E is a constant which does not enter into the optimizing choice $|x - g_i|$ can be rewritten in the form $(d_i^+ + d_i^-)$, and equation (27) can be expressed as follows:

$$f(x) = \sum_{i=1}^{N} a_i \, (d_i^+ + d_i^-) + Bx \qquad (30)$$

with the requirement that $d^+d^- = 0$.

In applying the general representation of equation (30) to the average total delay constraint set for each precinct, the average total delay in minutes was graphed against effective car hours. The results found in Precinct One are displayed in Figure 11. This function was then approximated for all eight precincts using three goal levels and four linear line segments, with the final line segment having a slope of zero. Given the established goal levels for each precincts' functional relationship, a simple linear regression was performed on each line segment for each precinct. This series of linear regressions provided the line segment slopes, K_i, necessary to calculate a_i and B in equation (30), and thus formulate the portion of the objective function associated with the average total delay performance measure. The results of the linear regressions are exhibited in Table 18, Linear Regression Results of Average Total Delay Functions, while Table 19 summarizes the entire set of values necessary to piecewise approximate all eight precinct relationships. A sample of the portion of the objective function associated with the average total delay function for Precinct One only is as follows:

$$\text{Minimize } .2921\,(d^+_{ij1,9} + d^-_{ij1,9}) + .0762\,(d^+_{ij1,10} + d^-_{ij1,10}) + .01845\,(d^+_{ij1,11} + d^-_{ij1,11}) + (-.38675)V_{ij1} \ldots \forall_i, \forall_j. \tag{31}$$

The objective function section associated with each of the other seven precincts is formulated in the same manner. These eight sections, together with the first eight sets of deviational variables associated with the other measures of performance, comprise the entire objective function as exhibited in Appendix C, Figure 21.

5.3.2 Objective Function Weights and Results

An inherent problem in using a goal programming approach such as the one formulated for this research is the determination of the appropriate relative and preemptive weights for the objective function.

TABLE 18

Linear Regression Results of Average Total Delay Functions

	Precinct 1	Precinct 4	Precinct 5	Precinct 6
Segment 1	y = 31.531 - .7735x	y = 26.638 - .62998x	y = 30.071 - .7182x	y = 58.708 - 1.9396x
Segment 2	y = 10.798 - .1893x	y = 10.174 - .1661x	y = 13.62 - .2286x	y = 10.15 - .2054x
Segment 3	y = 3.683 - .0369x	y = 4.504 - .0446x	y = 5.78 - .0536x	y = 3.15 - .0268x

	Precinct 8	Precinct 11	Precinct 12	Precinct 13
Segment 1	y = 47.002 - 1.499x	y = 60.689 - 1.956x	y = 57.747 - 1.866x	y = 36.443 - 1.088x
Segment 2	y = 10.5799 - .1982x	y = 15.995 - .3598x	y = 14.685 - .3277x	y = 11.29 - .1893x
Segment 3	y = 4.443 - .0417x	y = 3.617 - .044x	y = 3.497 - .0423x	y = 6.18 - .0589x

TABLE 19

SUMMARY VALUES FOR PIECEWISE APPROXIMATIONS OF AVERAGE TOTAL DELAY FUNCTION

	Precincts							
	1	4	5	6	8	11	12	13
g_1	35.49	35.49	33.6	28.0	28.0	28.0	28.0	28.0
g_2	46.69	46.69	44.8	39.2	39.2	39.2	39.2	39.2
g_3	63.49	57.89	61.6	67.2	56.0	56.0	56.0	50.4
K_1	-.7735	-.62998	-.7182	-1.9396	-1.499	-1.956	-1.866	-1.088
K_2	-.1893	-.1661	-.2286	-.2054	-.1982	-.3598	-.3277	-.1893
K_3	-.0369	-.0446	-.0536	-.0268	-.0417	-.044	-.0423	-.0589
K_4	0	0	0	0	0	0	0	0
a_1	.2921	.23194	.2448	.8671	.6504	.7981	.76915	.44935
a_2	.0762	.06075	.0875	.0893	.07825	.1579	.1427	.0652
a_3	.01845	.0223	.0268	.0134	.02085	.022	.02115	.02945
B	-.38675	-.31499	-.3591	-.9698	-.7495	-.978	-.933	-.544

The weighting is important in that it dictates the order in which the specified goals are attempted to be satisfied. The weighting of the objective function variables in this research was done in an iterative fashion which relied on a close interaction with the Planning and Research Department of the Division of Police.

The first step was the establishment of the relative weights which, as explained earlier, indicate the relative importance placed on positive versus negative deviations from within a particular goal. For the most part these weights were easily specified by the Planning and Research Department. They can be examined in Appendix C, Figure 21. The value 3 preceding deviational variable $d^{+}_{ij,1}$, the positive deviational variable set, as opposed to a coefficient of 1 for $d^{-}_{ij,1}$ indicates that it is three times as important to stay below the goal level specified for this deviation variable set as it is to be above the goal level. In other words, the penalty for staying above the goal level is three times as harsh as that of falling below the level. The relative weights concerning the average total delay measure are indicated by the W_R terms in the objective function in Figure 21. They were calculated during the objective function formulation associated with the average total delay as described in Section 5.3.1 and are the a_i and B values exhibited in Table 19.

The preemptive weights indicating the degree of importance placed on different goals themselves, however, were much more difficult to quantify due to the interactive nature of the individual goals. The procedure used to develop these weights falls within the general category of "Generating Techniques" discussed by Cohon [23; Chapter 5]. It is an iterative procedure which emphasizes the development of information concerning the multiobjective problem. Information is presented to the decision-maker which depicts a range of alternatives with the associated trade-offs concerning these alternatives. The information provided the decision-maker, in both graphical and tabular form, only approximates the noninferior solution set. Nonetheless, this procedure has the advantage of placing a small burden on the decision-maker. By emphasizing the demarcation of the range of choice, he needs only react to the information provided and, therefore, an explicit definition of his preferences is not required. The weights used in the objective function are only used to generate noninferior solutions to the problem and are not, as such, representative of the utility of the decision-maker.

Specifically, to obtain appropriate preemptive weightings, the goal program was initially run eight consecutive times. The goal program was run at The Ohio State University utilizing IBM's Mathematical Programming System, MPS/360 V2-M11. Each one of the first seven runs represented the situation where one performance measure was designated as a dominant goal and accordingly was assigned a large preemptive weight in relation to the other six performance measures. The dominant goal, in this case, was assigned a weight of 1.0 while all other goals were given a weight of .01. An eighth goal program was run in which the preemptive weights for every performance measure were set equal to .01 indicating the absence of a dominant goal.

In each of the eight initial goal program runs and throughout the remainder of the goal program analysis, the preemptive weights associated with constraint sets three and four in Table 15, the desired vehicle usage level and the total available manpower level, were set extraordinarily high at a value of 99.0. It was felt that this action was necessary to ensure the same resource levels were available for use as was available in the third quarter, 1975. It is important that the resource levels of quarter three, 1975 be adhered to since it is this period which acts as a data base for this research and will, in the final analysis, be used as a standard of comparison.

The results of the initial goal program runs were examined by the Planning and Research Department in terms of both the allocation of actual vehicle hours across an average week for each precinct and the percentage of goal attainment exhibited by each allocation pattern. The results are presented in Appendix D. Table 40 through Table 47 display the actual vehicle hours allocated across each precinct for each of the eight initial goal runs. Table 48 through Table 55 present the percentage goal attainment exhibited by each performance measure in each precinct for each of the eight initial vehicle allocations. These percentage attainment values were presented to the Planning and Research Department in a value path format and are displayed in Figure 22 through Figure 29. The value path format, as described by Schilling et al. [72], provides a means of comparing multiple solutions on a one dimensional scale.

The goal attainment values represent the average percentage attainment level a particular measure of performance reaches with respect to its individually specified goal level. The values are a composite average taken across all watches and all days for each precinct. Specific values are calculated by first, determining for each precinct, the average number of effective vehicle hours allocated per watch. Then, the average number of effective vehicle hours required per watch to satisfy a particular performance measure goal in each precinct is found by averaging the right-hand side of the constraints that are representative of the particular performance measure and precinct being considered. There will be twenty-one constraining right-hand sides to average for each value. The goal attainment level is the percentage value that results from dividing the average effective vehicle hours required to satisfy the goal target level into the average effective vehicle hours actually allocated by the goal program.

In general, as the number of effective vehicle hours allocated is increased, the goal attainment percentage increases, indicating an improvement in the performance measure level. There is, however, one exception to this rule. As the number of vehicle hours allocated increase, the utilization ratio exhibited by patrol vehicles decreases. The goal for the utilization ratio performance measure was set at forty-five percent. In order to reach this level, the number of vehicle hours allocated per average watch must be decreased because the average utilization per watch is presently below the forty-five percent target level. Therefore, to properly reflect the goal attainment percentage for the utilization ratio, the average vehicle hour values must be inverted so that the average effective vehicle hours actually allocated are divided into the average effective vehicle hours required to satisfy the goal target levels. This is the manner in which the goal attainment percentages were calculated in both Appendix D and Appendix E.

Within the Planning and Research Department of the Columbus Police a team of four policemen consisting of the Lieutenant in charge of the department, two Sergeants, and a Patrolman reviewed the results that are presented in Appendix D. The derivation of the goal attainment percentages for each measure of performance was explained to each member of the team along with a description of how the value path graphs were constructed. The four policemen were then free to peruse the results of the initial goal program runs without any further coaching or prompting from the researcher. After reviewing the results, the team of policemen selected four measures of performance that they felt should be considered "important criteria" in the allocation of patrol vehicles. The four measures of performance were average travel time, utilization ratio levels, average patrol frequencies, and the average number of cars available. The problem then became one of establishing the proper preemptive weighting scheme for the objective function of the goal program. A set of preemptive weights needed to be determined for the performance measure constraint sets that would reflect the importance of these four measures both between themselves and the other measures of performance.

To aid in the selection of appropriate preemptive weights an approach, similar to the one described by Huber [49, p. 446] as the "client-explicated model" which he uses to estimate multi-attribute utilities, was employed. Specifically, the team of four policemen from the Planning and Research Department were asked to rank, on a scale from zero to one, the importance of attaining, individually, each performance measure goal, given that it would be the only goal achieved and all other goals would exhibit very low attainment levels.

The use of an approach such as this relies on two conditions being met. The first is preference (or difference) independence and the second utility independence. Preference independence was validated by choosing two performance measures, average total delay and the probability of a call being delayed, and finding a point of indifference with respect to alternative levels of these measures. The set of alternatives settled on were a choice between a delay of six minutes and probability of twenty percent as opposed to a delay of four minutes and a probability of thirty percent. Since the patrol planner was indifferent to either set of these alternatives, to satisfy the condition of preference independence he should remain indifferent no matter what the level of the other five performance measures, as long as they are the same for each alternative. This proved to be the case and the condition was satisfied.

Utility independence was validated by using average travel time. The patrol planner was given a choice between the alternative of having a travel time of three minutes with certainty or having the alternative of a fifty-fifty chance of incurring a one minute or five minute travel time. Since the patrol planner was indifferent to either alternative as long as the other six performance measures were held constant at any other level, the utility independence condition was satisfied.

In using the forementioned technique, the team of four practitioners from the Planning and Research Department settled on two sets of rankings to indicate the relative importance of the measures of performance. For example, the team was asked to indicate the importance of the average travel time goal, being it was the only goal that could be attained and all others would exhibit very low attainment levels. The team assigned this goal the highest possible rank of 1.0, indicating the highest level of importance. Each of the other six performance measures were ranked by the practitioners in the same manner. Two sets of rankings were specified because agreement could not be reached concerning the relative importance between two of the measures of performance; the utilization ratio and the average patrol frequency.

The four measures identified as being the most important, average travel time, utilization ratio level, average patrol frequency, and average number of cars available were given rankings of 1.0, .8, .6, and .4 in the first set and rankings of 1.0, .6, .8, and .4 in the second set, respectively. Each of the other measures of performance in each case received a ranking of .1. The two sets of rankings were normalized by dividing the ranking of each performance measure by the summation of all performance measure rankings and used as preemptive weights in the formulation of two objective functions. The normalized weights are exhibited in Table 20.

Using the two sets of weights displayed in Table 20, two goal programs were run. The resulting allocations of vehicle hours arrived at in each run, along with the corresponding goal attainment percentages

TABLE 20

Normalized Weightings for the Goal Program Objective Function

Performance Measure	Weights Set 1	Weights Set 2
Average Travel Time	.303	.303
Utilization Ratio	.2424	.1818
Average Patrol Frequency	.1818	.2424
Average Number Cars	.1212	.1212
All Other Measures	.0303	.0303

and value paths, were presented to the Planning and Research Department for examination. These results are displayed in Appendix E. As can be seen, the vehicle hour allocations and the goal attainment levels exhibited by each goal program run are very similar. A thorough study of these results by the four member team from the Planning and Research Department indicated that they were indifferent as to which set of weights were to be used in the final solution procedure. They were satisfied that the assignment of vehicle hours, which resulted in either case, was valid and the respective goal attainment levels were, in both cases, acceptable. Therefore, it was unnecessary to perform further goal program runs due to both the similarity of the solutions and the satisfaction exhibited by the Planning and Research personnel.

As a final step, Planning and Research Department personnel transformed the assignment of vehicle hours derived from the final goal program runs into an integerized, feasible schedule of patrol vehicle allocations. This was necessary to ensure five day schedules for patrolmen and to provide a vehicle schedule to compare to the existing vehicle schedule present in quarter three, 1975. The actual vehicle allocation which existed in quarter three, 1975, the actual integerized goal program allocation, and the smoothed goal program allocation indicating feasible schedules are exhibited in Appendix E.

The actual derivation of an integerized, feasible schedule of patrol vehicles across watches, days, and precincts entailed the performance of two major tasks. First, the actual vehicle hours allocated across each watch, day, and precinct by the goal program model were integerized to reflect "whole" patrol vehicle unit allocations. The final goal program run chosen to be used in this integerization process was the one that assigned a preemptive weight of .6 (.1818 normalized) to the utilization ratio measure of performance and .8 (.2424 normalized) to the average patrol frequency measure. This particular goal program run resulted in marginally better levels of performance for all measures of performance except the utilization ratio. (See Tables 58 and 59). For this reason, this researcher took that particular vehicle hour allocation output and rounded each individual allocation upward to the nearest whole patrol vehicle. The only exceptions were cases where the vehicle hours allocated exhibited a level less than one hour above a "whole vehicle" level. In these instances, the fraction of an hour above the whole vehicle level was dropped. For example, if a particular watch was allocated 48.7 vehicle hours, then the number of vehicles assigned to that watch would be six, and the extra .7 hours would be dropped. If, however, the vehicle hours allocated were 49.6 hours, then seven vehicles would be assigned. The results of this intergerization process are exhibited in Table 61.

The second task, necessary to arrive at the final vehicle allocation prescribed by this research, entailed the smoothing of the vehicle schedule displayed in Table 61 to reflect "feasible" vehicle schedules. A "feasible" vehicle schedule is one that has smoothed the variations in the number of vehicles assigned across each day, for a particular watch, to permit the scheduling of individual patrolmen to conform to continuous five-day periods. The establishment of feasible schedules for each precinct was undertaken by one Sergeant from the Planning and Research Department. He was given Table 61, the integerized final goal program allocation, and was asked to develop a feasible operating schedule of patrol vehicles. The results of his efforts are shown in Appendix E, Table 62. As an example of this smoothing procedure, Table 61 shows the variation in the number of patrol vehicles allocated in the first watch for Precinct 1 to range from a low of four vehicles on Sunday to a high of seven vehicles on Monday. In order to provide a consecutive five-day working schedule for patrolmen assigned to these vehicles, the number of patrol vehicles assigned to the first watch for Precinct 1 was smoothed to indicate six vehicles allocated to Monday through Friday and five vehicles for both Saturday and Sunday. This allocation is displayed in Appendix E, Table 62. This schedule requires eight patrolmen two of which begin their tour of duty on Monday. The other six patrolmen each begin their respective tours of duty on a different day of the week. With each patrolman working five consecutive days, the vehicles allocated in Table 62 for the first watch in Precinct 1 can all be manned throughout the week.

The Sergeant completing the smoothed vehicle schedule required one full afternoon to complete the schedules for the eight precincts involved. It should be noted, however, that anyone could have derived a feasible operating vehicle schedule, given the time and patience, since the only information required to complete one is an initial integer vehicle allocation.

5.4 Concluding Remarks

Chapter V has described the development of a goal programming model which was used to derive an assignment of patrol vehicle hours across the watches of an average week for eight precincts. After the assignment of vehicle hours was determined, it was used to structure a patrol vehicle allocation which reflected feasible operating schedules. The arrival of feasible operating schedules for patrol vehicles across precincts is the culmination of the three stage methodology developed in this research. The only function remaining to be performed in this research is an analysis of the results obtained through the use of the outlined methodology. This analysis is discussed in Chapter VI. Appropriate conclusions and future research directions are presented in Chapter VII.

CHAPTER VI

ANALYSIS AND SUMMARY OF RESULTS

In Chapter V the formulation of a goal program was presented which, when initiated, resulted in the allocation of effective patrol vehicle hours for an average week on a per watch per day per precinct basis. As previously described, the effective vehicle hours were transformed into actual vehicle hours in order to take into consideration the assumption that thirty percent of the time patrol vehicles are unavailable to respond to calls-for-service. This assumption was made in Chapter IV when the input data for PCAM was described. This actual vehicle hours allocated per watch per day per precinct for the final goal program runs are displayed in Table 56 and Table 57.

Given these actual vehicle hour allocations, attainment level ratios were derived for each measure of performance and are displayed in Table 58, Table 59, and Figure 30. Finally, given the patrol planner's satisfaction with the results of the final goal program allocations and the corresponding attainment levels of the performance measures, the actual vehicle hours allocated were translated into the number of vehicles to be assigned to each watch on each day for each precinct. This action resulted in the development of two sets of vehicle assignments. Both of these assignments, the actual goal program allocation and the smoothed goal program allocation, are discussed in Appendix E and displayed in Table 61 and Table 62 along with the actual Columbus allocation shown in Table 60.

It is the aim of this chapter to analyze the results presented in Appendix E and to summarize the resultant findings.

The results of this research can be conveniently sectioned into two categories. First, there are the actual vehicle allocations which were developed and second, there are the expected levels of performance associated with these allocations. The categorization of results in this manner provides both the researcher and the reader with a simple straightforward structure in which to review and analyze the large amount of output generated by this research. In keeping with this structure, the vehicle allocation results are first analyzed followed by a discussion of the performance measure results.

6.1 Vehicle Allocation Results

The analysis of the vehicle allocations concentrates on Table 60, Table 61, and Table 62 in Appendix E. These tables represent, respectively, the actual vehicle allocation Columbus, Ohio maintained during the time period the data-base represents, the actual vehicle allocation derived from the goal program model, and the vehicle allocation arrived at by smoothing the actual goal program results in order to develop feasible working schedules.

Preliminary analysis indicates that the total number of vehicles allocated to the system are almost identical. Table 21 indicates that the average number of vehicles allocated at any point in time is 47.3 vehicles for the actual Columbus allocation, 46.2 vehicles for the goal program, and 47.0 vehicles for the smoothed goal program allocation. The increase in the average number of vehicles in the smoothed allocation

TABLE 21

THE TOTAL NUMBER OF VEHICLES

ALLOCATED IN ALL EIGHT PRECINCTS

Watch \ Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Average
Actual Columbus Allocation								
First	40	41	41	41	41	41	40	40.7
Second	55	55	58	56	56	58	58	56.6
Third	46	44	42	43	45	46	46	44.6
Total	141	140	141	140	142	145	144	47.3
Actual Goal Program Allocation								
First	36	54	40	46	42	47	41	43.7
Second	46	73	56	62	59	67	65	61.1
Third	42	28	28	31	29	34	45	33.9
Total	124	155	124	139	130	148	151	46.2
Smoothed Goal Program Allocation								
First	41	47	47	47	46	46	41	45.0
Second	58	61	63	63	63	65	62	62.1
Third	39	31	30	31	31	34	42	34.0
Total	138	139	140	141	140	145	145	47.0

as compared to the actual goal program allocation was necessary to accommodate the need for feasible schedules.

The results displayed in Table 21, therefore, show the total amount of resources allocated in each schedule are of a comparable level. This being the case, any differences that are present between the three allocation schemes must be due to the specific allocation of resources across watches, days, and precincts.

6.1.1 Analysis Across Days

A visual analysis of Table 21 shows the goal program allocation reducing the number of vehicles assigned to Sunday, Tuesday, and Thursday and, in turn, increasing the number of vehicles assigned to Monday, Friday, and Saturday, as compared to the actual Columbus allocation. This is an expected result when one looks at Table 22, Total Hourly Workload Per Watch Per Day Per Precinct. The values in Table 22 represent the total number of workload hours which occurred in each of the eight hour watches for each day and precinct in quarter three, 1975 in Columbus, Ohio. Monday, Friday, and Saturday exhibit consistantly higher workload levels and, therefore, should command a greater share of the resources.

Table 22 shows that for Wednesday the total hourly workload was greater than the overall average across all days in Precincts 1, 5, 8, 12, and 13. Lower totals were displayed in Precincts 4, 6, and 11. The total hourly workload for an average Wednesday was 31.63 hours. This compares to an overall average level for all days of 31.17 hours. Therefore, in terms of workload levels, Wednesday seems to be a relatively average day. The goal program allocations have recognized this and have allocated patrol vehicles accordingly. The average total number of vehicles allocated to any day for the actual Columbus, actual goal program, and smoothed goal program allocations were 141.9 vehicles, 138.7 vehicles and 141.1 vehicles, respectively. As shown in Table 21, the Wednesday allocations for both goal program allocations compare favorably to these averages.

These obvious differences in the total daily vehicle allocations become rather minimal when the goal program results are smoothed in order to provide feasible working schedules for the patrolmen. For the most part, the differences between the total daily vehicle allocations of the actual Columbus allocation and the smoothed goal program allocation are only one or two vehicles with the largest discrepancy being three vehicles on Sundays. When one considers the fact that these totals represent the sums of eight precincts, the one or two vehicle difference is a minor one.

6.1.2 Analysis Across Watches

When the allocations in Table 60, Table 61, and Table 62 are compared on a per watch basis, the differences prove to be significant. Table 21 indicates that substantially fewer vehicles were allocated to the third watch while more vehicles were allocated to the first watch and the second watch in both the actual goal program and its smoothed counterpart, as compared to the actual Columbus allocation. To test for the significance of these differences a Wilcoxon Matched-Pairs Signed-Ranks Test was performed.

The Wilcoxon Matched-Pairs Signed-Ranks Test is a nonparametric statistical test for location. A nonparametric test was chosen due to

TABLE 22

TOTAL HOURLY WORKLOAD

PER WATCH PER DAY PER PRECINCT

Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	All Days
				Precinct 1				
1	8.62	16.69	12.91	15.57	13.98	15.34	10.78	13.32
2	9.03	16.86	15.31	16.68	17.37	18.99	15.05	15.60
3	10.94	7.36	7.48	8.73	8.44	9.62	12.54	9.33
Total	28.94	40.91	35.70	40.98	39.39	43.95	38.37	38.24
				Precinct 4				
1	8.78	12.34	9.72	11.31	10.63	12.50	10.66	10.83
2	12.14	18.59	15.54	15.98	16.18	17.64	16.16	16.00
3	11.77	7.25	7.40	7.70	7.98	9.32	14.94	9.50
Total	32.70	38.18	32.66	[illegible]	34.79	39.47	41.76	36.34
				Precinct 5				
1	9.69	13.81	9.64	11.90	10.25	10.57	11.92	11.08
2	13.74	17.43	14.95	17.50	16.77	17.71	18.70	16.68
3	11.35	6.66	6.86	7.35	6.94	7.29	11.44	8.29
Total	34.77	37.91	31.46	36.75	33.97	35.8	42.06	36.05
				Precinct 6				
1	7.68	10.29	7.50	8.10	7.63	8.59	7.65	8.18
2	10.79	12.89	11.43	11.66	10.98	13.80	12.83	12.05
3	9.62	5.74	5.49	5.82	5.75	7.37	8.28	6.88
Total	28.10	28.91	24.42	25.58	24.36	29.75	28.77	27.11

TABLE 22 (continued)

Precinct 8

1	6.58	11.30	8.41	9.45	8.34	10.17	6.74	8.68
2	8.17	12.92	10.14	11.35	10.45	12.41	10.64	10.84
3	6.46	5.20	5.26	6.80	5.60	6.55	8.42	6.34
Total	21.21	29.42	23.81	27.60	24.38	29.13	25.80	25.87

Precinct 11

1	6.39	13.63	9.54	9.67	10.11	10.94	8.97	9.85
2	9.04	15.04	13.56	12.79	14.53	15.82	13.05	13.39
3	9.86	6.72	6.31	7.92	6.08	7.10	10.57	7.81
Total	25.29	35.38	29.41	30.39	30.72	33.86	32.59	31.04

Precinct 12

1	9.01	11.36	9.36	12.24	9.07	10.82	9.06	10.12
2	12.47	14.60	14.17	13.54	12.85	16.92	15.78	14.33
3	10.29	6.63	6.60	8.00	5.81	6.82	10.96	7.88
Total	31.77	32.59	30.12	33.78	27.73	34.56	35.79	32.33

Precinct 13

1	5.48	8.94	5.86	7.37	6.81	7.79	6.80	6.99
2	8.02	11.81	9.91	10.51	9.27	10.65	10.77	10.11
3	5.87	4.07	3.68	5.13	4.76	6.97	6.31	5.27
Total	19.37	24.82	19.45	23.01	20.85	25.42	23.88	22.37

the less stringent population assumptions required for a valid application of the test as compared to its parametric counterpart the "Student's t test." Specifically, there is no reason to believe that the vehicle allocations follow a normal distribution.

The specific Wilcoxon test employed was found in the SPSS Batch Release 7, Update Manual of March 1977 and was performed at the University of Georgia Computer Center. It tests the differences in central tendency between paired observations. Both the sign and the magnitude of the differences are taken into consideration. The differences are first ranked ignoring their signs and, theoretically, if the two distributions are the same, the sum of the ranks for the positive and for the negative differences should be approximately the same. The null hypothesis states there is no difference in the distributions of the variables while the alternative two-tailed hypothesis states that the two variables differ.

The textbook procedure of the performance of this statistical test is to directly compare the actual levels of the paired observations to each other and then rank the absolute differences that result. Although the Wilcoxon Matched-Pairs Signed-Ranks Test considers the magnitude of these differences as well as the sign, the relative importance of these magnitudes is not considered. For example, for a particular watch, day, and precinct if the actual Columbus allocation assigned four vehicles and the actual goal program allocation assigned three vehicles, the difference would be one vehicle. If for another particular watch, day, and precinct the allocations assigned nine and eight vehicles, respectively, the difference would still be only one vehicle. Therefore, the textbook procedure would assign the same rank to each of these differences; however, the relative importance in each case is not the same. A difference of one vehicle when only three vehicles are allocated is relatively more important than the same difference of one vehicle when eight vehicles are allocated. For this reason it was necessary to somehow weight the differences with respect to their relative importance.

The weighting of the differences was accomplished through the use of ratios. A series of ratios was calculated by dividing the actual Columbus vehicle allocation into each goal program allocation for each watch. Each observation then is weighted by the value of the denominator. In the example above the differences in three and four, and eight and nine vehicles would be assigned the same rank under the textbook procedure. Using the ratio method, two ratios are developed, 3/4 and 8/9. If each of the ratios are paired with a value of one the absolute differences become 1/4 and 1/9. Since the differences no longer are equal and the ranks are assigned from the lowest absolute value to the highest, the difference of 1/9 would have a lower ranking than that of 1/4. Therefore, the use of ratios being matched-paired with a value of one to derive the differences to be ranked, allows the relative importance of the magnitude of the differences to be considered.

In applying the Wilcoxon Matched-Pairs Signed-Ranks Tests just described to this research, two sets of tests were performed to judge the significance of the difference between the three vehicle allocations of Table 60, Table 61, and Table 62 on a per watch basis. In the first set of tests, a series of ratios was calculated by dividing the actual

Columbus vehicle allocation into the actual goal program vehicle allocation for each watch. With each of the eight precincts encompassing seven days a week, fifty-six ratios were calculated for each watch. In other words, Table 61 was, item-for-item, divided by Table 60. Each of the fifty-six ratios for each watch were matched with the value one. This meant that for the first set of tests, three tests were performed which compared the ratios for each watch with the value of one. The null hypothesis is that the ratio equals the value one while the two-tailed alternative declares that the ratio is not equal to the value one.

By structuring the test in this manner, the SPSS program calculates the differences such that a negative rank indicates a ratio value greater than the value one. This, in turn, means that the allocation derived from the actual goal program output from that particular observation is larger than the actual Columbus allocation. If the overall results of the test for a particular watch indicate that the null hypothesis should not be accepted then the ratio does not equal one and the allocations are presumed to differ. The direction of the differences is indicated by the number and mean of the negative versus the positive ranks. If, however, the null hypothesis can not be rejected then there is presumed to be no difference in the two allocations.

The second set of Wilcoxon tests compared the smoothed goal program allocation to the actual Columbus allocation. As with the first set of tests, a ratio is formed by dividing the actual Columbus allocation into the smoothed goal program allocation across each day of every precinct on a per watch basis. This results in three sets of ratios with fifty-six values in each set. The values again are paired with the value one and the tests performed under the same set of hypothesis and conditions. Table 23, Wilcoxon Matched-Pairs Signed-Ranks Tests: Comparison of Patrol Vehicle Allocations, displays the results of the six tests which were performed. The Ties column represents the number of times the ratio, developed for the comparison, exactly equaled the value of one. The Negative Ranks and Positive Ranks columns indicate the number of times negative and positive differences were derived, respectively, from the matched-pairs comparisons of the ratios to the value of one. The negative rank mean was calculated by summing all the rankings exhibiting a negative sign and dividing by the total number of negative ranks present to arrive at a mean value. Larger mean values indicate larger differences in the comparisons of the ratios to the value of one. The positive rank mean was calculated in the same manner using the positive values. The two-tailed probabilities represent the probability of obtaining the specific results indicated for each test in terms of the number and mean of the negative versus the positive ranks, given the null hypothesis is correct. These probabilities are derived through the use of the standard normal curve, the asymptotic approximation of the sampling distribution of a Wilcoxon signed rank statistic for a large number of observations.

Therefore, Table 23 indicates that there is a small probability that the values, exhibited for the number and mean of the negative and positive ranks, would occur given the ratios actually equal one. This means that both the actual and smoothed goal program allocations exhibit a significant difference from the actual Columbus allocation on

TABLE 23

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST:

COMPARISON OF PATROL VEHICLE ALLOCATIONS

	WATCH	CASES	TIES	NEGATIVE RANKS	NEGATIVE RANK MEAN	POSITIVE RANKS	POSITIVE RANK MEAN	Z	TWO-TAILED PROBABILITY
ACTUAL GOAL PROGRAM ALLOCATION / ACTUAL COLUMBUS ALLOCATION	FIRST	56	11	23	27.96	22	17.82	-1.417	0.157
	SECOND	56	9	23	32.17	24	16.17	-1.862	0.063
	THIRD	56	9	6	22.83	41	24.17	-4.519	0.000
SMOOTHED GOAL PROGRAM ALLOCATION / ACTUAL COLUMBUS ALLOCATION	FIRST	56	17	21	27.29	18	11.50	-2.554	0.011
	SECOND	56	8	25	33.20	23	15.04	-2.482	0.013
	THIRD	56	9	4	31.25	43	23.33	-4.646	0.000

a per watch basis. The first watch test for the actual goal program versus the actual Columbus ratio does indicate a 15.7% probability of occurrance which may be considered to indicate an insignificant difference.

Specifically, for each set of tests, the first watch displays a larger number of negative ranks and a much larger mean for the negative ranks. This means that not only are there a larger number of instances where the goal program allocations have allocated more vehicles but the differences in the number of vehicles allocated also tends to be greater. The first watch results must be viewed cautiously due to the larger number of ties. The ties reflect the number of observations that exactly equaled a value of one and, therefore, indicate instances where the allocations were identical.

The second watch results indicate that the number of negative versus positive ranks are about the same. Comparing the actual goal program allocation to the actual Columbus allocation shows the number of positive ranks actually exceeds the negative ranks. The mean of each set of ranks, however, overwhelmingly favor the negative ranks; this indicates that differences in the allocations are greater when the goal program allocations are larger.

The most definitive results are found in the comparisons of the third watch for each set of ratios. In both cases the number of positive ranks far surpass the number of negative ranks. This indicates that there are decidedly fewer vehicles allocated in the goal program allocations to the third watch than in the actual Columbus allocation. The negative rank means seem to be high in light of the small number of ranks present. Therefore, when the goal program does allocate more vehicles to the third watch than the actual Columbus allocation, the differences tend to be large. Table 23 tends to suggest that both goal program allocations assign a larger number of vehicles to the first and second watch and fewer vehicles to the third watch as compared to the actual Columbus allocation.

These results are consistent with the information presented in Table 22. The call-for-service workloads displayed here show that the first and particularly the second watch exhibit consistently higher values in every precinct. The only exceptions are the third watch on Saturday and Sunday for each precinct. In these instances the recorded call-for-service workload of the third watch is at least comparable and in most cases slightly higher than that recorded for the first watch. However, the call-for-service workloads averaged over all days for each watch support the results of the goal program model in indicating, across the board, higher workloads in the first and second watches as compared to the third watch for each precinct.

6.1.3 Analysis Across Precincts

Finally, when analyzing the vehicle allocation results, one must investigate the possible allocation differences occurring between precincts. Data concerning the actual number of patrol vehicles allocated across each watch for each day and every precinct are summarized in Appendix F, Table 63 through Table 86. The values are also recorded for each of the three allocation schemes of Table 60, Table 61, and Table 62. A review of this data reveals that each of the goal program allocations reallocated vehicles from precincts 1, 4, 6, 11, and 12 to

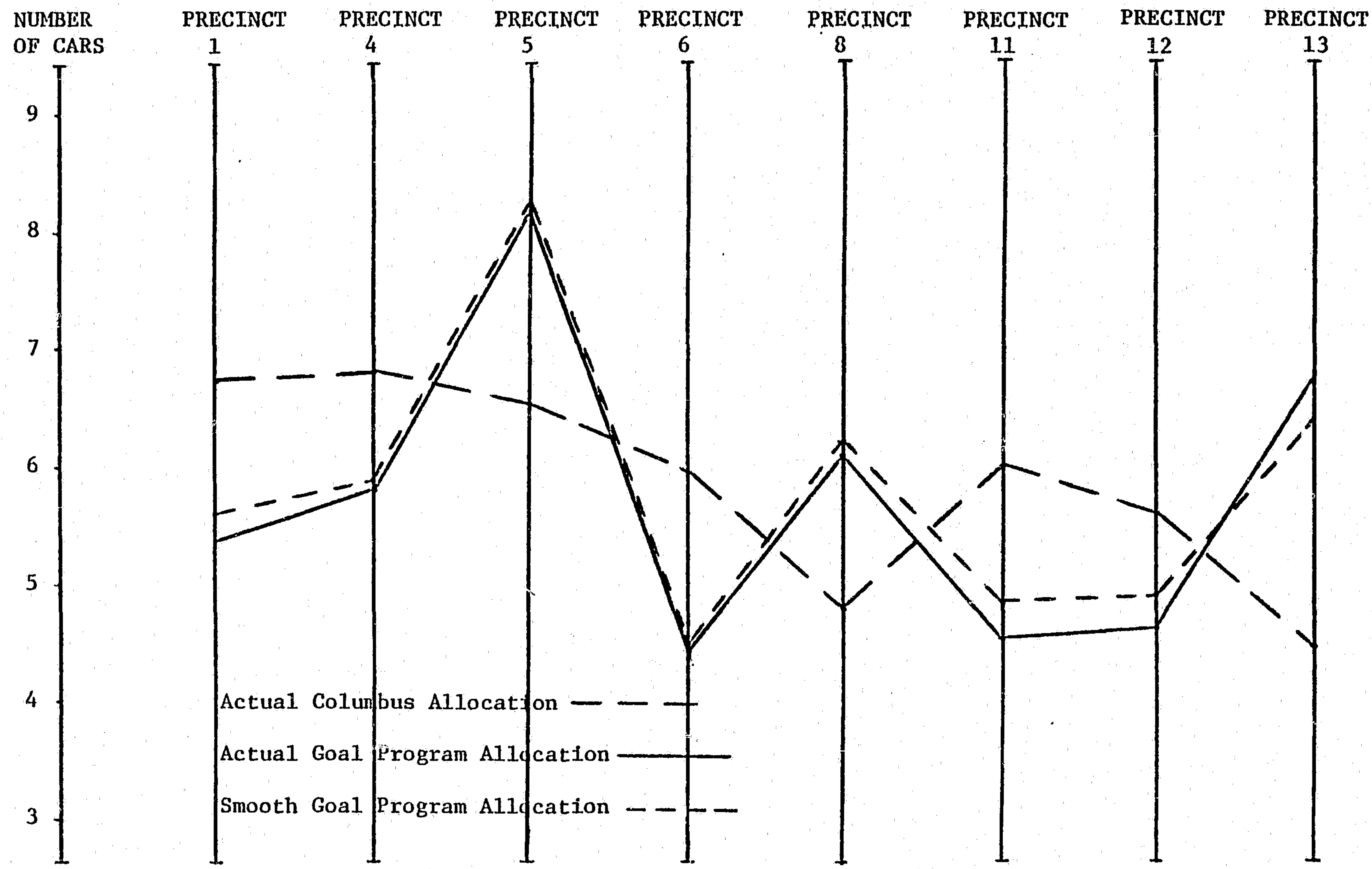

FIGURE 12 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: AVERAGE NUMBER OF CARS ALLOCATED.

precincts 5, 8, and 13. This reallocation is particularly noticeable when examining the value paths created by each allocation across each precinct. The value path analysis is presented in Figure 12.

In examining Figure 12, it is observed that the actual Columbus allocation usually stayed in the range from five to seven vehicles. The only two deviations occur in Precinct 8 and Precinct 13 when the average number of vehicles allocated fell to 4.8 and 4.6 vehicles, respectively. Both goal program allocations, on the other hand, are a stark contrast to the relatively level Columbus allocation. The goal program allocations exhibit a wider range in the number of vehicles assigned from a high of 8.3 vehicles in Precinct 5 to a low of 4.5 vehicles in Precinct 6. The average number of vehicles allocated for both goal program allocations range, predominately, between 4.5 and 6 vehicles, which is lower than the actual Columbus allocation range. However, Precinct 5, Precinct 8, and Precinct 13 show considerably higher average allocations than those displayed by the Columbus allocation, especially Precinct 5 with 8.3 vehicles being allocated, on the average.

The reallocation of resources among precincts, that is highlighted in Figure 12, can be explained by investigating the interaction between three contributing factors. The first and, perhaps, most important factor is the decision made by the Planning and Research Department concerning the relative importance of each performance measure. Three measures selected as having key goal levels to attain were travel time, utilization, and the average patrol frequency with the travel time being identified as the one most important measure to attain. This decision was the basis for the weighting of the objective function in the final goal program runs, as indicated in Table 56 and Table 57. The second interacting factor is the square miles each precinct encompasses and the final factor relates to the average daily workload exhibited in each precinct. These factors are displayed in Table 24.

To explain the reallocation of patrol vehicles that occurs between precincts when the goal program model is employed, the interactions which exist between the three stated factors must be understood. The average travel time, singled out as the most important goal to satisfy, is directly influenced by the square miles of area each precinct encompasses. As the area of the precinct increases the potential distance a patrol vehicle must travel to respond to a call-for-service also increases, thereby increasing the travel time. Since the goal program attempts to satisfy this number one goal to the best of its ability, it must allocate a larger number of resources to those precincts that extend over a larger area. In a similar fashion, in order to satisfy the average patrol frequency goal which also exhibits a high degree of importance, a greater number of vehicles must be allocated to those precincts having a greater area to patrol. In looking at Figure 12, the three precincts where the largest number of vehicles were reallocated are Precincts 5, 8, and 13. These are the three precincts which also encompass a substantially larger area, as evidenced in Table 24.

The utilization ratio performance measure comes into play by acting as a counterbalancing measure of performance. The specified goal was to maintain a utilization ratio of forty-five percent for each precinct. Once a utilization rate of this level is reached, if patrol

TABLE 24

AREA AND AVERAGE DAILY WORKLOAD DATA FOR EACH PRECINCT

Precinct	Area In Square Miles	Average Hours Of Workload Daily
1	4.96	38.24
4	8.95	36.34
5	14.52	36.05
6	5.92	27.11
8	10.30	25.87
11	3.48	31.04
12	3.36	32.33
13	16.95	22.37

vehicles are continued to be added the utilization rate will fall below forty-five percent. Because the utilization ratio was also identified by the Planning and Research Department as having a high degree of importance as a stated goal, it acts to limit the number of patrol vehicles allocated to a particular precinct, once a utilization ratio of forty-five percent has been attained. Therefore, for Precinct 8 and Precinct 13, their large area caused a greater number of patrol vehicles to be allocated to them, but, the allocations were limited by the low average daily workload which, affecting the numerator of the utilization ratio, enabled the utilization ratio goal of forty-five percent to be satisfied with fewer vehicles. Precinct 5, on the other hand, not only exhibited a large area but also a high daily average workload and, therefore, was allocated the largest number of patrol vehicles.

The same logic used to explain the increased vehicle allocations in Precincts 5, 8, and 13 can be employed to explain the lower vehicle allocations to Precincts 6, 11, and 12. Precincts 11 and 12 have a small area relative to the other precincts thus requiring a lower number of vehicles to attempt to satisfy travel time and average patrol frequency goals. Precinct 6, although encompassing a larger area than either Precinct 11 or Precinct 12, exhibits a smaller daily average workload and thus, the utilization ratio goal limits the number of vehicles allocated.

6.2 Performance Measure Results

The previous section analyzed the differences that prevailed between the actual Columbus allocation of patrol vehicles being utilized in

Quarter Three, 1975 and the allocations derived as a result of this research. This analysis was directed toward the differences in the actual number of vehicles assigned. The analysis presented in this section concerns the differences exhibited by the measures of performance which arise from the various vehicle allocations. In proceeding through this analysis, two sets of tables along with a corresponding value path analysis of each set are analyzed.

6.2.1 Percentage Attainment Levels

The analysis begins with the investigation of the percentage attainment results presented in Table 58, Table 59, and Figure 30 of Appendix E. These results are derived from and directly correspond to the actual vehicle hours allocated by the final goal program runs on a per watch per day per precinct basis. These vehicle hour allocations for each of the two final goal program runs are displayed in Appendix E, Table 56 and Table 57.

In reviewing Tables 58 and 59 and Figure 30, two important findings are readily apparent. First, two measures of performance, identified by the Columbus Division of Police as being important goal measures to attain, do not reach their specified goal level. These measures of performance are the utilization ratio with a goal of forty-five percent and the average patrol frequency which had a goal specified of once per hour. The only exception occurs in Precinct 13 where the average patrol frequency measure exhibits a percentage attainment value of over one-hundred percent. This exception is explained shortly.

Secondly, the results displayed in Tables 58 and 59 and in Figure 30 substantiate the presence of a direct trade-off relationship between the utilization ratio level and the levels of the other measures of performance. This relationship was first theorized in Chapter I, Section 1.2 when the utilization ratio was proposed as the major decision variable for the police patrol function and was later used to model the goal constraints in the goal program model.

Specifically, a review of Table 58 and Table 59 indicates that when the utilization ratio measure is weighted at the .8 level as in Table 59, the percentage attainment for the utilization ratio exhibits a higher level, which signifies utilization ratios closer to the forty-five percent goal. However, Table 58 displays equal or higher percentage attainment values for every other measure of performance. Even the total average delay, which is expressed in minutes rather than percentage attainment values, exhibits equal or better levels in Table 58. As shown below Table 58, the utilization ratio measure was assigned a weight of .6 for the results displayed therein. Therefore, as the weight of the utilization ratio measure is increased, the level tends to approach the goal of forty-five percent. However, this is accomplished at the expense of a deterioration in the levels of all other performance measures.

On a precinct-by-precinct basis, the results of Table 58 and Table 59 reflect the analysis of the actual vehicle allocations discussed in the previous section. Those precincts having a large area were allocated a greater number of vehicles to satisfy the average travel time goal. These are the precincts that tend to exhibit low utilization ratio levels and low percentage attainment values for the average travel time measure. However, because of the greater number of vehicles assigned to these precincts, Precincts 5, 8, and 13, the percentage attainment levels exhibited for the other measures of performance were higher than in the other five precincts. This tendency is best exemplified by Precinct 13. Because Precinct 13 is the largest precinct, with an area of 16.95 square miles, a greater number of vehicles was allocated to it in an attempt to satisfy the average travel time goal. This increased allocation of vehicles coupled with the lowest average daily workload level exhibited by any precinct caused the utilization ratio to become very low and the other measures of performance to reach very high attainment levels.

6.2.2 Actual Value of Performance Measures

The analysis presented in this section concentrates on the actual values each of the measures of performance exhibits with respect to the actual Columbus vehicle allocation, the actual goal program vehicle allocation, and the smoothed goal program vehicle allocation. The data that is analyzed is displayed in Appendix F. As explained at the beginning of the appendix, it is comprised of twenty-four tables which represent the expected levels of performance for each measure in every precinct for each of the three vehicle allocation schemes. These expected levels of performance are a result of each allocation scheme's performance being simulated within the context of the Patrol Car Allocation Model, which was described in Chapter IV.

Due to the large amount of output generated by the PCAM simulation, it is helpful to begin analyzing the results of Table 63 through Table 86 by means of a value path analysis. A value path for each of the three allocation schemes being compared was developed for each measure of performance and extends across all eight precincts involved in this research. The levels exhibited by the individual paths represent total average values which were obtained by calculating the overall average that occured across the seven days of the week in each precinct. The value paths, seven sets in all representing the seven measures of performance utilized in this research, are presented in Figure 13 through Figure 19.

An initial investigation of Figure 13 through Figure 19 quickly establishes the presence of two prevailing characteristics found throughout each of the seven value path sets. The first characteristic, not surprisingly, concerns the behavior of the performance levels with respect to Precincts 5, 8, and 13. As a group, the performance measure levels associated with these precincts react in an opposite and more extreme manner than those measures associated with the other five precincts. Results of this nature are surely to be expected given the analysis previously presented which has shown vehicles being reallocated from Precincts 1, 4, 6, 11, and 12 to Precincts 5, 8, and 13. A second distinguishable characteristic found to exist in the value paths of every measure of performance is the very close relationship the levels of the two goal program allocations exhibit. They are, for the most part, mirror images of each other. This characteristic gives some indication that the "rough allocations" coming directly from a goal program model can be molded into a "smoothed allocation", which allows for feasible working schedules for patrolmen, without having a substantial affect on the expected performance measure levels.

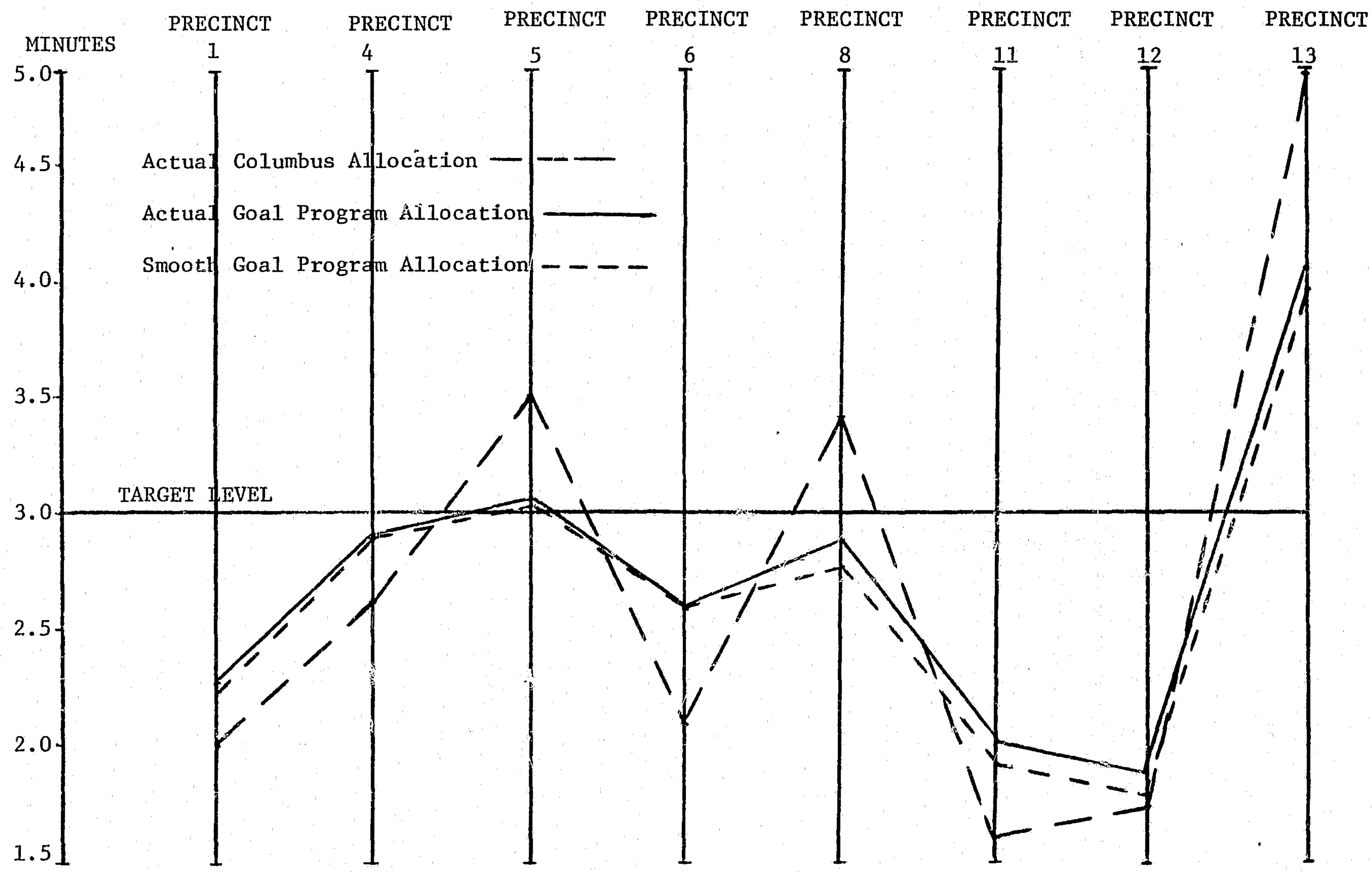

FIGURE 13 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: TRAVEL TIME

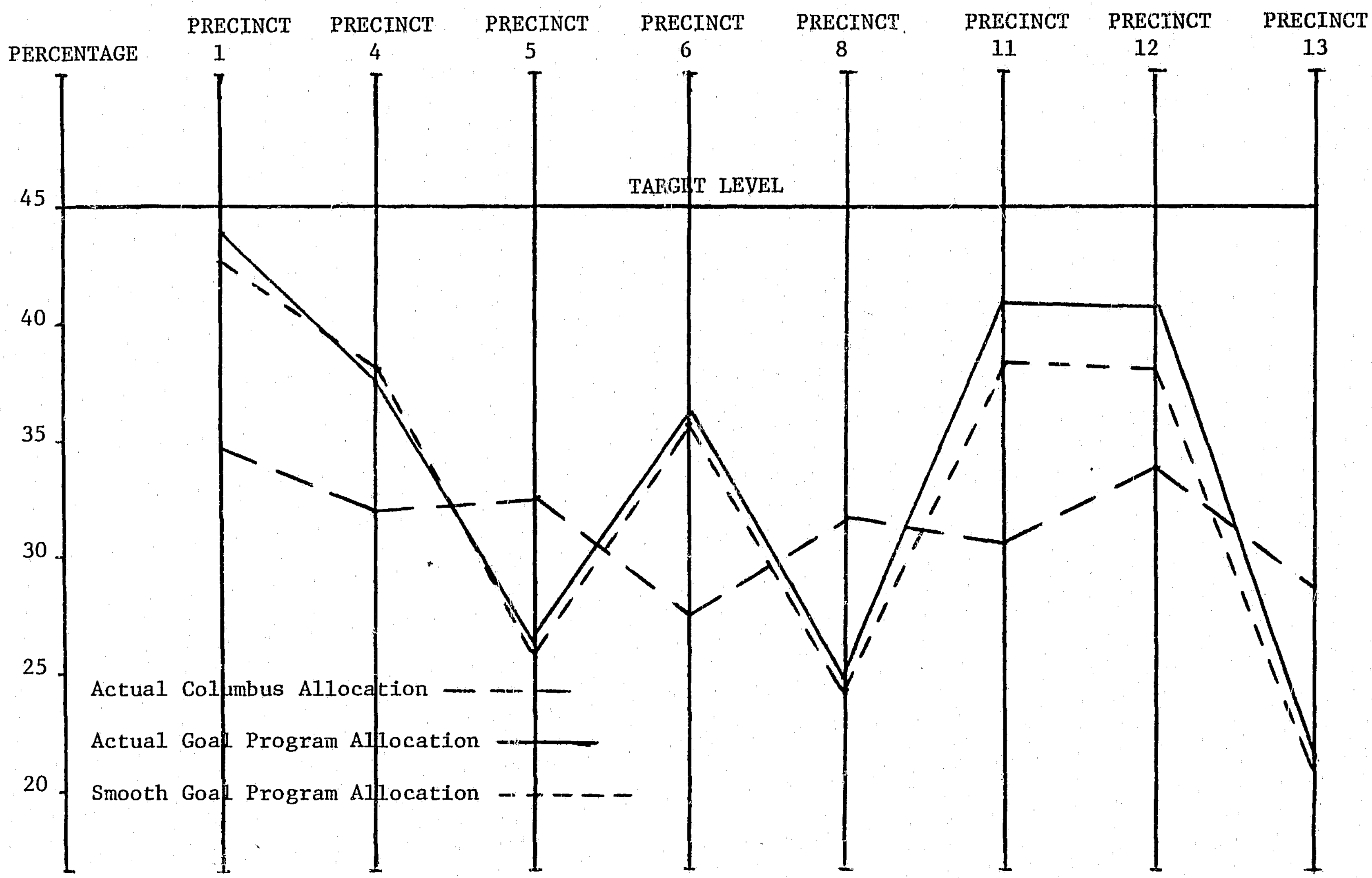

FIGURE 14 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: UTILIZATION RATIO

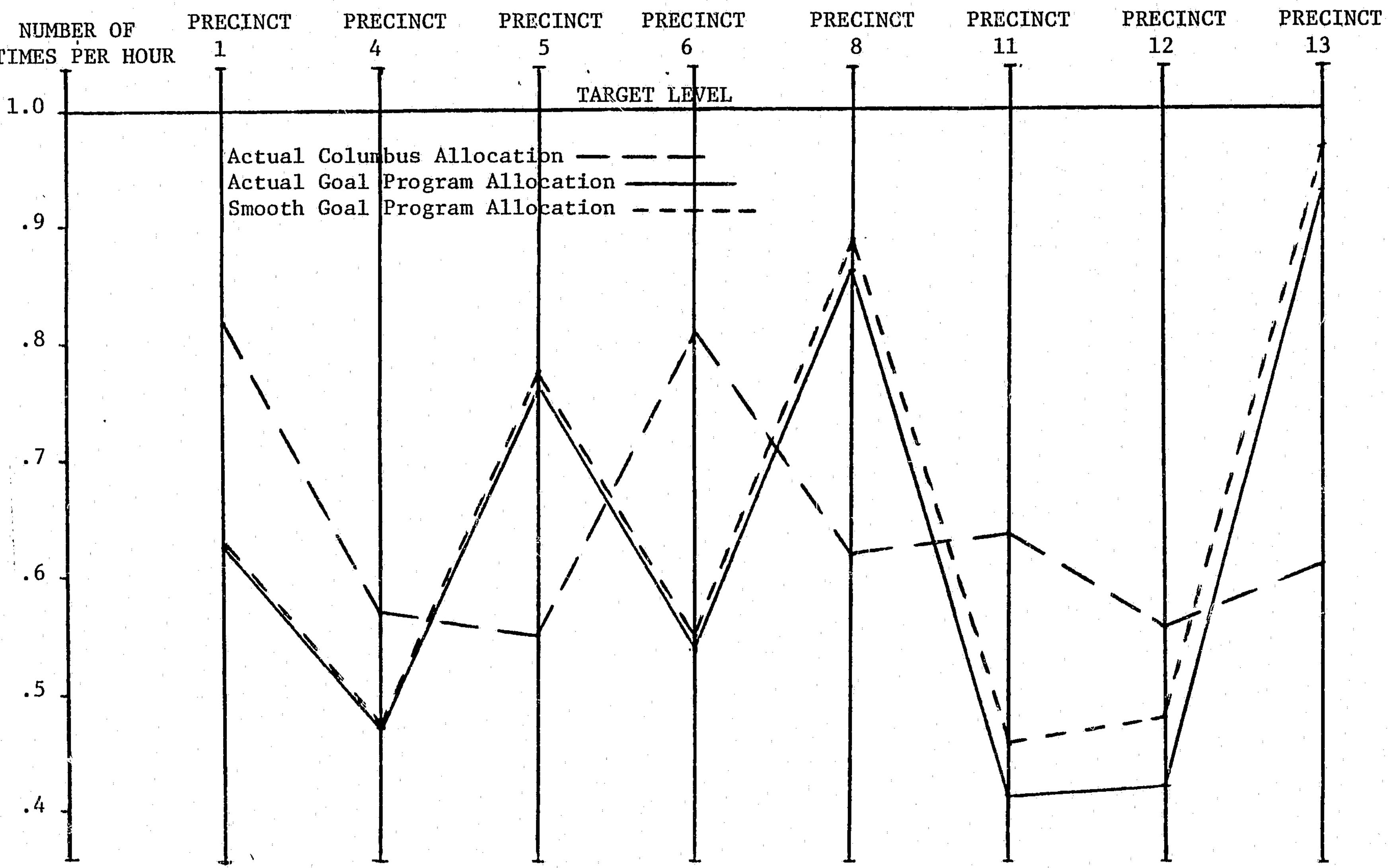

FIGURE 15 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: AVERAGE PATROL FREQUENCY

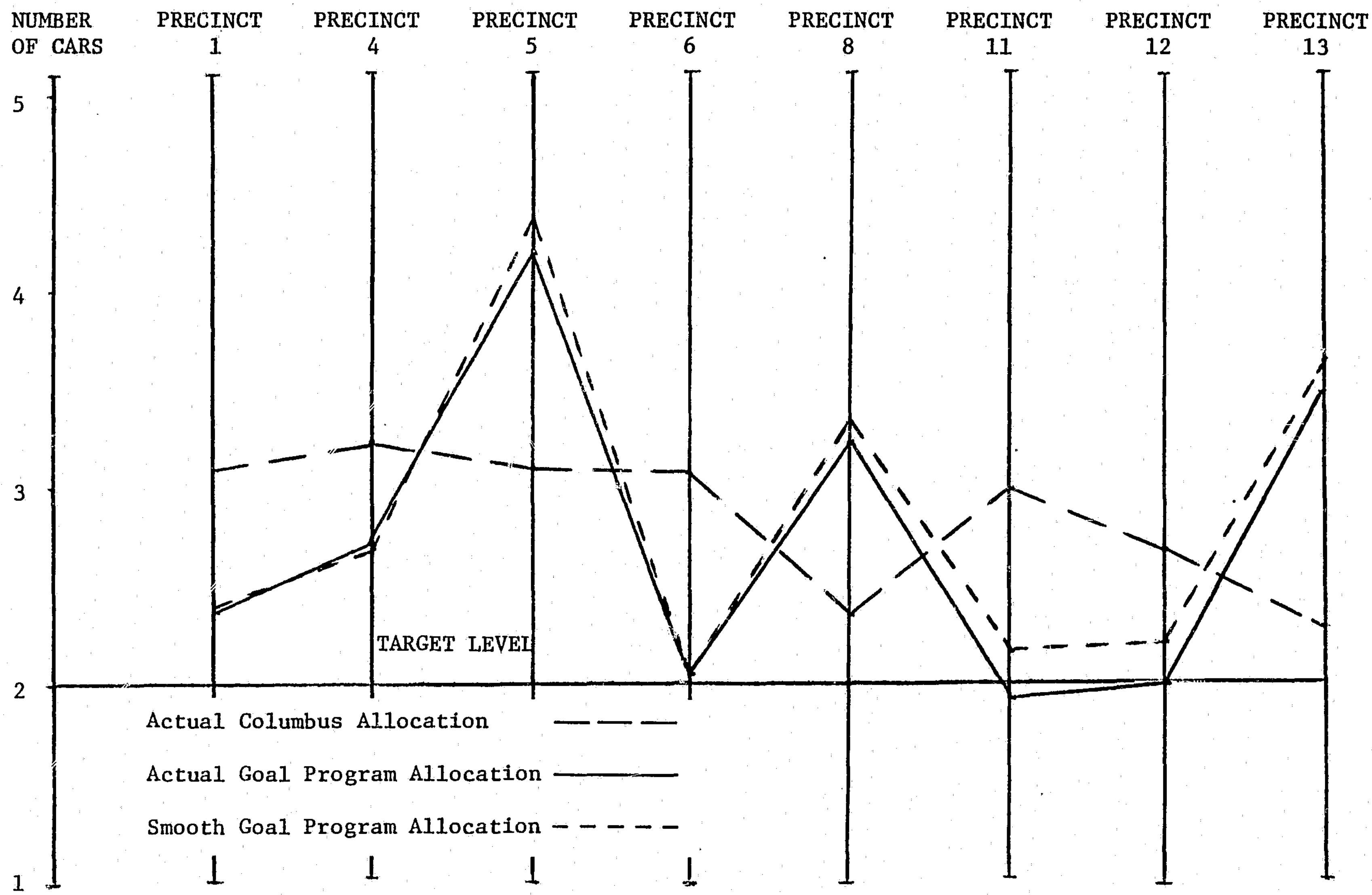

FIGURE 16 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: AVERAGE NUMBER OF CARS AVAILABLE

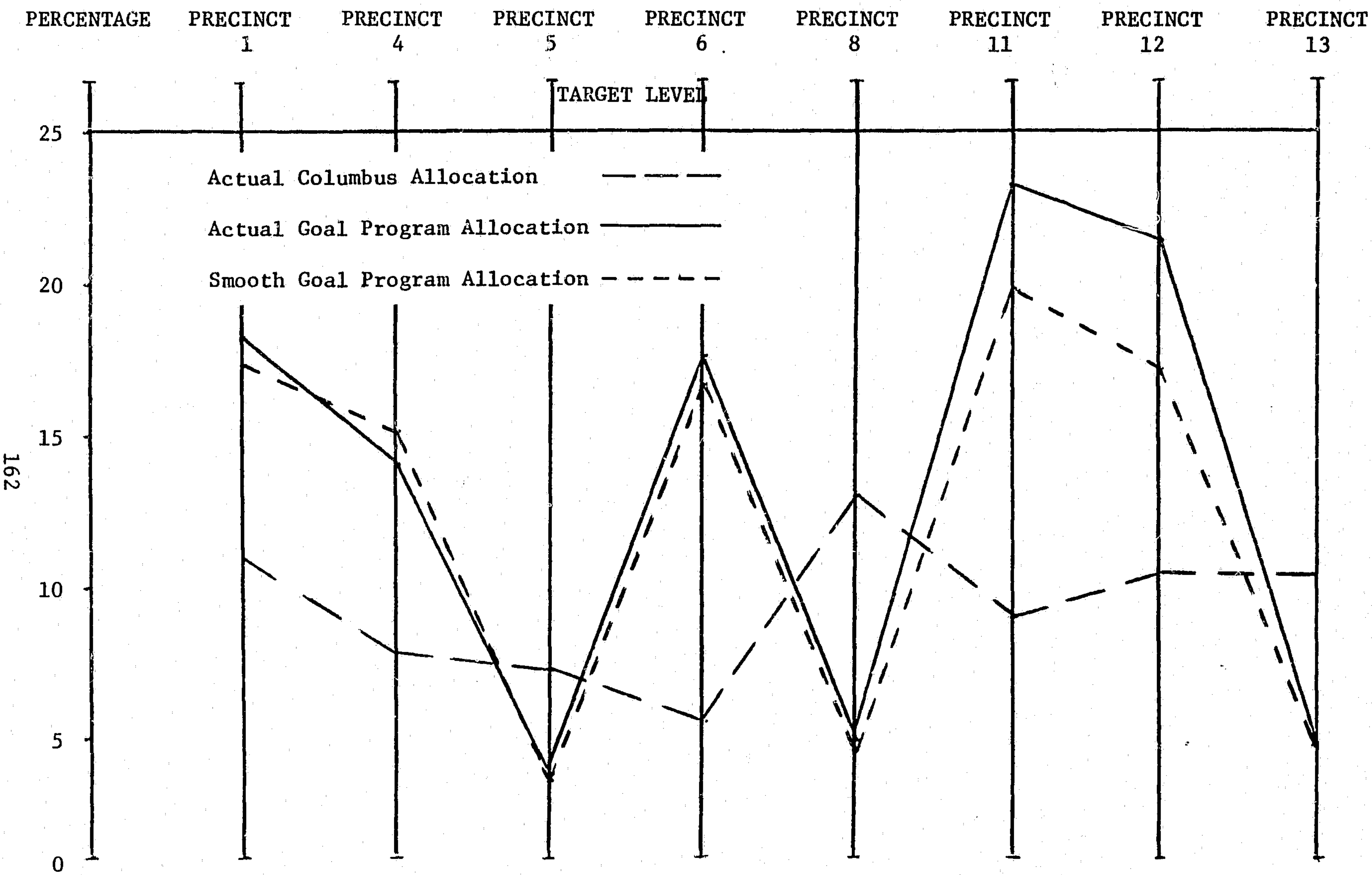

FIGURE 17 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: PROBABILITY CALL DELAYED

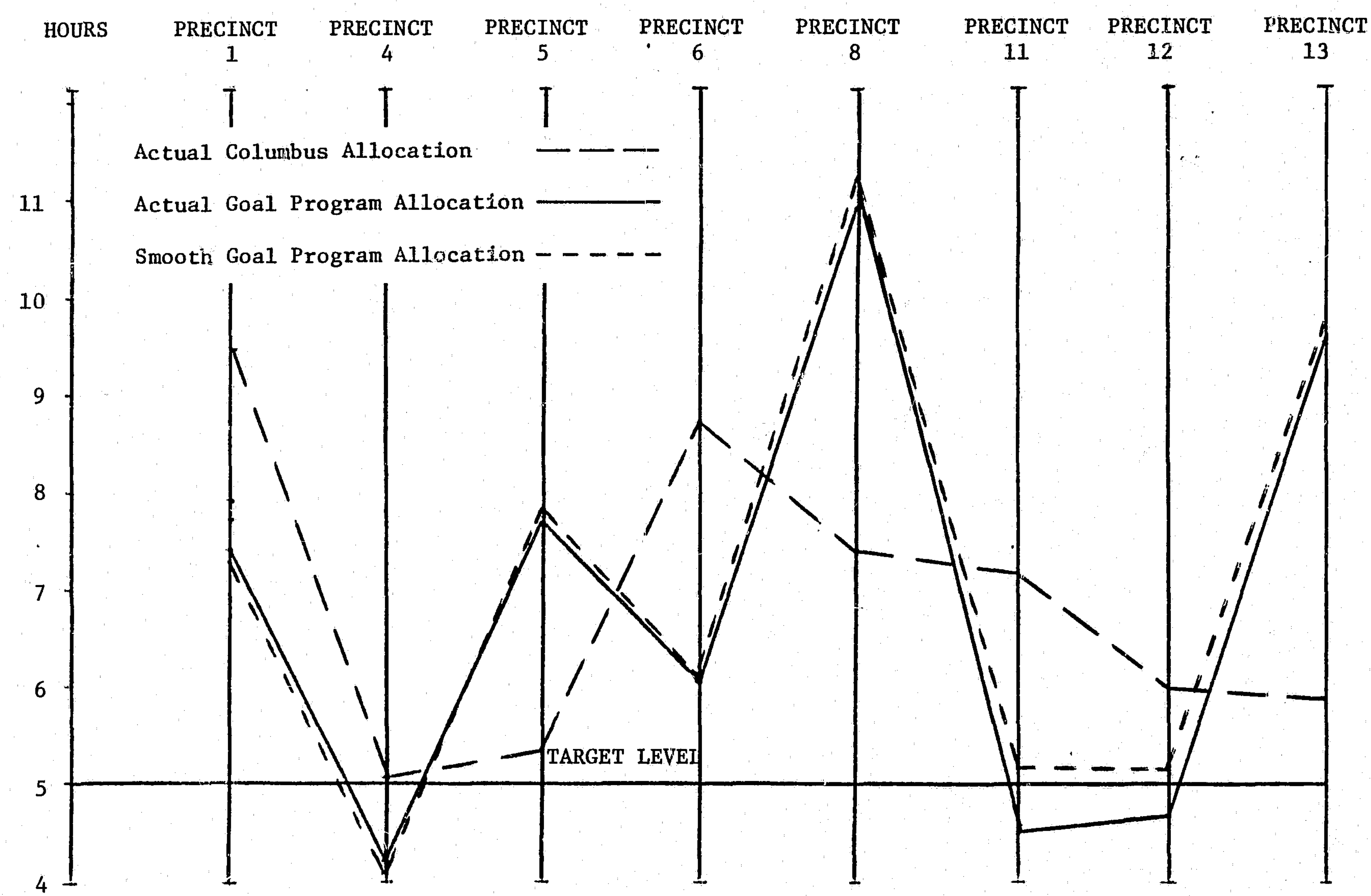

FIGURE 18 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: PATROL HOURS PER SUPPRESSIBLE CRIME

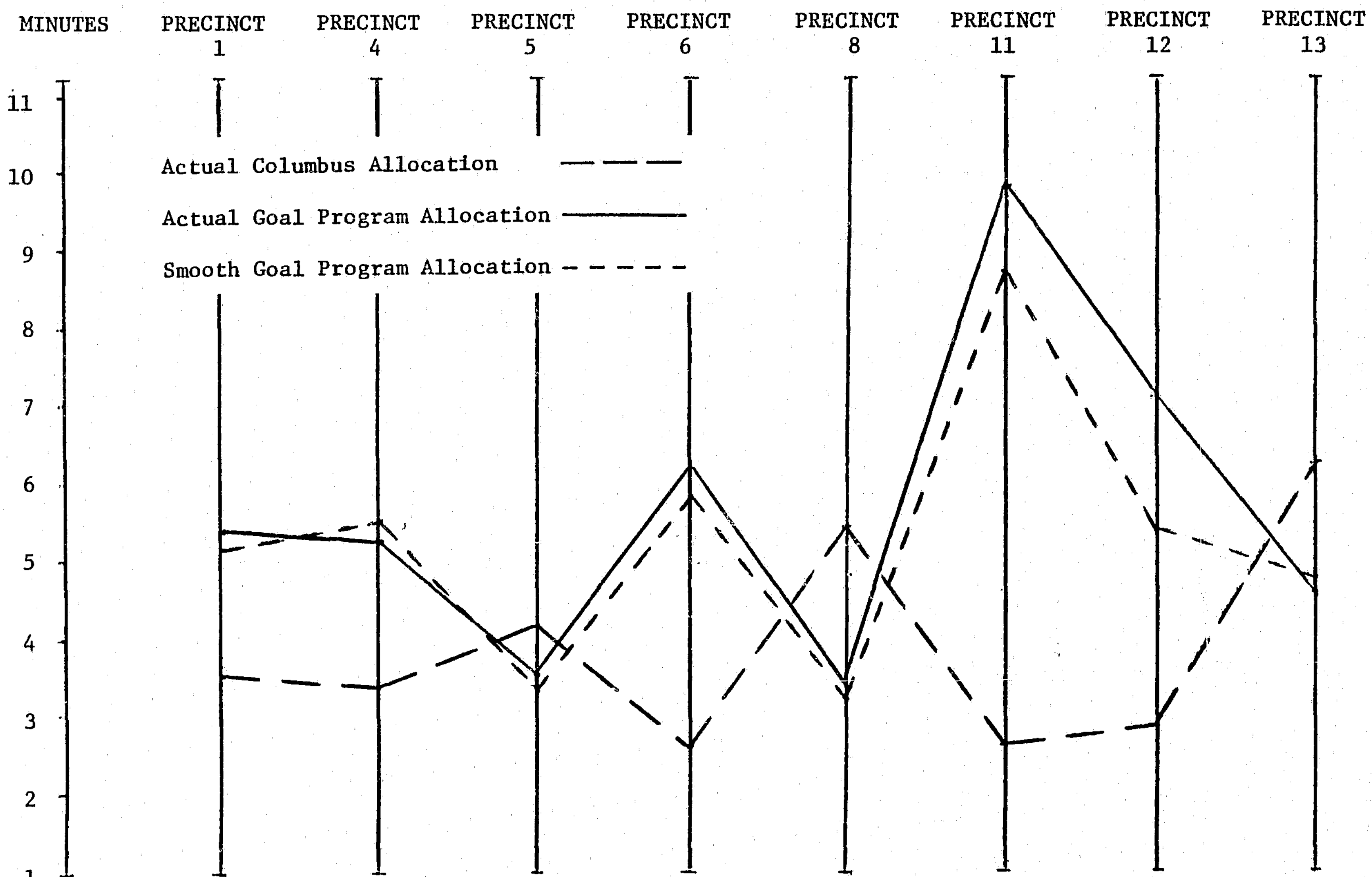

FIGURE 19 VALUE PATH ANALYSIS OF PERFORMANCE MEASURE ATTAINMENT FOR FINAL ALLOCATIONS: AVERAGE TOTAL DELAY

A more in-depth analysis indicates that for the average travel time measure of performance in Figure 13, the actual Columbus allocation resulted in more erratic levels of performance between precincts than did either of the goal program allocations. This was the only performance measure to exhibit this tendency. As a matter of fact, for every other measure of performance the levels of performance exhibited across precincts showed a smaller variance in the case of the actual Columbus allocation. Furthermore, the actual Columbus allocation exhibited better levels of performance in every measure except the utilization ratio for all precincts except Precincts 5, 8, and 13. The goal program allocations resulted in utilization ratios closer to the goal of forty-five percent in all precincts but Precincts 5, 8, and 13. These results reinforce earlier analysis which indicated a major tradeoff being present between the utilization ratio and all other measures of performance.

The fact that the actual Columbus allocation resulted in better levels of performance in five out of eight precincts for all but one performance measure is not surprising and should be further explained. The key to these results, again, lie in the average travel time measure having the highest weight. The value paths in Figure 13 indicate that travel time is a problem area in Precincts 5, 8, and 13 for the actual Columbus allocation; therefore, vehicles are reallocated to these precincts in an attempt to satisfy the established goal of three minutes. This goal level was satisfied for Precinct 8, virtually satisfied for Precinct 5, and for Precinct 13, although the goal of three minutes was not reached, the resulting travel time was greatly reduced by the use of the smoothed goal program allocation. This action caused vehicles to be removed from the other five precincts resulting in the measures of performance in those precincts to exhibit less desirable levels; however, the travel time goal in each of those precincts was still attained and the system as a whole, therefore, benefited from the reallocation.

A change in a particular measure of performance to a less desirable level is not necessarily bad. The utilization ratio value paths indicate low levels of utilization for the actual Columbus allocation. This may indicate an inefficient use of resources. The goal program allocations have increased the utilization of resources in five of eight precincts while at the same time enabled Precinct 5 and Precinct 8 to meet the travel time goal. The average patrol frequency measure of performance was never satisfied by any of the allocations, however, Precinct 8 and Precinct 13 display the best levels of performance and this is when the goal program allocation is used. Furthermore, the average number of cars available measure and the probability a call is delayed measure are both satisfied when employing the goal program allocations. The only exception is that the average number of cars available in Precinct 11 is just shy of the goal of two cars.

The goal program allocation does not fair as well when considering the patrol hours per suppressible crime measure. The goal of five hours was not met in Precinct 4 by either goal program allocation or in Precinct 11 and Precinct 12 by the actual goal program allocation only.

Likewise, the largest discrepancy in the total average delay levels occurs in Precincts 6, 11, and 12 for the goal program allocations.

Overall, the actual goal program allocation and the smoothed goal program allocation have compared very favorably to the actual Columbus allocation in terms of the total level of resources employed, the actual utilization of these resources, and the satisfaction of performance measures by these resources. The final stage of the analysis of the research results concerns an investigation into the levels of significance that are associated with the differences in the levels of performance exhibited by each vehicle allocation.

To test for any significant differences which may be present between the actual levels of performance exhibited by either of the goal program allocations as compared to the actual Columbus allocation, the Wilcoxon Matched-Pairs Signed-Ranks Test was once again employed. As previously used in the testing for significant differences in vehicle allocations between watches, the test for differences in performance measure levels was structured such that for each measure of performance, the ratio of the goal program value over the actual Columbus value was paired with a value of one. The ratios were calculated using both the actual goal program performance levels and the smoothed goal program performance levels. In each case, seven sets of fifty-six ratios were computed corresponding to the seven measures of performance extending across the seven days of the week for each of the eight precincts. Once again ratios were used in the calculation of the differences to be ranked in order to consider the relative importance of the differences in performance measure levels. For example, a thirty second difference in travel time is relatively more important at a two minute level than it is at a ten minute level. The use of ratios allows this relative importance to be considered in the Wilcoxon test.

The mechanics of the Wilcoxon Matched-Pairs Signed-Ranks Tests are identical to its previous usage as described in Section 6.1.2. This particular test for central tendency was, again, chosen because of its less restrictive distribution assumptions necessary for its performance. The same SPSS package, documented in SPSS Batch Release 7, Update Manual of March 1977 was used to actually perform the tests.

In testing each measure of performance, the ratio values were compared to their paired values of one. The absolute differences were then ranked from smallest to largest. The significance of the difference between the ratios and the value of one relies on both the number of negative versus positive ranks and each set of ranks' mean value. If these factors indicate a significant difference to exist between the computed ratios and a value of one, then the value of the ratio itself is different from one and thus, the two allocations comprising the ratio value are different. A larger number of negative ranks signals a ratio greater than the value one which indicates that the goal program performance level is larger than the corresponding actual Columbus allocation value. The larger the mean, the larger are the individual differences. By structuring the tests in this manner, the null hypothesis states that the computed ratio is equal to the value of one. The alternative hypothesis, which represents a two-tailed test, states that the ratio does not equal one.

Reviewing the results of the actual goal program performance levels as compared to the actual Columbus performance levels first, Table 25 reveals that four of the seven measures of performance exhibit results which have a very low probability of occurring when the computed ratio does equal the value of one. For these measures of performance, the average travel time, the utilization ratio, the probability of a call delay, and the average total delay, a significant difference does occur in the levels exhibited for each allocation. In each case, the number of negative ranks was greater and the mean larger. These results indicate that the performance levels for the actual goal program are significantly larger.

Taken by themselves, these results may seem detrimental to the goal program model for they indicate a higher travel time, probability of a call delayed, and average total delay all of which are contrary to the goal direction desired. The utilization ratio is the only measure of performance where a higher level, up to forty-five percent, is desirable. It must be remembered, however, that the travel time goal for the goal program allocation was achieved in all but one precinct and the probability of a call delayed was achieved for all precincts. Goal levels were not established for the average total delay. Therefore, these results do not downgrade the goal program model since the goal levels are either being attained or, in the case of the utilization ratio, significantly improved.

TABLE 25

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST:

PERFORMANCE MEASURE EVALUATION FOR RATIO OF

ACTUAL GOAL PROGRAM RESULTS TO ACTUAL COLUMBUS RESULTS

PERFORMANCE MEASURE	CASES	TIES	NEGATIVE RANKS	NEGATIVE RANK MEAN	POSITIVE RANKS	POSITIVE RANK MEAN	Z	TWO-TAILED PROBABILITY
AVERAGE TRAVEL TIME	56	1	33	31.18	22	23.23	-2.170	0.030
UTILIZATION RATIO	56	0	35	30.31	21	25.48	-2.145	0.032
AVERAGE PATROL FREQUENCY	56	0	22	34.09	34	24.88	-0.392	0.695
AVERAGE NUMBER CARS AVAILABLE	56	0	22	33.64	34	25.18	-0.473	0.636
PROBABILITY CALL DELAYED	56	0	33	36.82	23	16.57	-3.402	0.001
AVERAGE TOTAL DELAY	56	0	33	38.27	23	14.48	-3.793	0.000
PATROL HOURS PER SUPPRESSIBLE CRIME	56	0	22	38.32	34	22.15	-0.367	0.714

The remaining measures of performance, the average patrol frequency, the average number of cars available, and the patrol hours per suppressible crime exhibit a high probability of occurrance for the results shown, given the ratios actually equal the value one. Therefore, it cannot be stated that there is any significant difference in the levels of performance of these measures. The results do tend to indicate that when the goal program level of performance is greater, the difference tends to be large. These large differences can be attributed to the large allocation of vehicles made in Precincts 5, 8, and 13.

Moving to a comparison of the smoothed goal program performance levels to the actual Columbus levels of performance, Table 26 shows, that except for the probability of a call delayed and the average total delay measures which still indicate significant differences, the levels of significance displayed by the measures of performance have leveled out across each measure.

The differences in the levels of performance for the average travel time and the utilization ratio are not as significant with each result having a probability of occurrance, respectively, of twenty-six and seventeen percent under the null hypothesis. Although the number of negative ranks for each measure is still greater than the number of positive ranks, the mean of the negative ranks has become smaller than that of the positive ranks. This indicates that the magnitude of the differences has decreased when the goal program level of performance is larger.

The probability of a called delayed and the average total delay measures exhibit nearly the same results as the actual goal program

TABLE 26

WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST:

PERFORMANCE MEASURE EVALUATION FOR RATIO OF

SMOOTHED GOAL PROGRAM RESULTS TO ACTUAL COLUMBUS RESULTS

PERFORMANCE MEASURE	CASES	TIES	NEGATIVE RANKS	NEGATIVE RANK MEAN	POSITIVE RANKS	POSITIVE RANK MEAN	Z	TWO-TAILED PROBABILITY
AVERAGE TRAVEL TIME	56	0	34	27.53	22	30.00	-1.126	0.260
UTILIZATION RATIO	56	0	35	27.66	21	29.90	-1.387	0.166
AVERAGE PATROL FREQUENCY	56	1	22	39.86	33	20.09	-0.896	0.370
AVERAGE NUMBER CARS AVAILABLE	56	0	22	40.23	34	20.91	-0.710	0.478
PROBABILITY CALL DELAYED	56	0	36	34.06	20	18.50	-3.491	0.000
AVERAGE TOTAL DELAY	56	0	36	36.39	20	14.30	-4.176	0.000
PATROL HOURS PER SUPPRESSIBLE CRIME	56	0	21	43.81	35	19.31	-0.995	0.320

ratios. The number of negative ranks are greater, the means are larger, and the probability of the results occurring under the null hypothesis are virtually zero.

The probability of occurrence for the results associated with the average patrol frequency, the average number of cars available, and the patrol hours per suppressible crime have all been reduced from the actual goal program tests results. None of the probabilities indicate levels of significant difference, however, they are all below a fifty percent occurrence rate. The relationship between the number of negative versus positive ranks is virtually unchanged with the average patrol frequency and average number of cars available, and the patrol hours per suppressible crime all showing a greater number of positive ranks. The mean of the negative ranks, however, has increased in each case relative to the mean of the positive ranks. This suggests the magnitude of the differences that occur when the smoothed goal program levels are larger have increased from the actual goal program test results. This increase in magnitude can again be attributed to the greater number of vehicles allocated to Precincts 5, 8, and 13.

6.3 Concluding Remarks

Chapter VI has presented a rather detailed analysis of the culminating results of this research. To begin, the differences exhibited in vehicle allocations on a per watch per day per precinct basis between the actual Columbus allocation, the actual goal program allocation, and the smoothed goal program allocation were analyzed. This was followed by a thorough analysis of the resulting levels of performance for each allocation. Throughout the chapter, the results were presented, their meaning interpreted, and their reasons for occurring explained.

In Chapter VII this research effort culminates with a summary of the results discussed in this chapter, a synthesis of the research effort, the contributions it has made to the patrol allocation problem area, and, finally, a discussion of possible extensions to this research.

CHAPTER VII

SUMMARY, SYNTHESIS, CONTRIBUTIONS, AND EXTENSIONS

This chapter represents the culmination of the research effort described in this document. It begins with a summary of specific research results obtained in the performance of this study. The overall effort is then synthesized to bring everything into the proper perspective. Finally, the contributions this research has made in the area of police patrol allocation are discussed and future research extensions to this study are proposed.

7.1 Summary of Results

In summarizing the results, two things must be kept in mind. First, the availability of both manpower and patrol vehicles was limited in the goal program model in order to maintain the same levels actually exhibited in Columbus, Ohio for Quarter Three, 1975. Therefore, the fact that the results in Table 21 show the total average number of vehicles assigned at any one time in each allocation scheme to be almost identical, is not surprising. The levels were restricted to enable a valid comparison of the vehicle allocations derived from this research methodology to the actual Columbus vehicle allocation which existed. Secondly, for the most part, the analysis of the research results was performed on average measures. Although the use of average values may have a slight effect on the results, their use was necessary to condense the extremely large amount of output generated by this research into a manageable level for analysis.

7.1.1 Vehicle Allocations

The vehicle allocations prescribed by the goal program methodology of this research has the opportunity to differ from the actual allocations existing in Columbus, Ohio in each of three dimensions. These opportunities occur with respect to the watches of each day, the days of each week, and the precincts of the city. The results of the goal program model indicate differences in all three dimensions. The goal program allocations assigned significantly less vehicles to the third watch and more vehicles to the first and second watches. These results are supported by nonparametric statistical tests and can be mainly attributed to the workload levels exhibited in Table 22, which show higher levels for the first and second watches. Also, the goal program model has allocated less vehicles to Sunday, Tuesday, and Thursday which exhibit lower workload levels and more vehicles to Monday, Friday, and Saturday which exhibit higher workload levels.

Finally, a reallocation has occurred between the precincts. Precincts 5, 8, and 13 have been allocated more vehicles while the other precincts, Precincts 1, 4, 6, 11, and 12 have suffered a loss of vehicles. This difference is especially noticeable when one realizes that the actual Columbus allocation assigned its lowest average number of vehicles to Precinct 8 and Precinct 13. The major reason for the reallocation of vehicles among precincts is attributed to the large areas of Precincts 5, 8, and 13 and the need to assign additional vehicles to satisfy the most highly weighted goal, the average travel time.

7.1.2 Performance Measures

The levels of performance obtained in the actual goal program results and the results of the smooth goal program allocations are very similar; both exhibit differences with respect to the actual Columbus allocation levels of performance. The largest differences are observed in the levels associated with Precincts 5, 8, and 13. In the goal program allocations, the levels of performance for these precincts exhibit extreme values with respect to all measures of performance except the average travel time measure. The average travel time has the highest weight of any of the specified goals and, since Precincts 5, 8, and 13 have such a large area to traverse, a higher number of vehicles was allocated to those precincts in order to satisfy the goal. These increased allocations, in turn, resulted in the other measures of performance reaching a high attainment level. However, the other precincts which incurred a loss of vehicles exhibit lower attainment levels for the performance measures.

The exception to this behavior was the utilization ratio measure. Contrary to the other performance measures, as the number of vehicles allocated increased, the level of attainment for the utilization ratio declines. The utilization ratio goal of forty-five percent was never attained in any precinct. The high allocations in Precincts 5, 8, and 13 resulted in very low utilization levels. The other precincts, however, displayed more desirable utilization ratios because the number of vehicles assigned to each was decreased. Therefore, on the average, the reallocation of vehicles by the goal program to Precincts 5, 8, and 13 resulted in better performance results for both the average travel time and the utilization ratio.

Aside from the utilization ratio, the only other performance measure whose level was consistantly below the specified goal was the average patrol frequency. Although never actually satisfied, this measure of performance reached better attainment levels for the goal program allocations as opposed to the actual Columbus allocations. All in all, the goal program allocations have exhibited better overall results with respect to the levels of performance attainment. This is particularly apparent when one considers the number of performance measures satisfied in each precinct and, the fact that once a specified goal level is attained, it may actually be detrimental to continue to increase the attainment percentage beyond that point.

7.2 Synthesis

The research conducted and described in this document addresses the patrol allocation problem. This problem area was defined in Figure 1 as having three hierarchical decision-making levels; the staff sizing of each district, the vehicle and manpower tour schedule, and the design of the patrol beats. Specifically, this research has been directed toward the second level of the decision process in that the desired result was the development of a vehicle allocation schedule which compared favorably with the existing vehicle allocation with respect to various performance measure levels.

The research methodology is structured into three distinct stages. Stage one involves the statistical analysis of the relationships that exist between the call-for-service workload of a particular geographic area and the factors which contribute to that workload. The statistical analysis itself entailed a factor analysis of pertinent factors thought to contribute to the call-for-service workload. The aim of this analysis was an understanding of the relationships existing between workload factors. The factor analysis was followed by a regression analysis upon the independent factors.

The aim of this first stage was the development of an equation whereby the call-for-service workload for any geographical area could be forecasted. The regression analysis provided this equation which is important to this research for two reasons. First, by estimating the call-for-service workload the utilization ratio exhibited by patrol vehicles in a particular area can be estimated. Secondly, knowing the relationships that exist between workload and its contributing factors should help provide patrol planners with some insight into causes of utilization ratio variation between districts. This type of information is important when attempting to design patrol beats.

Stage two employs a simulation model, the Patrol Car Allocation Model [15], to model the relationships that exist between utilization ratio levels and the corresponding levels of other measures of performance. The aim of this stage is to provide the patrol planner with information that will assist him in prescribing appropriate levels for various performance measures. Toward this end, the simulation model was run at least eight times for each precinct starting with a small number of vehicles being allocated to each watch for each day. For each run, the number of vehicles allocated to each watch was sequentially increased by one vehicle. The process continued until the levels of performance no longer improved significantly. By increasing the vehicles allocated in this manner and recording the resulting changes in the levels of performance, the trade-off relationships between varying levels of utilization and the corresponding levels of the measures of performance were derived. Therefore, the results of stage two enable the patrol planner to estimate expected levels of performance for a particular geographical area with the aid of utilization ratio information developed in stage one.

The final stage of this research methodology integrates the information processed in the first two stages to construct a goal program model to allocate patrol vehicles on a per watch per day per precinct basis. A goal programming approach was chosen due to its great flexibility that allows for the solution of a system of complex objectives without requiring a homogeneous unit of measure for each. This is exactly what is needed when allocating patrol vehicles with respect to various measures of performance with varying units of measure.

The third stage operates by constructing a series of goal constraints and specifying appropriate goal levels for each set of constraints. It is here that all three stages are integrated to arrive at the vehicle allocations desired. Taking the estimates of the utilization ratio level from stage one, the patrol planner is then able to estimate the expected levels of important performance measures for each precinct by using the output from stage two. This information is then used to specify appropriate goal levels for the various performance measures under consideration. The goal levels are input into the goal program which results in a patrol vehicle allocation. This vehicle allocation is the aim of the entire research effort.

7.3 Contributions

There are a number of contributions this research has made to the whole problem area of police patrol allocation. They mainly concern the objectives this research has attempted to satisfy as put forth in the introduction of this document. Briefly, the two major objectives were to establish the utilization ratio as a key decision variable in the patrol allocation problem and to develop a decision-making methodology which would aid the patrol planner in solving problems at all levels in the patrol allocation problem structure.

The major contribution this research has made is the development of a procedure whereby patrol vehicles are able to be allocated across watches, days and precincts with regard to both workload levels that vary considerably for each watch, day, and precinct and a set of conflicting nonhomogeneous goals. The procedure is a structured approach which leads the patrol planner through a series of stages to arrive at a set of vehicle allocations. Previously there did not exist a structured approach to the vehicle allocation problem that considered such factors as these. Decisions were made on more of a heuristic basis or to maintain a certain status quo. The methodology developed in this research provides a means both to estimate measures of performance and to satisfy a set of reasonable goals most efficiently.

While specifically addressing the vehicle allocation problem, this research helps join together all three levels of the disaggregation structure of the patrol allocation problem. Information is generated and processed by this methodology in such a manner as to act as valuable input into the staff sizing and beat design level decisions. By knowing the number of vehicles that are to be assigned to any one precinct, the manpower level required to staff these vehicles can be determined.

The information generated in this research is particularly helpful in the beat design decision area. This research has established a procedure that models the relationships that exist between various geographic and demographic characteristics of a particular area and the call-for-service workload exhibited in the same area. This enables a patrol planner to estimate workload levels for any geographic and demographic configuration. Patrol beats can then be structured to smooth the expected workload of each beat which, in turn, leads to an equalization of utilization among patrolmen and vehicles.

The contributions discussed up to this point have been predominately associated with the objective of providing a decision aid to the patrol planner. Contributions have also been made concerning the establishment of the utilization ratio as a key decision variable for the patrol function. Through this research it was discovered that the utilization ratio was a convenient measure to which other measures of performance could be compared. This was accomplished in Chapter IV when a series of trade-offs were modeled between utilization ratio levels and corresponding levels of other performance measures. These trade-off relationships enable the patrol planner to set goal levels for each measure of performance by establishing the number of vehicle hours necessary to attain a specific utilization ratio. The utilization ratio thus became the key element in modeling each goal.

The establishment of the utilization ratio as a key service measure should also contribute to the solution of the patrol allocation problem by providing means whereby different solution techniques can be compared across a common measure. Although the utilization ratio is not the only measure of service, it is one that is easily estimated, needing only workload estimates and the allocation of vehicle hours. Therefore, even the simplest allocation methodology should be able to provide utilization ratio estimates for comparative purposes. And, if solution techniques can be compared, then the most effective one can be identified and used.

7.4 Extensions

This research has been specifically directed toward a small part of the overall patrol allocation problem and its many facets. This specific direction has been toward the development of patrol vehicle allocations. Being a small portion of a larger problem area, many extensions of this research come to mind.

An obvious extension is the broadening of the scope to encompass manpower scheduling. The question of developing feasible schedules for patrolmen, fixed or rotating, was not specifically addressed in this research. The Planning and Research Department did take a goal program allocation and smooth it to allow for feasible schedules; however, there is no provision for doing such within the scope of this research effort.

Along the same lines, this research generates information helpful in the beat design decision. The two decision levels, however, are never actually linked together such that the beat design impacts the vehicle allocation decision and vice versa. The same could be said for the staff sizing and vehicle allocation decisions.

Other extensions may include an attempt to simplify the goal program model by consolidating various measures of performance. The Wilcoxon Matched-Pairs Signed-Ranks Test performed on the performance measures showed indications that correlations may be present among certain measures. Specifically, Table 25 indicates this may be so in the case of the average patrol frequency, the average number of cars available, and the patrol hours per suppressible crime measures. The results of each of these measures show very similar levels indicating similar traits and reactions to various changes.

Finally, it would be interesting to compare the results of this particular methodology with other solution techniques. For example, the vehicle allocation problem could also be modeled in the classical manner such as the linear decision rule used in aggregrate planning problems. The linear decision rule attempts to establish production rates and workforce levels by modeling pertinent relationships and combining them into a single equation to be solved by classical calculus methods. In a similar fashion, vehicle allocations and perhaps manpower allocations may be established by taking the relationships modeled for the various measures of performance and creating a single equation to be solved by calculus methods. Such comparisons may be helpful in simplifying the methodology presented here in this research.

These are some of the possible extension to consider in expanding this research. They are but a few in a list that could stretch as far as one's imagination. They do, however, represent areas which would aid in the efficient solution of the patrol allocation problem.

BIBLIOGRAPHY

1. Arrow, K. "Utilities, Attitudes, Choices: A Review Note," Econometrica, Vol. 26 (1958), pp. 1-23.

2. Balderston, F.E. "Optimal and Feasible Choice in Organizations Having Multiple Goals," Working Paper No. 12, Management Science News, Institute of Industrial Relations, University of California, Berkeley, California, February, 1960.

3. Becker, E.M., Degroot, H.M. and Marshak, J. "Measuring Utility by a Single Response Method," Behavior Science, Vol. 9 (1964).

4. Beeson, R.M., and Meisel, W.S. "The Optimization of Complex Systems with Respect to Multiple Criteria," in Proceedings of Systems, Man, and Cybernetics Conference: Joint National Conference on Major Systems, October, 1971, 144-149.

5. Benayoun, R., Tergny, J., and Keuneman, D. "Mathematical Programming with Multi-Objective Functions: A Solution by P.O.P. (Progressive Orientation Procedure)," Metra, Vol. 9, No. 2 (June 1970), pp. 279-299.

6. Benayoun, R., Montgolfier, J., Tergny, J., and Laritchev, O. "Linear Programming with Multiple Objective Functions: Step Methods (STEM)," Mathematical Programming, Vol. 1 (1971), pp. 366-375.

7. Bodin, L.D., "Towards a General Model for Manpower Scheduling: Parts I and II," Urban and Policy Sciences Program, State University of New York, Stony Brook, New York, September, 1972.

8. Briskin, L.E. "A Method of Unifying Multiple Objective Functions," Management Science, Vol. 12, No. 10 (June 1966), pp. 406-416.

9. Brownlee, K.A. Statistical Theory and Methodology in Science and Engineering, John Wiley and Sons, New York, 1960.

10. Buffa, E.S., and Dyer, J.S. Management Science/Operations Research-Model Formulation and Solution Methods, John Wiley and Sons, 1977.

11. Candlier, W., and Boehije, M. "Use of Linear Programming in Capital Budgeting with Multiple Goals," Journal Paper No. 3441, Purdue Agricultural Experiment Station.

12. Capaul, J., Heller, N., and Meisenheimer, E. "A Stochastic Model for Allocating Police Patrol Units to Districts Which Reflects Each Districts' Rates of Injury, Property Loss, and Fear," Paper presented at the 38th National Meeting of

Operations Research Society of America, 1970.

13. Chaiken, J. "Patrol Allocation Methodology for Police Departments," RAND Report, R-1852-HUD, Sept., 1975.

14. Chaiken, J. "Hypercube Queuing Model: Executive Summary," RAND Corporation Report, R-1688/1-HUD, The New York City RAND Institute, N.Y., July, 1975.

15. Chaiken, J.M., and Dormont, P. Patrol Car Allocation Model: Executive Summary, R-1786/1-HUD/DOJ, Patrol Car Allocation Model: User's Manual, R-1786/2-HUD/DOJ, Patrol Car Allocation Model: Program Description, R-1786/3-HUD/DOJ, The RAND Corporation, Santa Monica, California, Sept., 1975.

16. Chaiken, J.M., and Larson, R.C. "Methods for Allocating Urban Emergency Units: A Survey," Management Science, Vol. 19, No. 4, December, Part 2, 1972.

17. Charnes, A., and Cooper, W.W. "Goal Programming and Multiple Objective Optimizations," Paper prepared for release at Joint ORSA-TIMS Meeting, Las Vegas, November, 1975.

18. Charnes, A., Cooper, W.W., De Voe, J.K., Learner, D.B., and Reinectk, W. "A Goal Programming Model for Media Planning," Management Science, Vol. 14, No. 8 (1968), B423-B430.

19. Charnes, A., Cooper, W.W., and Nichaus, R.J. "A Goal Programming Model for Manpower Planning," Management Science Research Report, No. 115, Carnegie-Mellon University, August, 1968.

20. Charnes, A., Cooper, W.W., Nichaus, R.J., and Stedry, A. "Static and Dynamic Assignments Models with Multiple Objectives, and Some Remarks on Organization Design," Management Science, Vol. 15, No. 8 (April 1969), pp. 365-375.

21. Churchman, C.W., Ackoff, R.L., and Arnoff, E.L. Introduction to Operations Research, John Wiley and Sons, New York, 1957.

22. Chochrane, J. and Leleng, M. (Eds), Multiple Criteria Decision Making, University of South Carolina Press, 1973.

23. Cohon, Jared L. Multiobjective Programming and Planning, Academic Press, Inc., New York, New York, 1978.

24. Colton, K.W. "Use of Computers by Police: Patterns of Success and Failure," Urban Data Services, International City Management Association, Vol. 4, No. 4, April 1972.

25. Contini, B. "A Stochastic Approach to Goal Programming," Operations Research, Vol. 16, No. 3, (May-June, 1968), pp. 576-586.

26. Cooley, W.W., and Lohnes, P.R. Multivariate Procedures for the Behavioral Sciences, John Wiley and Sons, Inc., New York, 1962.

27. Cooper, L., and Steinberg, D. Introduction to Methods of Optimization, W.B. Saunders Co., 1970, Philadelphia, Pennsylvania.

28. Crowther, R.F. "The Use of a Computer System for Police Manpower Allocation in St. Louis, Missouri," Department of Police Administration, Indiana University, 1964.

29. Dyer, J.S. "Interactive Goal Programming," Management Science, Vol. 19, No. 1 (Sept., 1972), pp. 62-70.

30. Dyer, J.S. "A Time-Sharing Computer Program for the Solution of the Multiple Criteria Problem," Management Science, Vol. 19, No. 12 (August, 1973), pp. 1379-1383.

31. Dyer, James S. "On the Relationship Between Goal Programming and Multiattribute Utility Theory," Discussion Paper No. 69, October, 1977. Prepared for presentation at the International Symposium on External Methods and Systems Analysis, University of Texas, Austin, Texas, September 13-15, 1977.

32. Easton, A. Complex Managerial Decisions: Introducing Multiple Objectives, John Wiley and Sons, Inc., New York, 1973.

33. Eckenrode, R.T. "Weighting Multiple Criteria," Management Studies, Vol. 12, No. 3 (Nov., 1965), p. 180.

34. Eilon, S. "Goals and Constraints," Journal of Management Studies, Vol. 8 (1971), pp. 292-303.

35. Eilon, S. "Goals and Constraints in Decision Making," Operational Research Quarterly, Vol. 23 (1972), pp. 3-15.

36. Ezekiel, M., and Fox, K.A. Methods of Correlation and Regression Analysis, John Wiley and Sons, New York, 1959.

37. Ferreira, J. Comparing Methods of Allocating Patrol Units, M.I.T., Cambridge, Mass., 1975.

38. Fishburn, P.C. Decision and Value Theory, John Wiley and Sons, Inc., New York, 1964.

39. Fishburn, Peter C. "Methods of Estimating Additive Utilities," Management Science, Vol. 13, No. 7, March, 1967, pp. 435-452.

40. Fishburn, P.C. Utility Theory for Decision Making, John Wiley and Sons, New York, 1970.

41. Fruchter, B. Introduction to Factor Analysis, D. Van Nostrand, Inc., New York, 1954.

42. Gearing, C.E. "An Optimal Resolution of a Multiple Criteria Decision Problem," Proceedings of 5th Annual Meeting of American Institute of Decision Sciences, Boston, November, 1973.

43. Geoffrion, A., Dyer, J.S., and Feinberg, A. "An Interactive Approach for Multi-Criterion Optimization, with an Application to the Operations of an Academic Department," Management Science, Vol. 19, No. 4, Part I (Dec., 1972), pp. 357-368.

44. Goodman, L. "On Methods of Amalgamation," in R.M. Thrall et. al. Decision Processes, New York, John Wiley and Sons, 1954, pp. 39-48.

45. Gunn, S.C. "Incorporating Alternative Goal Ranking Systems and Stochastic Elements into Goal Programming," Ohio State University, July, 1971.

46. Hatfield, G. "The Theory and Application of Linear Programming," Paper Presented at VIII International Symposium on Mathematical Programming, Stanford University, California, August, 1973.

47. Heller, N.B. "Proportional Rotating Schedules," Ph.D. thesis, University of Pennsylvania, August, 1969.

48. Henderson, W.B. and W.L. Berry, "Determining Optimal Shift Schedules for Telephone Traffic Exchange Operators," Working Paper No. 507, Krannert Graduate School of Industrial Administration, Purdue University, April, 1975.

49. Huber, George P. "Methods for Quantifying Subjective Probabilities and Multi-Attribute Utilities," Decision Sciences, Vol. 5, No. 3, July, 1974, pp. 430-458.

50. Kakalik, J.S., and Wildhorn, S. "Aids to Decisionmaking in Police Patrol," The RAND Corporation, R-593-HUD/RC, 1971.

51. Keeney, R.L., and Raiffa, H. Decisions with Multiple Objectives: preferences and value trade-offs, John Wiley and Sons, New York, 1976.

52. Klahr, C.N. "Multiple Objectives in Mathematical Programming," Operations Research, Vol. 6, No. 6 (1958), pp. 849-855.

53. Kolesar, P., and Walker, W. "A Simulation Model of Police Patrol Operations," The RAND Corporation, R-1625/1-HUD (Executive Summary), R-1625/2-HUD/NYC (Program Description), 1975.

54. Krajewski, L.J., and Henderson, J. "Decision Making in the Public Sector: An Application of Goal Interval Programming for Disaggregation in the Post Office," Conference on the Disaggregation Problem Proceedings, Columbus, Ohio, March 10-11, 1977.

55. Krajewski, LeRoy J., and Ritzman, Larry P. "Disaggregation in Manufacturing and Service Organizations: Survey of Problems and Research," Working Paper WPS 76-1, The Ohio State University, June, 1976.

56. Larson, R. Urban Police Patrol Analysis, M.I.T. Press, Cambridge, Mass., 1972.

57. Lee, S.M. "Decision Analysis Through Goal Programming," Decision Science, Vol. 2, No. 2 (April, 1971), pp. 172-180.

58. Lee, S.M. Goal Programming for Decision Analysis, Aurback Publishers, Inc., Philadelphia, Pennsylvania, 1972.

59. Lee, S.M. "Goal Programming for Modern Decision Analysis," Proceedings of 5th Annual Meeting of American Institute of Decision Sciences, Boston, Nov. 1973.

60. Lee, S.M., and Clayton, E.R. "A Goal Programming Model for Academic Resource Allocation," Management Science, Vol. 18, No. 8 (April, 1972), pp. 395-408.

61. MacCrimmon, K.R. "An Overview of Multiple Objective Decision Making," in J. Cochrane and M. Leleny (Eds.), Multiple Criteria Decision Making, University of South Carolina Press, 1973, pp. 18-44.

62. McEwen, R. Project Director, "Allocation of Patrol Manpower Resources in the Saint Louis Police Department," Vols. I and II, 1966.

63. Neter, J., and Wasserman, W. Applied Linear Statistical Models - Regression Analysis of Variance, and Experimental Design, Richard D. Irwin, Inc., Homewood, Illinois, 1974.

64. Nie, Norman H. SPSS: Statistical Package for the Social Sciences, Second Edition, McGraw-Hill Book Company, New York, New York, 1975.

65. Ostle, B. Statistics in Research, The Iowa State University Press, Ames, Iowa, 1972.

66. Price, W.L., and Piskor, W.G. "The Application of Goal Programming to Manpower Planning," INFOR (Canada), Vol. 10, No. 3 (Oct., 1972), pp. 221-231.

67. Ritzman, L.P., and Krajewski, L.J. "Multiple Objectives in Linear Programming - An Example in Scheduling Postal Resources," Decision Sciences, Vol. 4, No. 3 (July, 1973), pp. 364-378.

68. Roy, B. "Problems and Methods with Multiple Objective Functions," Mathematical Programming, Vol. I, No. 2, (Nov., 1971), pp. 239-266.

69. Ruefli, T.W. "A Generalized Goal Decomposition Model," Management Science, Vol. 17, No. 8 (April, 1971), pp. 505-518.

70. Sasser, W. Earl, Olsen, R. Paul, and Wyckoff, D. Daryl, Management of Service Operations Text, Cases, and Readings, Allyn and Bacon Inc., Boston, 1978.

71. Sayeki, Yutaka, and Vesper, Karl H. "Allocation of Importance in a Hierarchical Goal Structure," Management Science, Vol. 19, No. 6, February, 1973, pp. 667-675.

72. Schilling, David A., ReVelle, Charles S., Cohon, Jared L., and Elzinga, D. Jack, "A New Approach to the Display and Analysis of Multi-Objective Problems," Working Paper, The Ohio State University, January, 1979.

73. Seinfeld, J.H., and McBride, W.Z. "Optimization with Multiple Performance Criteria," I & EC Process Design and Development, Vol. 9, No. 1 (1970) pp. 53-57.

74. Shumate, R.P., and Crowther, R.F. "Quantitative Methods for Optimizing the Allocation of Police Resources," J. Crim. Law, Criminology, and Police Science, Vol. 57, 1966, pp. 197-206.

75. Silverman, J., and Hatfield, G.B. "A Theoretical Approach to Multi-Objective Problems," A Paper Presented at TIMS 20th International Meeting, Tel Aviv, Israel, June, 1973.

76. Sohn, R.L., and Kennedy, R.D. "Patrol Force Allocation for Law Enforcement - An Introductory Planning Guide," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, Feb. 16, 1976.

77. Terry, H. "Comparative Evaluation of Performance Using Multiple Criteria," Management Science, Vol. 9, No. 3 (1963), pp. 431-442.

78. Vitt, L.D. "Aggregate Programming for Police Patrol," Proceedings of Midwest Conference, American Institute for Decision Sciences, Indianapolis, Indiana, April, 1975.

79. Wilson, O.W. "Distribution of the Police Patrol Force," Publication 74, Public Administration Service, Chicago, Illinois, 1941.

80. Wilson, O.W. Police Planning, Charles C. Thomas Publisher, Springfield, Illinois, 2nd ed., 1975.

81. Wilson, O.W. Police Administration, 2nd ed., McGraw-Hill, New York, 1963.

APPENDIX A

FACTOR ANALYSIS RESULTS

Introduction

The factor analysis technique was introduced into this research as a data reduction device. The goal was to reduce a set of sixteen intercorrelated geographic and demographic variables into a smaller set of independent factors. The basis for this reduction was a maximization of the accountability of the variance present between the initial variables. This appendix is a representation of the results of the factor analysis. Herein are displayed the results of the initial factor analysis runs utilizing the recommended default eigenvalue of one, and the final factor analysis runs which settled on a set of five independent factors.

Initial Factor Analysis

The initial factor analysis runs were used to determine a starting point for the analysis. At this point the researcher was totally unaware of the number of independent factors that would be necessary to account for a substantial percentage of the variability between the initial variables. The number of factors extracted is normally determined by the specification of the eignenvalue, which is a measure of the variance accounted for between variables in the data by a certain factor. Since the required number of factors was unknown, the accepted convention of specifying a minimum eigenvalue of one was taken.

The results that follow show the extraction of four factors having eigenvalues of one or greater. The factors were rotated orthogonally using three rotation procedures; varimax. quartimax, and equimax. The rotation of factors is employed to enhance the interpretability of the extracted factors. A dependent variable is said to load onto a factor by the display of a high correlation coefficient between the two. Varimax rotation centers on simplifying the columns of a factor matrix. Here the variance of the squared loadings in each column is maximized. The quartimax rotation centers on simplifying the rows of a factor matrix. The initial factors are rotated in such a manner that a variable loads high on one factor and very low on all other factors. Finally, the equimax is a compromise rotation procedure where neither the rows or columns are concentrated on individually. It should be noted that the amount of variance accounted for by any orthogonal rotation procedure remains unchanged.

The interpretability of a factor is dependent on how easily the dependent variables which have loaded on that factor can be generalized under a common descriptive heading. After examining Table 30, Table 31, and Table 32, the varimax rotation procedure displayed in Table 30 allows the clearest interpretation of the factors. The resulting factors are described as; population, density, affluence, and vacancy.

TABLE 27

Proportion of Variance as Calculated from the Unaltered Correlation Matrix

FACTOR	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENTAGE
1	5.83864	36.5	36.5
2	4.25384	26.6	63.1
3	1.39439	8.7	71.8
4	1.03832	6.5	78.3
5	0.87316	5.5	83.7
6	0.60951	3.8	87.5
7	0.52740	3.3	90.8
8	0.37459	2.0	93.2
9	0.32696	2.0	95.2
10	0.25444	1.6	96.8
11	0.16798	1.0	97.4
12	0.14813	.9	98.8
13	0.11181	.7	99.5
14	0.06553	.4	99.9
15	0.01269	.1	100.0
16	0.00248	.0	100.0

TABLE 28

UNROTATED FACTOR MATRIX: INITIAL FOUR FACTOR SOLUTION

	Factor 1	Factor 2	Factor 3	Factor 4
Population	0.23775	0.87860	0.27673	-0.19104
Growth	0.69647	0.20668	-0.25406	0.15469
Population Density	-0.60536	0.11366	0.42876	0.17914
Acreage	0.74490	0.14007	-0.15500	0.06042
Percent Black	-0.43751	-0.21200	-0.08700	-0.06049
Total Housing	0.14455	0.84885	0.32903	-0.12124
Housing Density	-0.74346	0.12088	0.49514	0.34947
Vacant Housing	-0.59187	-0.07933	-0.22794	0.35077
Owner Occupied	0.84106	-0.06099	0.14488	-0.27637
Substandard	-0.70708	-0.11284	-0.09565	-0.11708
Median Value	0.82608	0.01194	0.01502	0.38590
Median Rent	0.79426	0.13726	0.10176	0.43125
Part 1 Offenses	-0.17274	0.95174	-0.11794	0.02589
Total Offenses	-0.15034	0.96527	-0.09358	-0.01877
Persons Charged-1	-0.22746	0.65892	-0.35551	0.09208
Total Persons Charged	-0.58313	0.42674	-0.40444	0.05077

TABLE 29

Percent of Common Variance Accounted for by Unrotated Factors

FACTOR	EIGENVALUE	PERCENT OF* VARIANCE	CUMULATIVE* VARIANCE
1	5.54247	47.9	47.9
2	4.12290	35.6	83.5
3	1.11529	9.6	93.1
4	0.79677	6.9	100.0

*Note that these percentages refer to only the percent of variance that has been explained by the factors and not the total variation present between variables. Therefore, they are relative only to each other.

TABLE 30

VARIMAX ROTATED FACTOR MATRIX

	Factor 1 Population	Factor 2 Density	Factor 3 Affluence	Factor 4 Vacancy
Population	0.85904*	0.05085	0.20834	-0.39700
Growth	0.14272	-0.44144	0.63206*	-0.03900
Population Density	0.11867	0.69837*	-0.29178	0.09145
Acreage	0.07946	-0.43768	0.60875*	-0.18364
Percent Black	-0.16340	0.10599	-0.40744	0.20892
Total Housing	0.82624*	0.16506	0.18214	-0.34828
Housing Density	0.11338	0.89278*	-0.28215	0.21238
Vacant Housing	-0.06208	0.27079	-0.25858	0.62207*
Owner Occupied	-0.10136	-0.42569	0.46759	-0.63115*
Substandard	-0.03679	0.20806	-0.63425*	0.29772
Median Value	-0.10048	-0.20698	0.87251*	-0.13193
Median Rent	0.01639	-0.09960	0.90241*	-0.14657
Part 1 Offenses	0.95719*	0.05710	0.00916	0.17512
Total Offenses	0.97292*	0.04470	0.00206	0.12201
Persons Charged-1	0.67562*	-0.07880	-0.05302	0.39408
Total Persons Charged	0.48166	0.02407	-0.38579	0.55398*

Note: The asterisks designate those variables which have loaded on each factor.

TABLE 31

QUARTIMAX ROTATED FACTOR MATRIX

	Factor 1 Affluence	Factor 2 Population	Factor 3 Density	Factor 4 Vacancy
Population	0.31429	0.81969*	0.14977	-0.38528
Growth	0.72749*	0.13394	-0.21328	0.15360
Population Density	-0.51760	0.13759	0.55509*	-0.01849
Acreage	0.74720*	0.05728	-0.20086	0.01553
Percent Black	-0.46694	-0.14328	-0.05019	0.08070
Total Housing	0.23712	0.79353*	0.24411	-0.34481
Housing Density	-0.61054	0.14724	0.72827*	0.09906
Vacant Housing	-0.51075*	0.00024	0.10645	0.50874
Owner Occupied	0.74689*	-0.16541	-0.18406	-0.43520
Substandard	-0.72648*	-0.00829	-0.03635	0.07991
Median Value	0.88467*	-0.11142	0.09579	0.16547
Median Rent	0.88341*	0.00561	0.20707	0.15065
Part 1 Offenses	-0.03580	0.97033*	0.02976	0.08093
Total Offenses	-0.02102	0.98072*	0.02147	0.02716
Persons Charged-1	-0.11988	0.70793*	-0.13943	0.29291
Total Persons Charged	-0.50525	0.52997*	-0.16339	0.35420

Note: The asterisks designate those variables which have loaded on each factor.

TABLE 32

EQUIMAX ROTATED FACTOR MATRIX

	Factor 1 Population	Factor 2 Density	Factor 3 Affluence	Factor 4 Vacancy
Population	0.88890*	0.01629	0.16628	-0.35141
Growth	0.14653	-0.50308	0.57868*	-0.08263
Population Density	0.11779	0.72291*	-0.21318	0.11573
Acreage	0.09386	-0.49767	0.54168*	-0.22861
Percent Black	-0.18162	0.14918	-0.37132	0.23354
Total Housing	0.85388*	0.13335	0.15643	-0.30504
Housing Density	0.10642	0.91663*	-0.17269	0.23081
Vacant Housing	-0.10643	0.30134	-0.16676	0.63321*
Owner Occupied	-0.05505	-0.47404	0.35881	-0.67230*
Substandard	-0.06315	0.27225	-0.57772*	0.35164
Median Value	-0.08309	-0.29123	0.83127*	-0.22108
Median Rent	0.03635	-0.18883	0.86908*	-0.23182
Part 1 Offenses	0.94247*	0.04621	0.02696	0.24314
Total Offenses	0.96180*	0.03387	0.01327	0.19255
Persons Charged-1	0.64301*	-0.07754	-0.02398	0.44803
Total Persons Charged	0.43536	0.06114	-0.32635	0.62331*

Note: The asterisks designate those variables which have loaded on each factor.

Final Factor Analysis Results

In the final analysis, the factor analysis portion of this research resulted in the extraction of five independent factors. These five factors were the culmination of an intensive analysis of the results displayed by the extraction of three, four, five, and six factors. The aim, as previously mentioned, was to account for as much of the common variance between the variables as possible while at the same time providing easily interpretable factors. Due to space limitations only the results of the final factor analysis run are displayed here. As stated in Chapter III, the two variables, growth and percent black population, have been eliminated from the final run. This was done on the basis of the Pearson Correlation Coefficient Analysis shown in Table 2, Chapter III and subsequently led to a clearer interpretation of the extracted factors.

TABLE 33

Proportion of Variance as Calculated from the Unaltered Correlation Matrix

Factor	Eigenvalue	Percent of Variance	Cumulative Percentage
1	5.19329	37.1	37.1
2	4.10231	29.3	66.4
3	1.30012	9.3	75.4
4	1.01108	7.2	82.9
5	0.58745	4.2	87.1
6	0.52400	3.7	90.8
7	0.40460	2.9	93.7
8	0.27277	1.9	95.7
9	0.21337	1.5	97.2
10	0.16501	1.2	98.4
11	0.12997	0.9	99.3
12	0.07842	0.6	99.9
13	0.01471	0.1	100.0
14	0.00281	0.0	100.0

TABLE 34

UNROTATED FACTOR MATRIX: INITIAL FIVE FACTOR SOLUTION

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Population	-0.02910	0.93104	0.23053	-0.18575	-0.14080
Population Density	0.61817	-0.03746	0.49979	0.10039	0.24826
Acreage	-0.64848	0.29421	-0.12894	0.06764	0.12337
Total Housing	0.05370	0.88623	0.29083	-0.12359	-0.21700
Housing Density	0.75410	-0.07136	0.57201	0.23574	0.11095
Vacant Housing	0.55725	-0.22409	-0.14754	0.36630	-0.19857
Owners Occupied	-0.86831	0.17153	0.10105	-0.29121	0.27158
Substandard	0.65943	-0.28969	-0.08101	-0.15381	-0.01118
Median Value	-0.78804	0.21009	0.02517	0.43610	0.02127
Median Rent	-0.72191	0.32099	0.11420	0.45990	-0.02313
Part 1 Offenses	0.40956	0.86747	-0.10802	0.03666	0.04421
Total Offenses	0.39064	0.88623	-0.09130	-0.00945	0.04026
Persons Charged-1	0.39760	0.58171	-0.36499	0.15160	0.17500
Total Persons Charged	0.69299	0.25487	-0.40714	0.07760	0.14562

TABLE 35

PERCENT OF COMMON VARIANCE ACCOUNTED FOR BY UNROTATED FACTORS

Factor	Eigenvalue	Percent of* Variance	Cumulative* Percentage
1	4.97523	44.4	44.4
2	3.99728	35.7	80.1
3	1.10255	9.8	90.0
4	0.79477	7.1	97.1
5	0.32578	2.9	100.0

*Note that these percentages refer only to the percent of variance that has been explained by the factors and not the total variation present between variables. Therefore, they are relative only to each other.

TABLE 36

VARIMAX ROTATED FACTOR MATRIX: FINAL SOLUTION

	Factor 1 Population	Factor 2 Affluence	Factor 3 Density	Factor 4 Arrest	Factor 5 Vacancy
Population	0.93930*	0.15817	-0.00265	0.16138	-0.20441
Population Density	0.06713	-0.27813	0.78083*	0.07475	0.10322
Acreage	0.07103	0.54743*	-0.33364	0.03973	-0.35479
Total Housing	0.94458*	0.13571	0.06789	0.11311	-0.08470
Housing Density	0.09823	-0.28030	0.87975*	0.03059	0.32517
Vacant Housing	-0.17836	-0.20636	0.18140	0.18070	0.64647*
Owner Occupied	0.03513	0.44889	-0.30260	-0.24143	-0.77432*
Substandard	-0.15205	-0.62860*	0.20633	0.12615	0.26902
Median Value	0.01330	0.88079*	-0.21572	-0.10839	-0.14885
Median Rent	0.12498	0.89074*	-0.13739	-0.10210	-0.10707
Part 1 Offenses	0.71382*	-0.01982	0.09409	0.64218	0.06337
Total Offenses	0.74425*	-0.03246	0.08174	0.62109	0.02531
Persons Charged-1	0.32108	-0.02955	0.00232	0.75120*	0.12257
Total Persons Charged	0.09721	-0.37021	0.08856	0.70848*	0.28616

Note: The asterisks designate those variables which have loaded on each factor.

APPENDIX B

REGRESSION ANALYSIS RESULTS

Introduction

Because multiple regression is a general statistical technique that analyzes relationships between a dependent variable and a set of independent variables, it has a wide variety of application. This research utilizes the multiple regression technique as a descriptive tool by which the linear dependence of one variable, workload, on a set of independent factors, population, affluence, density, arrest, and vacancy, is summarized. The goal is to find the best linear prediction equation for workload.

The key term being used is the word 'linear'. It is this desire to model 'linear' relationships that led to a series of preliminary regression analyses. Each analysis entailed a simple linear regression be performed with call-for-service workload as the dependent variable and one of the five extracted factors from the factor analysis as the independent variable. This meant that five individual simple linear regressions must be performed. The results of these five regression analyses are displayed in Table 37. These results indicate both the strengths of the individual relationships present between workload and each of the independent factors and the lack of nonlinear relationships between the same.

TABLE 37

REGRESSION ANALYSIS RESULTS BETWEEN WORKLOAD AND EACH INDEPENDENT FACTOR INDIVIDUALLY

Factor	Simple R	R Square	Standard Error	B	BETA	F	Significance Level
Population	0.63084	0.39796	2.26207	1.862846	0.63084	40.322	.999
Affluence	-0.31144	0.09699	2.77038	-0.9462016	-0.31144	6.552	.975
Density	0.06337	0.00402	2.90951	0.1895666	0.06337	0.24593	Insignificant (<.50)
Arrest	0.61319	0.37600	2.30296	1.903464	0.61319	36.756	.999
Vacancy	0.17863	0.03191	2.86848	0.554525	0.17863	2.01058	<.90

Validation of Regression Assumptions

The validity of any regression analysis result is dependent on the assumptions, or more directly the accuracy of the assumptions, which are made concerning the residuals of the regression analysis. The assumptions of importance concern normality, homogenity, and linearity. Table 38 uses the chi-square goodness-of-fit test to validate the assumption that the residuals conform to a normal distribution. Another nonparametric test, the Spearman rank correlation test, validates the assumption of the consistancy of variance in Table 39. Finally, Figure 20 shows a plot of the standard residual. A visual analysis of this table indicates that a linear relationship is present. Therefore, it is assumed the results of the final regression analysis displayed in Table 3, Chapter III are valid.

TABLE 38

CHI-SQUARE GOODNESS-OF-FIT TEST FOR NORMALITY OF THE RESIDUALS

					63 Observations
Category	f	e	f-e	$(f-e)^2$	$(f-e)^2/e$
A	15	12.6 → 13	2	4	.308
B	27	25.2 → 25	2	4	.16
C	39	37.8 → 38	1	1	.026
D	55	50.4 → 50	5	25	.5
E	57	56.7 → 57	0	0	0
F	60	59.9 → 60	0	0	0
G	61	62.4 → 62	-1	1	.016
					1.01

H: Probability function of observed standardized residual is normal distribution.

A: Probability function of observed standardized residual is different from normal distribution.

Test Statistic = 1.01

Degrees of Freedom = r-1, where r equals the number of categories.

Therefore, degrees of freedom equal 6.

Chi-Square Table - 6 degrees of freedom

Probability	Test Statistic Value
.99 →	.87
.98 →	1.13

Therefore, the probability of reaching such a sample outcome when H is true is between 98% and 99%, and the null hypothesis can not be rejected.

TABLE 39

SPEARMAN RANK CORRELATION TEST FOR CONSISTANCY OF VARIANCE

x Predicted Workload		y Standardized Residual		D	D^2
-.4406	1	.9206	55	-54	2916
-.1808	2	.5808	47	-45	2025
.5122	3	-.2722	24	-21	441
.8785	4	1.1215	58	-54	2916
1.0889	5	-.6889	14	- 9	81
1.6181	6	.6219	49	-43	1849
1.772	7	.8680	54	-47	2209
1.8375	8	-1.2775	5	3	9
2.2651	9	-.9051	12	- 3	9
2.607	10	-.4470	20	-10	100
2.804	11	-.4039	21	-10	100
3.2685	12	.0915	35	-23	529
3.5027	13	-1.503	4	9	81
3.5648	14	-1.245	6	8	64
3.5706	15	.1094	36	-21	441
3.7993	16	-.1193	29	-13	169
4.1313	17	.5086	45	-28	784
4.1503	18	-.3103	22	- 4	16
4.2735	19	-.0335	33	-14	196
4.3018	20	-.2218	26	- 6	36
4.3384	21	-1.2184	8	13	169
4.3682	22	-.04823	31	-9	81
4.378	23	.5819	48	-25	625

TABLE 39, (continued)

X		Y		D	D^2
4.5183	24	-.6783	15	9	81
4.6008	25	-.6008	17	8	64
4.785	26	.9749	56	-30	900
4.8274	27	.1326	37	-10	100
4.9969	28	.6831	51	-23	529
5.1409	29	-1.2209	7	22	484
5.1541	30	-.9141	10	20	400
5.1904	31	-.4704	19	12	144
5.3411	32	.9788	57	-25	625
5.3846	33	-1.8646	2	31	961
5.466	34	.4539	43	-9	81
5.5135	35	-.0735	30	5	25
5.654	36	.8258	52	-16	256
5.718	37	-1.798	3	34	1156
5.7523	38	.4077	41	-3	9
6.012	39	-.17199	28	11	121
6.0602	40	-.3002	23	17	289
6.2045	41	1.8755	61	-20	400
6.332	42	.2275	40	2	4
6.446	43	4.753	63	-20	400
6.514	44	-.0336	32	12	144
6.5314	45	.5085	44	1	1
6.8899	46	-.8899	13	33	1089
7.0583	47	-.2583	25	22	484
7.2968	48	.1432	38	10	100
7.3009	49	-.1809	27	22	484
7.3745	50	-.9745	9	41	1681

TABLE 39, (continued)

X			Y	D	D^2
7.4381	51	.6419	50	1	1
7.552	52	.4477	42	10	100
7.604	53	-.5646	18	35	1225
7.7203	54	1.319	60	- 6	36
7.9284	55	.5510	46	9	81
7.9737	56	1.146	59	-3	9
8.0289	57	.2110	39	18	324
8.7359	58	-.0158	34	24	576
9.653	59	-.6130	16	43	1849
9.8787	60	2.3613	62	- 2	4
10.804	61	-3.684	1	60	3600
11.06	62	.8595	53	9	81
12.106	63	-.9059	11	52	2704
					37448

Spearman coefficient → $R = 1 - \frac{6 \Sigma D^2}{n(n^2 - 1)}$

$$R = 1 - \frac{6\ (37448)}{249984}$$

$$= 1 - \frac{224688}{249984}$$

$$= 1 - .8988$$

$$\underline{R = .1012}$$

P - value

$Z = R\sqrt{n-1}$

$Z = .1012\ \sqrt{63-1}$

$Z = .1012\ (7.874)$

$Z = .7968$

H: no association

A: association exist

p = .2119 one-tail

p = .4238 two-tail

The null hypothesis of no association can not be rejected indicating homogenity of the residuals.

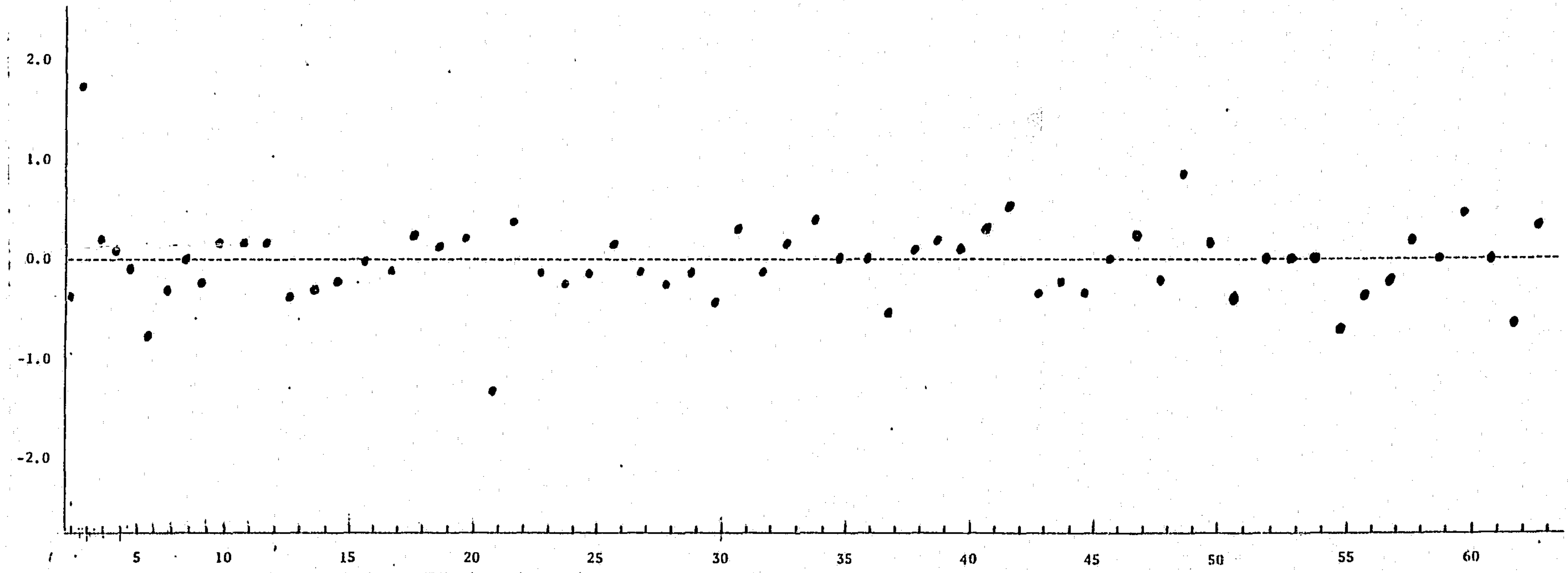

FIGURE 20 PLOT OF STANDARDIZED RESIDUAL

APPENDIX C

GOAL PROGRAM MODEL

AND

MATRIX GENERATOR

OBJECTIVE FUNCTION: W_p - PREEMPTIVE WEIGHT

W_R - RELATIVE WEIGHT

$$\text{Min } Z = W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} W_R V_{ijp}] + W_p[\sum_{i=1}^{3}\sum_{j=1}^{7} (3\, d^+_{ij,1} + d^-_{ij,1})] + W_p[\sum_{i=1}^{3} (3\, d^+_{i,2} + d^-_{i,2})] +$$

$$W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (d^+_{ijp,3} + d^-_{ijp,3})] + W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (d^+_{ijp,4} + d^-_{ijp,4})] + W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (2d^+_{ijp,5} + d^-_{ijp,5})] +$$

$$W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (d^+_{ijp,6} + d^-_{ijp,6})] + W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (d^+_{ijp,7} + d^-_{ijp,7})] + W_p[\sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} (d^+_{ijp,8} + 2d^-_{ijp,8})] +$$

$$W_p \sum_{i=1}^{3}\sum_{j=1}^{7}\sum_{p=1}^{8} [W_R(d^+_{ijp,9} + d^-_{ijp,9}) + W_R(d^+_{ijp,10} + d^-_{ijp,10}) + W_R(d^+_{ijp,11} + d^-_{ijp,11})]$$

CONSTRAINT SETS:

Total Available Effective Hours

$$\sum_{p=1}^{8} V_{ijp} \leq 599.2 \qquad V_i,\ V_j$$

Management Constraint of 3 Vehicles/Precinct

$$V_{ijp} \geq 16.8 \qquad V_i,\ V_j,\ V_p$$

Desired Vehicle Usage Level

$$\sum_{p=1}^{8} V_{ijp} + d^-_{ij,1} - d^+_{ij,1} = 358.4 \qquad V_i,\ V_j$$

AGGREGATE MANPOWER/WATCH CONSTRAINTS:

$$\sum_{j=1}^{7}\sum_{p=1}^{8} 1.17\, V_{1jp} + d^-_{1,2} - d^+_{1,2} = 2363.2$$

$$\sum_{j=1}^{7}\sum_{p=1}^{8} 1.3\, V_{2jp} + d^-_{2,2} - d^+_{2,2} = 4015.2$$

$$\sum_{j=1}^{7}\sum_{p=1}^{8} 1.32\, V_{3jp} + d^-_{3,2} - d^+_{3,2} = 3063.2$$

UTILIZATION RATIO CONSTRAINTS:

$$V_{ijp} + d^-_{ijp,3} - d^+_{ijp,3} = \frac{W_{ijp}}{.45} \quad V_i,\ V_j,\ V_p$$

PERFORMANCE MEASURE CONSTRAINTS: (Represents five different measures of performance)

$$V_{ijp} + d^-_{ijp,n} - d^+_{ijp,n} = \frac{b \times W_{ijp}}{P - a} \quad V_i,\ V_j,\ V_p, \text{ and } n = 4, \ldots, 8.$$

Where:

W_{ijp} = Workload for Watch i, Day j, Precinct p.

P = Level of Performance Desired

a, b = Regression coefficients from PCAM Output Curves

n represents the pair of deviational variables associated with each of the five performance measures.

TOTAL AVERAGE DELAY CONSTRAINTS:

$$V_{ijp} + d^-_{ijp,n} - d^+_{ijp,n} = G_m \qquad V_i,\ V_j,\ V_p,\ V_n;\ n = 9, 10, 11;\ m = 1, 2, 3$$

Where:

G_m = the three goal levels for the piecewise approximation

n represents the three pairs of deviational variables that correspond to the goal levels, G_m.

FIGURE 21 MODEL FORMULATION

```
      DIMENSION VAL (5256)
      DIMENSION 8 (1900), C (3300)
      DIMENSION IROWS (1900,2), ICOLS (3300,2)
      INTEGER DAT (5256,2)
      DATA DAT/10512*0/,VAL/5256*0./
      DATA IR, IX, IBLANK/'R', 'X', '    '/
      DATA EL, GEE, EE/' L  ', ' G  ', ' E  '/
      DATA ROW1, ROW2, COL1, COL2/'  RO', 'W   ', ' COL', 'UMN '/
      DATA RHS, OBJ, TECH/'RHS ', 'OBJ ', 'TECH'/
      DATA OBJ1, OBJ2/'OBJE', 'CT  '/
      DATA MAX, MIN/'MAX', 'MIN'/
      DATA ISTAR, JSTAR, IL, IG, IE, MINMAX, NAMES, ISPARS, IRANGE, IBOUND
     +/1725, 3240, 21, 168, 1536, 'MIN', 0, 1, 0, 0/
CCCCC READ INPUT DATA
CCCCC INPUT DATA REPRESENTS DECISION VARIABLE COEFFICIENTS
      READ (5,3)(VAL(L),L=1,2184)
    3 FORMAT (8F10.6)
CCCCC GENERATE DEVIATIONAL COEFFICIENTS
      DO 5 L=2185, 3720
      VAL(L)=1.0
    5 CONTINUE
      DO 6 L=3721, 5256
      VAL(L)=-1.0
    6 CONTINUE
CCCCC INDENTIFY LOCATION OF DATA IN DAT ARRAY
      NUM=0
      INUM=0
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 1
   10 DO 20 J=1,21
      DO 18 N=1,8
      NO=N-1
      NUM=NUM+1
      DAT(NUM,1)=J
      DAT(NUM,2)=J+NO*21
   18 CONTINUE
   20 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 2
      DO 25 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+21
      DAT(NUM,2)=J
   25 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 3
      DO 35 J=1,21
      DO 30 N=1,8
      NO=N-1
      NUM=NUM+1
      DAT(NUM,1)=J+189
      DAT(NUM,2)=J+NO*21
   30 CONTINUE
```

```
   35 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 4
      DO 50 J=1,3
      NO1=J-1
      ISTA=NO1*7
      DO 45 K=1,8
      NO2=1
      IF(K.EQ.1)NO2=0
      ISTA=ISTA+NO2*14
      DO 40 L=1,7
      NUM=NUM+1
      DAT(NUM,1)=J+210
      ISTA=ISTA+1
      DAT(NUM,2)=ISTA
   40 CONTINUE
   45 CONTINUE
   50 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 5
      DO 55 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+213
      DAT(NUM,2)=J
   55 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 6
      DO 60 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+381
      DAT(NUM,2)=J
   60 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 7
      DO 65 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+549
      DAT(NUM,2)=J
   65 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 8
      DO 70 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+717
      DAT(NUM,2)=J
   70 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 9
      DO 75 J=1,168
      NUM=NUM+1
      DAT(NUM,1)=J+885
      DAT(NUM,2)=J
   75 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 10
      DO 80 J=1, 168
      NUM=NUM+1
      DAT(NUM,1)=J+1053
      DAT(NUM,2)=J
   80 CONTINUE
CCCCC GENERATE LOCATION FOR CONSTRAINT SET 11
```

```
      DO 100 J=1,8
      NO=J-1
      IVAL=NO*21
      DO 95 K=1,3
      DO 90 L=1,21
      NUM=NUM+1
      INUM=INUM+1
      DAT(NUM,1)=1221+INUM
      DAT(NUM,2)=L+IVAL
   90 CONTINUE
   95 CONTINUE
  100 CONTINUE
CCCCC GENERATE LOCATION FOR NEGATIVE DEVIATIONALS WITH
    C POSITIVE COEFFICIENT
    C LPMPS - A USER INTERFACE WITH MPS/360
    C SIMPLIFIES MPS INPUT FORMATS
    C FOR DETAILS CONTACT D.S. RUBIN, SCHOOL OF BUSINESS ADMINISTRATION
    C UNIVERSITY OF NORTH CAROLINA, CHAPEL HILL
    C OR P.G. MCKEOWN
    C SCHOOL OF BUSINESS ADMINISTRATION
    C STATE UNIVERSITY OF NEW YORK, ALBANY
    C SEE "A USER'S GUIDE TO LPMPS", BY MCKEOWN AND RUBIN
    C A HOLDS TECHNOLOGY MATRIX IF NONSPARSE INPUT SPECIFIED
    C SIZE LIMITATIONS & NONSPARSE (30,30), SPARSE (300,300)
    C IROWS AND ICOLS HOLD ROW AND COLUMN NAMES
 8999 FORMAT (5I3,A3, 4I1)
    C ISTAR=#ROWS, JSTAR=# COLUMNS, IL=#LE, IG=#GE, IE=#EQ
    C NAMES=0 FOR INTERVAL, 1 FOR USER SUPPLIED
    C ISPARS=0 FOR NONSPARSE, 1 FOR SPARSE
    C IRANGE=0 FOR NO SENSITIVITY, 1 FOR RANGE SECTION OF MPS
    C IBOUND=0 FOR ALL STANDARD VARIABLES, 1 FOR NONSTANDARDS
    C GENERATE INTERNAL NAMES
  150 CONTINUE
      DO 160 I=1,ISTAR
      IROWS(I,1)=IR
  160 IROWS(I,2)=1000+I
      DO 170 I=1,JSTAR
      ICOLS(I,1)=IX
  170 ICOLS(I,2)=1000+I
    C READ RHS
 9005 FORMAT (8F10.6)
      DO 200 I=1,ISTAR
  200 B(I)=1.0
    C READ OBJECTIVE COEFFICIENTS
  210 READ (5,9005)(C(J),J=1,JSTAR)
  300 WRITE (6,9007) MINMAX, IBOUND, IRANGE
 9007 FORMAT ('NAME', 10X, 'CONTROL'/4X,'XCHAR01=''',A3,''''/4X,'XINT01=',I
      11/4X,'XINT02=',I1/'ENDATA'/'NAME',10X,'DATA',7X,'BINARY'/'ROWS'/'2N  OBJECT')
    C START MPS INPUT FILE, WRITE ROWS SECTION
      IF (IL.EQ.0) GO TO 320
      DO 310 I=1,IL
 9003 FORMAT (A4,A1,I4)
  310 WRITE (6,9003) EL, (IROWS(I,J),J=1,2)
```

```
 320 ILG=IL+1
     IGG=IL+IG
     IF (IG.EQ.0) GO TO 340
     DO 330 I=ILG,IGG
 330 WRITE (6,9003) GEE, (IROWS(I,J),J=1,2)
 340 IF(IE.EQ.0) GO TO 400
     IGE=IGG+1
     DO 350 I=IGE,ISTAR
 350 WRITE (6,9003) EE, (IROWS(I,J),J=1,2)
   C END OF ROWS SECTION.  START COLUMNS SECTION.
 400 WRITE (6,9008)
9008 FORMAT ('COLUMNS')
   C COLUMNS SECTION FOR SPARSE DATA
     DO 810 J=1,168
     WRITE (6,9011(ICOLS(J,JJ),JJ=1,2),OBJ1,OBJ2,C(J)
     DO 800 L=1,2184
     IF (DAT(L,2).NE.J) GO TO 800
     WRITE (6,9012)(ICOLS(J,JJ),JJ=1,2),(IROWS(DAT(L,1),JJ),JJ=1,2),
     + VAL(L)
 800 CONTINUE
 810 CONTINUE
     NUM=2184
     DO 110 J=1,1536
     NUM=NUM+1
     II=J+189
     LL=J+168
     WRITE (6,9011)(ICOLS(LL,JJ),JJ=1,2),OBJ1,OBJ2,C(LL)
 110 WRITE (6,9012)(ICOLS(LL,JJ),JJ=1,2),(IROWS(II,JJ),JJ=1,2),
     + VAL(NUM)
     DO 120 J=1,1536
     NUM=NUM+1
     II=J+189
     LL=J+1704
     WRITE (6,9011)(ICOLS(LL,JJ),JJ=1,2),OBJ1,OBJ2,C(LL)
 120 WRITE (6,9012)(ICOLS(LL,JJ),JJ=1,2),(IROWS(II,JJ),JJ=1,2),
     + VAL(NUM)
9011 FORMAT (4X,A1,I4,5X,2A4,2X,F12.6)
9012 FORMAT (4X,A1,I4,5X,A1,I4,5X,F8.5)
   C WRITE RHS COLUMN
 600 WRITE (6,9003) RHS
     DO 620 I=1,ISTAR
9021 FORMAT (T5,A4,T15,A1,I4,T25,F8.1)
 620 WRITE (6,9021) RHS,(IROWS(I,II),II=1,2),B(I)
 690 WRITE (6,9013)
9013 FORMAT ('ENDATA')
     STOP
     END
```

APPENDIX D

RESULTS OF INITIAL GOAL PROGRAMMING RUNS

Introduction

Appendix D presents the results of the eight initial goal programming runs used in the derivation of the preemptive weights for the objective function. The first eight tables, Table 40 through Table 47 express the actual vehicle hours assigned to each watch over an average week for each of the eight precincts. Each row of these tables reflects the dominant measure of performance indicated for a particular goal program run with the last row representing the case where all performance measures were weighted equally. The specific values exhibited are in units of actual vehicle hours and have been calculated from the goal program output which, is in units of effective vehicle hours, by multiplying effective vehicle hours times 1.4286 (1/.7).

TABLE 40

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 1

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	27.4	28.7	34.7	53.0	53.5	24.0	41.0	48.6	24.0	49.4	52.9	27.7	43.1	55.1	26.8	48.7	60.3	30.5	34.2	47.7	39.8
Probability Call Delay	27.4	28.6	34.7	53.1	53.5	24.0	40.9	48.6	24.0	50.8	52.9	27.7	43.2	55.2	26.8	43.0	60.3	30.5	34.2	47.8	39.8
Average Travel Time	24.0	24.0	27.2	41.5	41.9	24.0	32.1	38.1	185.5	38.7	41.4	24.0	33.8	43.2	24.0	38.1	47.1	24.0	26.8	37.4	31.2
Average Patrol Frequency	37.6	39.4	47.6	72.9	55.4	32.1	56.2	66.7	32.6	68.0	72.9	38.1	59.3	75.6	36.8	66.7	60.8	41.9	47.0	65.5	54.7
Patrol Hours/ Suppressible Crime	26.8	28.1	34.1	51.9	52.5	24.0	40.2	47.6	24.0	48.4	51.9	27.2	42.3	54.1	26.3	33.6	59.3	29.9	40.6	46.8	39.0
Average Number Cars Available	28.3	29.6	35.9	54.7	55.4	24.1	42.4	50.3	24.5	51.0	54.7	28.6	44.5	56.9	27.7	50.3	62.4	31.5	35.4	49.4	41.2
Total Average Delay	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
All Equal	24.0	24.0	27.2	24.0	24.0	24.0	32.1	24.0	24.0	24.0	24.0	27.2	33.8	24.0	26.8	24.0	24.0	24.0	26.8	24.0	31.2

TABLE 41

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 4

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	27.9	38.5	37.4	39.2	59.0	24.0	30.8	49.3	24.0	35.9	50.7	24.4	33.7	51.4	25.3	39.7	56.0	29.6	33.8	51.3	47.4
Probability Call Delay	28.3	39.1	38.0	39.8	60.0	24.0	31.4	50.1	24.0	36.5	51.6	24.8	34.3	52.3	25.7	40.4	56.9	30.1	34.4	52.1	48.3
Average Travel Time	32.5	44.9	43.6	45.6	68.7	26.8	36.0	57.6	27.4	41.9	59.0	28.4	39.4	59.8	29.5	46.2	65.2	34.5	39.4	59.8	55.4
Average Patrol Frequency	66.4	91.6	88.7	24.0	24.0	54.7	36.0	32.2	56.0	35.9	49.1	58.3	35.9	27.1	60.3	24.0	24.0	70.4	36.0	36.3	101.4
Patrol Hours/ Suppressible Crime	36.2	50.1	48.6	50.8	76.8	29.9	40.0	64.1	30.5	46.7	65.8	31.7	43.8	66.8	32.9	51.6	72.9	38.4	43.9	66.8	61.6
Average Number Cars Available	29.6	40.9	39.7	41.6	62.6	24.5	32.8	52.5	25.0	38.2	53.9	26.0	35.9	54.5	26.9	42.1	59.5	31.5	36.0	54.5	50.5
Total Average Delay	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
All Equal	27.9	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0	24.0	24.0	24.8	24.0	24.0	25.7	24.0	24.0	29.6	24.0	24.0	24.0

TABLE 42

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 5

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	30.8	43.6	36.0	44.2	55.3	24.0	30.6	47.5	24.0	37.8	55.6	24.0	32.5	53.2	24.0	33.6	56.2	24.0	37.8	59.4	36.3
Probability Call Delay	31.7	44.9	37.1	45.1	56.9	24.0	31.5	48.9	24.0	38.8	57.1	24.0	33.4	54.7	24.0	34.5	57.8	24.0	38.9	61.1	37.4
Average Travel Time	53.1	75.2	62.1	75.6	95.2	36.4	52.7	81.6	37.6	65.2	95.9	40.2	56.0	91.6	38.0	57.8	97.2	40.0	65.2	102.8	62.6
Average Patrol Frequency	59.5	85.9	82.6	24.0	24.0	48.4	70.0	50.0	49.9	37.8	24.0	53.5	39.5	53.2	50.5	40.7	24.0	53.1	37.8	24.0	83.1
Patrol Hours/ Suppressible Crime	37.3	148.1	43.7	53.1	67.1	25.6	37.1	57.6	26.4	45.8	67.4	28.3	39.5	64.6	26.7	40.7	68.3	28.1	45.9	72.2	44.1
Average Number Cars Available	32.5	46.1	38.0	46.2	58.3	24.0	32.3	50.1	24.0	39.9	58.5	24.6	34.3	56.2	24.0	35.4	59.3	24.4	39.9	62.6	38.3
Total Average Delay	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
All Equal	30.8	24.0	24.0	24.0	24.0	24.0	30.6	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0

TABLE 43

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 6

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	24.4	34.3	30.5	32.7	40.9	24.0	24.0	36.3	24.0	25.7	37.0	24.0	24.2	34.9	24.0	27.2	43.8	24.0	24.3	40.7	26.3
Probability Call Delay	27.3	38.3	34.1	36.5	45.8	24.0	26.6	40.6	24.0	28.7	41.4	24.0	27.1	29.0	24.0	30.5	49.1	26.2	27.2	45.6	29.4
Average Travel Time	24.7	34.8	31.0	33.1	41.5	24.0	24.1	36.8	24.0	26.1	37.6	24.0	24.6	35.4	24.0	27.6	44.5	24.0	24.6	41.3	26.7
Average Patrol Frequency	40.1	56.2	50.1	53.7	67.4	29.9	39.1	59.8	28.6	42.3	60.8	30.4	39.8	57.4	30.0	44.8	72.2	38.5	39.9	67.1	43.2
Patrol Hours/ Suppressible Crime	27.5	38.7	34.5	36.9	46.2	24.0	26.9	41.1	24.0	29.0	41.8	24.0	27.4	39.4	24.0	30.8	49.4	26.5	27.4	46.1	29.7
Average Number Cars Available	28.7	40.2	35.9	38.4	48.1	24.0	28.0	42.6	24.0	30.2	43.5	24.0	28.4	41.1	24.0	32.0	51.6	27.5	28.6	47.9	30.9
Total Average Delay	40.0	40.0	40.0	40.0	40.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	43.8	40.0	40.0	41.3	40.0
All Equal	40.1	283.0	282.3	53.7	63.4	40.0	40.0	59.8	40.0	42.3	223.2	30.4	40.0	57.4	304.5	44.8	72.2	299.2	40.0	178.3	43.2

TABLE 44

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 8

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	24.0	25.9	24.0	35.9	41.0	24.0	26.7	32.2	24.0	30.0	36.0	24.0	26.5	33.2	24.0	32.3	39.4	24.0	24.0	33.8	26.7
Probability Call Delayed	24.0	29.5	24.0	40.7	46.5	24.0	30.3	36.5	24.0	34.1	40.9	24.5	30.1	37.7	24.0	36.7	44.8	24.0	24.3	38.4	30.3
Average Travel Time	34.9	43.4	34.3	60.0	68.7	27.6	44.6	53.9	27.9	50.1	60.3	36.1	44.2	55.6	29.8	53.9	65.8	34.7	35.8	56.5	44.8
Average Patrol Frequency	37.4	46.5	36.7	64.4	73.6	29.6	47.8	57.6	29.9	53.7	64.6	38.7	47.5	59.5	31.9	57.8	70.7	37.3	38.3	60.5	47.9
Patrol Hours/ Suppressible Crime	24.0	28.9	24.0	40.0	45.8	24.0	29.8	35.9	24.0	33.5	40.1	24.1	29.5	37.0	24.0	36.0	43.9	24.0	24.0	37.7	29.8
Average Number Cars Available	25.1	31.3	24.7	43.2	49.4	24.0	32.2	38.8	24.0	36.2	43.4	26.0	31.8	40.0	24.0	38.9	47.5	25.1	25.8	40.7	32.2
Total Average Delay	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
All Equal	25.2	31.3	24.7	43.2	49.4	27.6	40.0	38.8	27.9	40.0	43.4	36.1	40.0	40.0	29.8	40.0	44.8	34.8	35.8	40.7	40.0

TABLE 45

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 11

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	24.0	28.7	31.3	47.4	47.7	24.0	30.3	43.0	24.0	30.7	40.6	25.1	32.1	46.1	24.0	34.7	50.2	24.0	28.5	41.4	33.6
Probability Call Delayed	24.0	30.9	33.7	46.5	51.4	24.0	32.6	46.4	24.0	33.1	43.7	27.0	34.6	49.6	24.0	37.4	54.1	24.3	30.6	44.6	36.2
Average Travel Time	24.0	24.0	24.0	29.0	32.0	24.0	24.0	28.9	24.0	24.0	27.3	24.0	24.0	30.9	24.0	24.0	33.7	24.0	24.0	27.8	24.0
Average Patrol Frequency	41.9	59.3	64.6	89.3	95.8	44.1	62.6	88.7	41.4	63.5	84.0	51.9	66.4	95.2	39.9	71.8	103.5	46.5	58.8	85.5	69.3
Patrol Hours/ Suppressible Crime	24.0	32.2	35.1	48.6	53.5	24.0	34.0	48.3	24.0	34.4	45.5	28.2	36.0	51.8	24.0	38.9	56.2	25.3	31.9	46.5	37.7
Average Number Cars Available	24.0	31.7	34.6	47.8	52.7	24.8	33.5	47.6	24.0	33.9	44.9	27.8	35.5	51.0	24.0	38.4	55.6	24.9	31.5	45.8	37.1
Total Average Delay	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4	655.4
All Equal	24.0	40.0	64.6	274.7	234.1	305.9	62.6	254.0	42.8	63.5	84.0	294.3	281.1	267.9	40.0	286.4	229.5	46.[illegible]	58.8	85.5	252.3

TABLE 46

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER DOMINANT PERFORMANCE MEASURE

Precinct 12

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Utilization Ratio	28.6	39.6	32.7	36.1	46.3	24.0	29.7	45.0	24.0	38.8	43.0	25.4	28.8	40.8	24.0	34.3	53.7	24.0	28.8	50.1	34.8
Probability Call Delayed	30.0	41.5	34.3	37.8	48.6	24.0	31.2	47.[illegible]	24.0	40.8	45.1	26.7	30.2	42.8	24.0	36.1	56.5	24.0	30.2	52.5	36.5
Average Travel Time	24.0	25.5	24.0	24.0	29.8	24.0	24.0	28.9	24.0	25.0	27.6	24.0	24.0	26.2	24.0	24.0	34.5	24.0	24.0	32.2	24.0
Average Patrol Frequency	57.6	79.8	65.8	72.9	93.4	42.5	60.0	91.0	42.3	78.5	86.6	51.2	58.1	82.1	37.2	69.3	86.3	43.7	58.1	101.3	70.4
Patrol Hours/ Suppressible Crime	31.8	44.1	36.4	40.1	51.6	24.0	33.1	50.1	24.0	43.3	47.8	28.2	32.0	45.6	24.0	37.8	59.8	24.1	31.9	55.8	38.2
Average Number Cars Available	30.9	42.8	35.3	38.9	50.1	24.0	32.1	48.6	24.0	42.0	46.4	27.4	31.1	44.1	24.0	37.1	58.1	24.0	31.1	54.1	32.6
Total Average Delay	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	24.0
All Equal	40.0	56.0	40.0	40.1	51.6	42.5	40.0	56.0	42.3	266.9	56.0	51.2	40.0	45.4	37.2	40.0	59.8	24.1	40.0	101.3	70.4

Percentage Attainment Tables

Tables 48 through Table 55 reflect the average percentage of attainment of the performance measures for each of the eight precincts given a dominant performance measure. The dominant performance measure is indicated on each table. Each row reflects the attainment level of the specified measure of performance for each precinct with the total average attainment achieved across all precincts indicated in the last column. The actual calculation of these values is thoroughly described in Chapter V, Section 5.3.2. The Total Average Delay, as always, is displayed in minutes due to the absence of a specific overall goal level being established. This was caused by the piecewise approximation of this measure of performance.

CONTINUED

3 OF 5

TABLE 48

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
UTILIZATION RATIO DOMINANT MEASURE

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	.999	.998	.951	.962	.941	.972	.981	.861	.958
Probability Call Delayed	1.007	.9866	.9837	.9312	.9355	.9563	.9712	.9745	.9682
Average Travel Time	1,278	.8599	.5863	1.025	.6351	1.535	1.585	.3218	.9782
Average Patrol Frequency	.7292	.4208	.4410	.6329	.5926	.4982	.5053	.5427	.5453
Patrol Hours Per Suppressible Crime	1.028	.7716	.8334	.9210	.9526	.9182	.9165	.8442	.8981
Average Number Cars Available	.9688	.9421	.9582	.8851	.8817	.9315	.9441	.8345	.9182
Total Average Delay (Min)	9.8	8.0	10.4	15.0	13.5	9.8	9.0	13.0	11.06

TABLE 49

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
PROBABILITY CALL DELAYED DOMINANT MEASURE

	Precincts								Total Average Attainment
	1	4	5	6	8	11	12	13	
Utilization Ratio	1.004	.983	.929	.875	.861	.918	.941	.802	.914
Probability Call Delayed	1.002	1.002	1.007	1.023	1.024	1.011	1.012	1.067	1.0185
Average Travel Time	1.271	.8735	.6005	1.127	.6951	1.624	1.653	.3526	1.0245
Average Patrol Frequency	.7256	.4275	.4516	.6957	.6486	.5271	.5269	.5946	.5747
Patrol Hours Per Suppressible Crime	1.023	.7838	.8535	1.012	1.042	.9714	.9557	.9249	.9457
Average Number Cars Available	.9640	.9571	.9813	.9728	.9651	.9855	.9845	.9143	.9655
Total Average Delay (Min)	10.0	9.2	10.5	7.8	9.0	7.8	7.5	10.3	9.0125

TABLE 50

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
AVERAGE TRAVEL TIME DOMINANT MEASURE

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	1.003	.858	.558	1.053	.598	1.266	1.326	.289	.869
Probability Call Delayed	1.003	1.147	1.677	.9419	1.473	.7333	.7183	3.030	1.340
Average Travel Time	1.273	1.000	1.000	1.037	1.000	1.177	1.172	1.000	1.082
Average Patrol Frequency	.7265	.4895	.7521	.6402	.9332	.3820	.3737	1.687	.7480
Patrol Hours Per Suppressible Crime	1.024	.8974	1.4215	.9315	1.500	.7041	.6779	2.625	1.222
Average Number Cars Available	.965	1.095	1.634	.8953	1.388	.7143	.6983	2.594	1.247
Total Average Delay (Min)	10.0	6.5	3.2	12.2	3.5	≈24.0	≈22.0	3.2	10.6

TABLE 51

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
AVERAGE PATROL FREQUENCY DOMINANT MEASURE

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	.755	.783	.759	.608	.558	.485	.503	.487	.617
Probability Call Delayed	1.334	1.258	1.233	1.471	1.578	1.914	1.893	1.796	1.559
Average Travel Time	1.692	1.096	.7349	1.621	1.071	3.073	3.090	.5931	1.621
Average Patrol Frequency	.9658	.5367	.5527	1.000	1.000	.9974	.9851	1.000	.8797
Patrol Hours Per Suppressible Crime	1.362	.9839	1.044	1.455	1.607	1.838	1.786	1.555	1.453
Average Number Cars Available	1.283	1.201	1.201	1.398	1.487	1.864	1.840	1.537	1.476
Total Average Delay (Min)	3.6	4.8	5.8	2.8	3.7	1.1	1.1	4.4	3.412

TABLE 52

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
PATROL HOURS PER SUPPRESSIBLE CRIME DOMINANT MEASURE

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	1.026	.770	.793	.867	.873	.886	.894	.719	.854
Probability Call Delayed	.9809	1.279	1.180	1.032	1.009	1.048	1.065	1.190	1.097
Average Travel Time	1.244	1.115	.7036	1.137	.6852	1.683	1.740	.3932	1.087
Average Patrol Frequency	.7101	.5458	.5292	.7016	.6394	.5463	.5546	.6632	.6112
Patrol Hours Per Suppressible Crime	1.001	1.000	1.000	1.020	1.027	1.006	1.005	1.031	1.011
Average Number Cars Available	.9434	1.221	1.149	.9811	.9514	1.021	1.036	1.019	1.040
Total Average Delay (Min)	10.0	4.4	6.8	7.8	9.1	7.0	6.0	8.1	7.4

TABLE 53

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES: AVERAGE NUMBER OF CARS AVAILABLE DOMINANT MEASURE

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	.968	.941	.908	.838	.818	.897	.917	.697	.873
Probability Call Delayed	1.040	1.046	1.030	1.068	1.077	1.035	1.039	1.202	1.067
Average Travel Time	1.319	.9123	.6143	1.177	.7313	1.662	1.696	.3972	1.064
Average Patrol Frequency	.7529	.4465	.4621	.7264	.6824	.5394	.5406	.6698	.603
Patrol Hours Per Suppressible Crime	1.062	.8187	.8733	1.056	1.096	.9941	.9805	1.041	.9902
Average Number Cars Available	1.000	.9996	1.004	1.015	1.015	1.008	1.010	1.029	1.010
Total Average Delay (Min)	9.2	7.6	10.0	6.4	8.0	7.8	7.0	8.2	8.025

TABLE 54

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES
TOTAL AVERAGE DELAY DOMINANT MEASURE

	Precincts 1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	1.687	1.603	1.530	.717	1.142	.050	.855	1.010	1.074
Probability Call Delayed	.5964	.6142	.6118	1.247	.7710	18.49	1.114	.8673	3.038
Average Travel Time	.7568	.5354	.3646	1.374	.5233	29.69	1.818	.2864	4.418
Average Patrol Frequency	.4317	.2620	.2743	.8480	.4884	9.638	.5797	.4830	1.625
Patrol Hours Per Suppressible Crime	.6091	.4804	.5183	1.233	.7850	17.76	1.051	.7513	2.898
Average Number Cars Available	.5736	.5866	.5959	1.185	.7266	18.01	1.083	.7427	2.932
Total Average Delay (Min)	17.8	15.0	17.2	4.2	22.0	<1.0	5.8	18.5	12.65

TABLE 55

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES:
ALL WEIGHTS SET EQUAL

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	1.575	1.566	1.494	.264	.744	.210	.578	.829	.908
Probability Call Delayed	.639	.6289	.6264	3.385	1.184	4.427	1.647	1.033	1.696
Average Travel Time	.811	.5481	.3733	3.729	.8037	7.107	2.688	.3410	2.050
Average Patrol Frequency	.4626	.2683	.2808	2.301	.750	2.307	.8568	.575	.9752
Patrol Hours Per Suppressible Crime	.6526	.4919	.5307	3.348	1.206	4.251	1.554	.8945	1.616
Average Number Cars Available	.6145	.6006	.6101	3.218	1.116	4.313	1.601	.8842	1.620
Total Average Delay (Min)	18.0	15.0	18.0	1.4	6.1	<1.0	1.4	12.0	9.11

Value Path Analysis

The final section of Appendix D presents a value path analysis of the percentage attainment levels of the performance measures for each precinct. The scales on the vertical axis are all percentages with each line, extending across the figure, representing the levels of attainment each measure of performance exhibits when a particular measure is designated as a dominant criteria. Figure 22 through Figure 29 reflect the results exhibited in each of the eight precincts. A percentage attainment value is not shown for the Total Average Delay Measure of Performance. This is because a single goal level was never specified for this measure due to the piecewise approximation. Note that for each value path, the dominant measure of performance is indicated by the first letters of its name as shown below:

UR = Utilization Ratio
PCD = Probability Call Delayed
ATT = Average Travel Time
APF = Average Patrol Frequency
PH/SC = Patrol Hours Per Suppressible Crime
ACA = Average Number Cars Available
AWSE = All Weights Set Equal
TAD = Total Average Delay

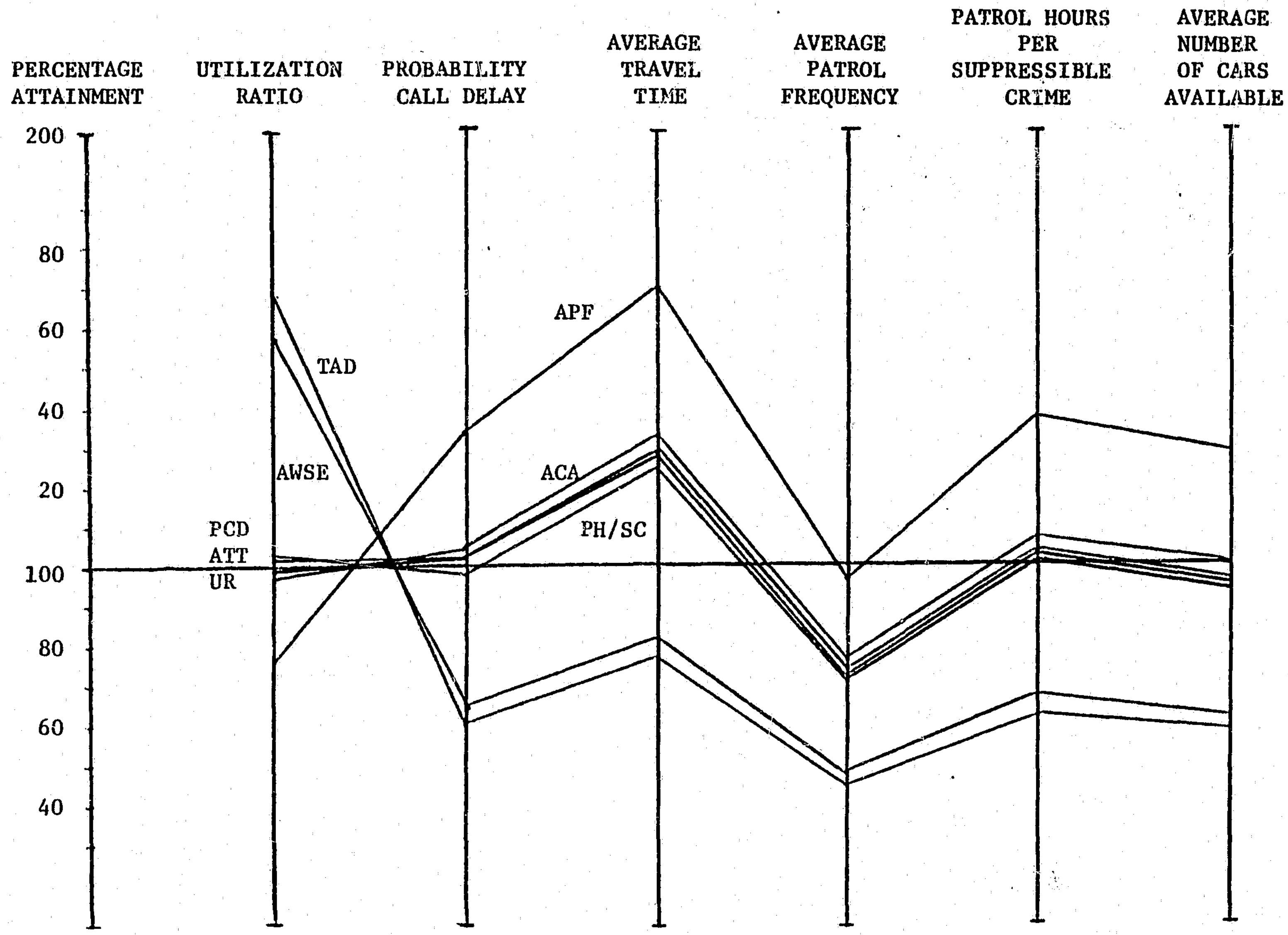

FIGURE 22 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 1

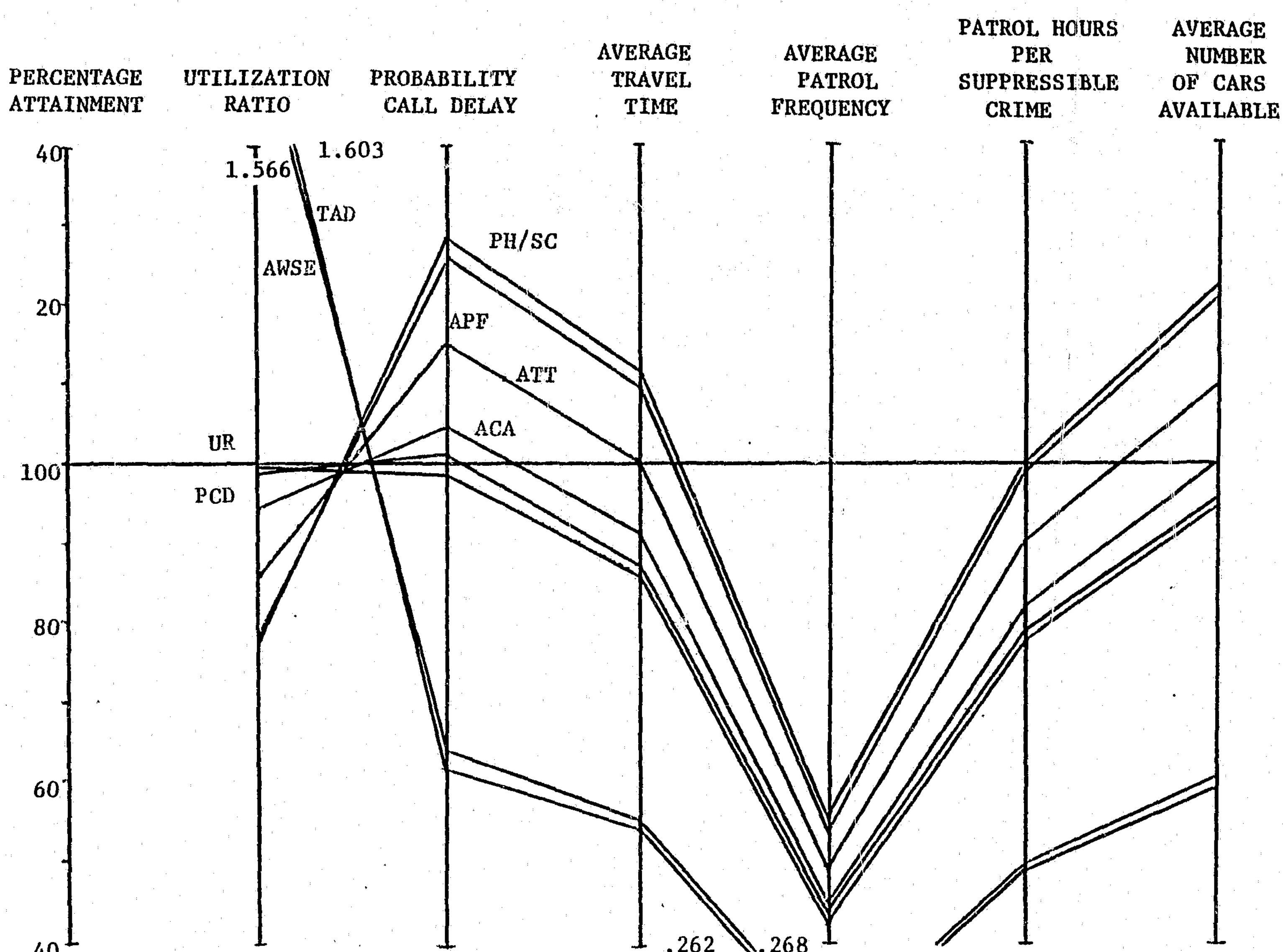

FIGURE 23 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 4

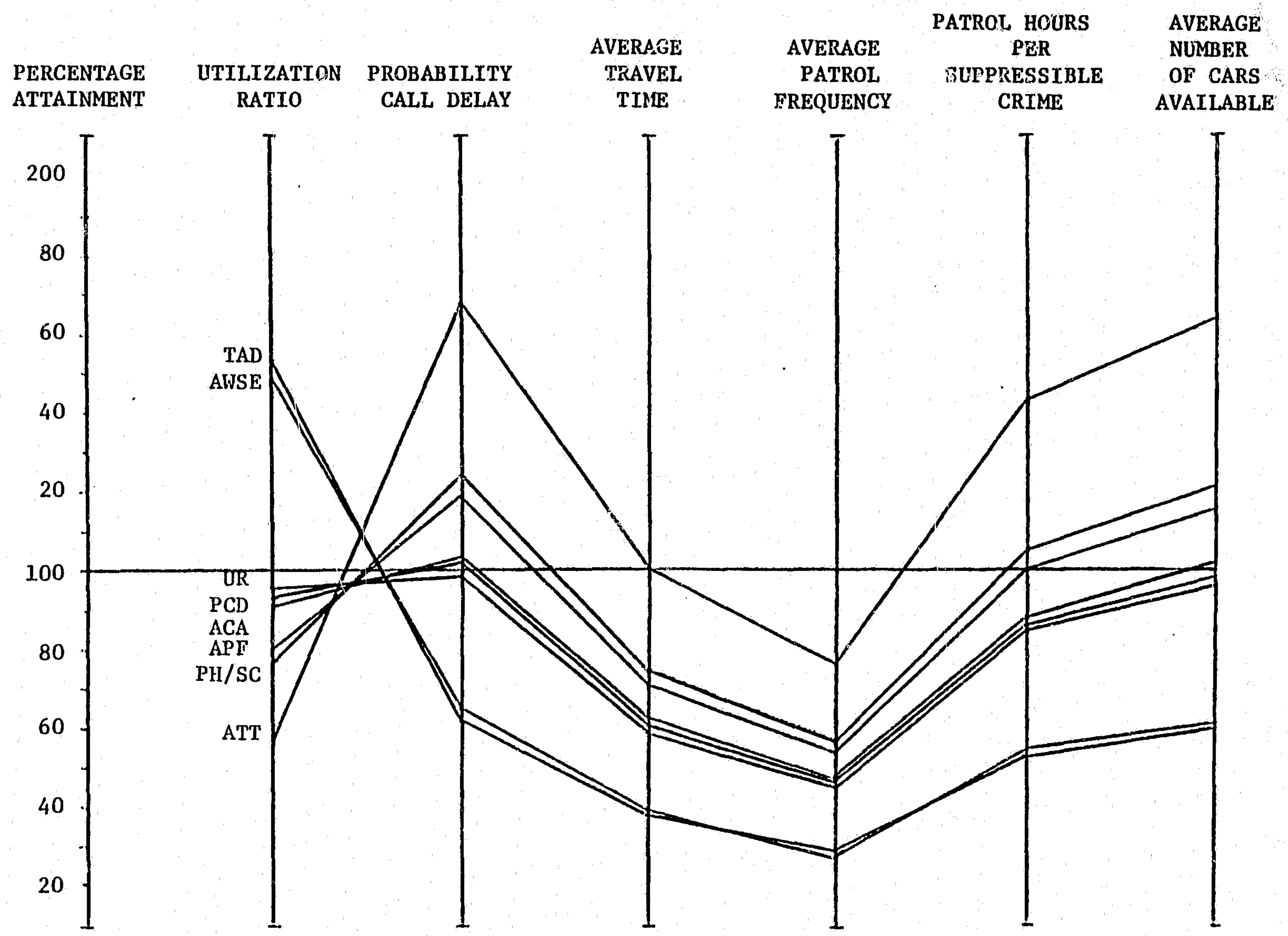

FIGURE 24 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 5

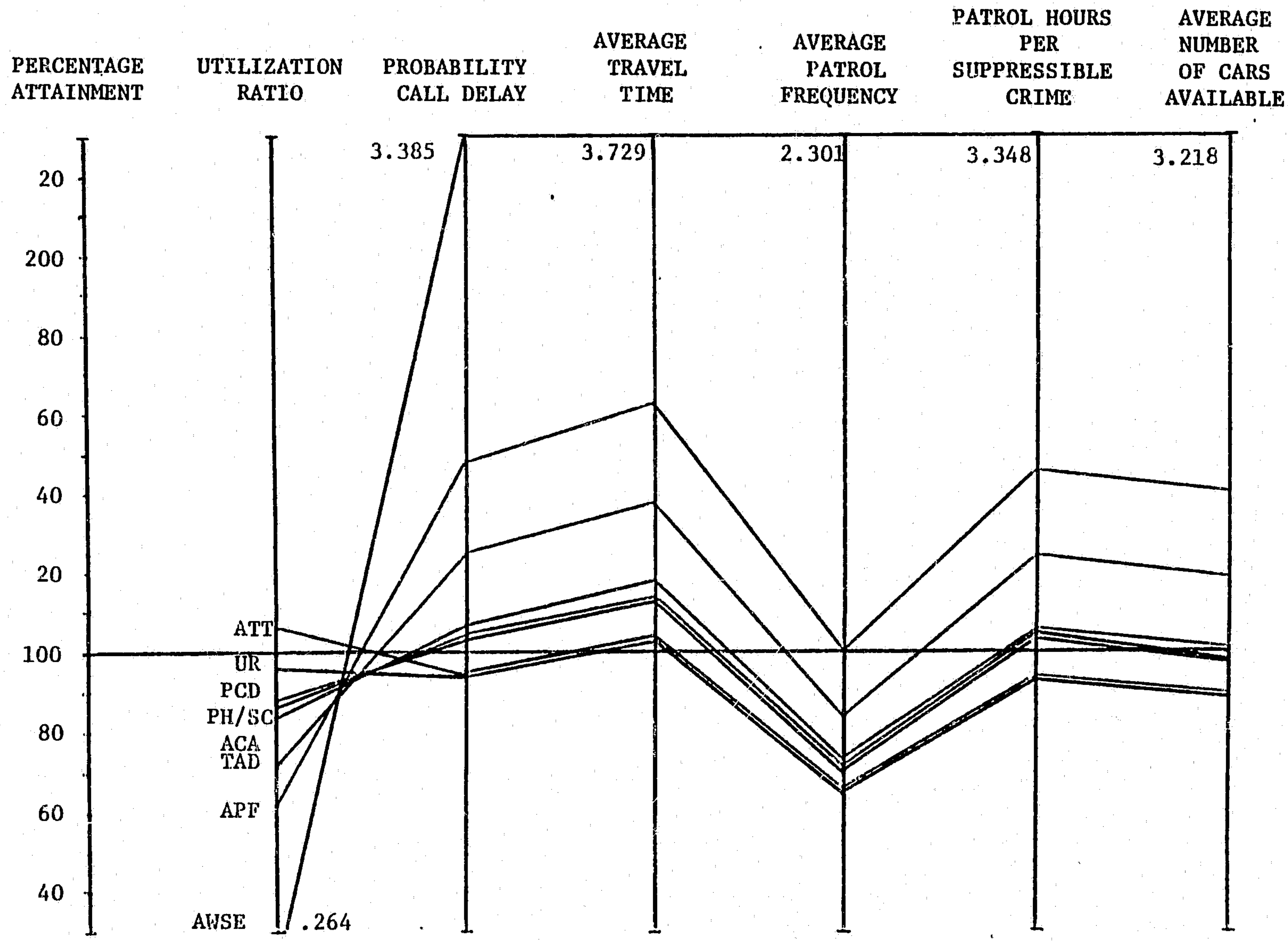

FIGURE 25 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 6

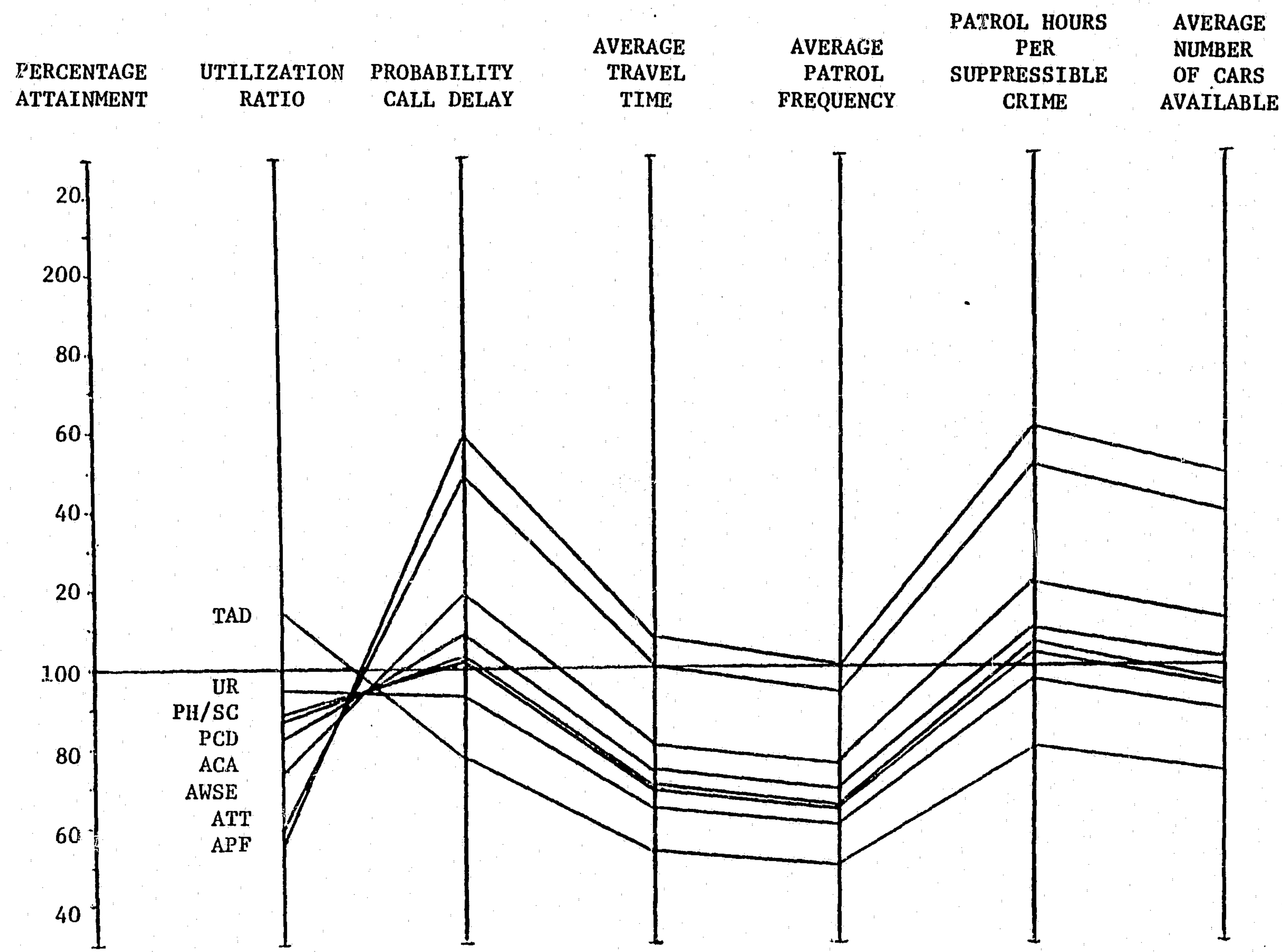

FIGURE 26 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 8

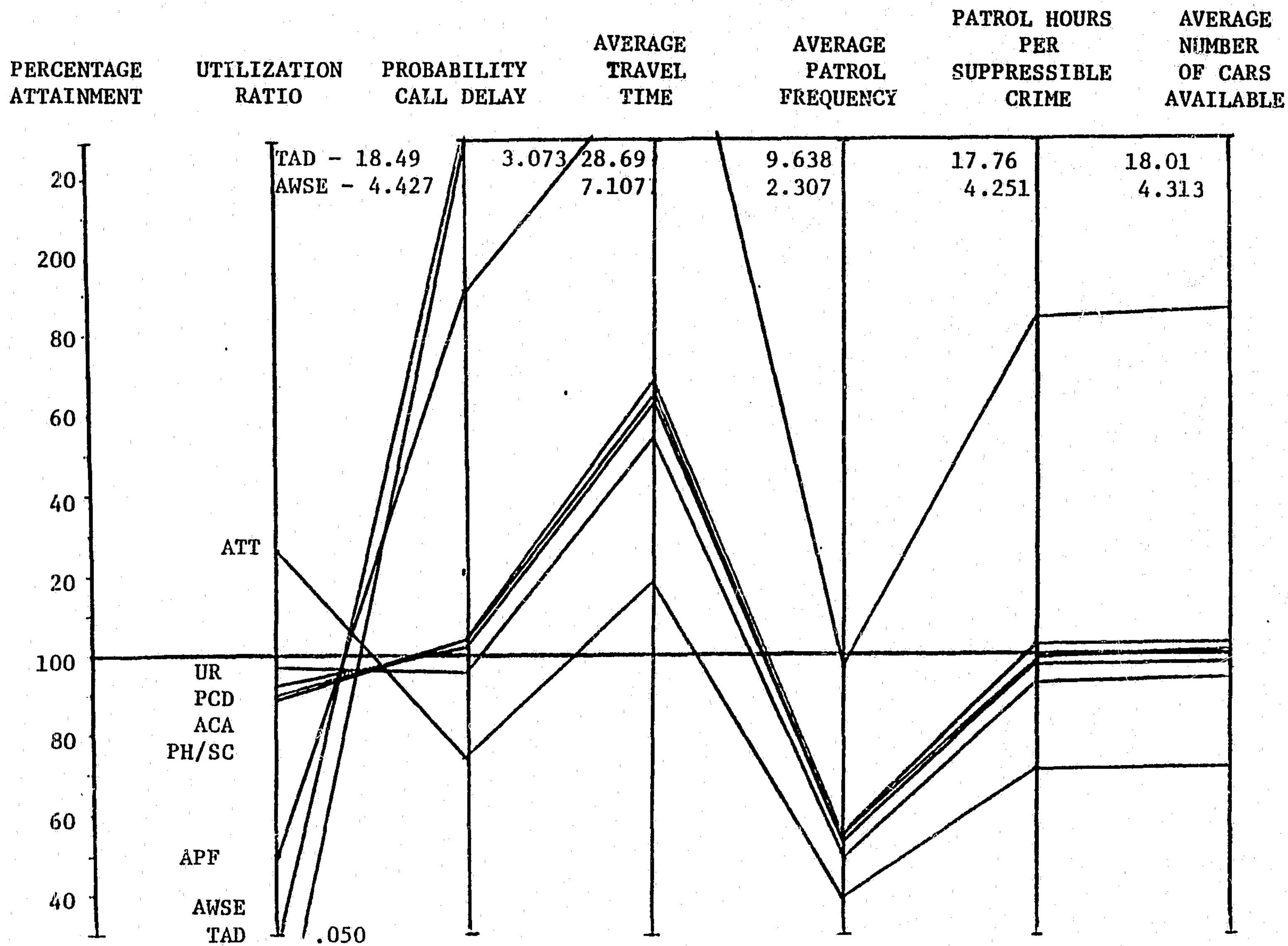

FIGURE 27 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 11

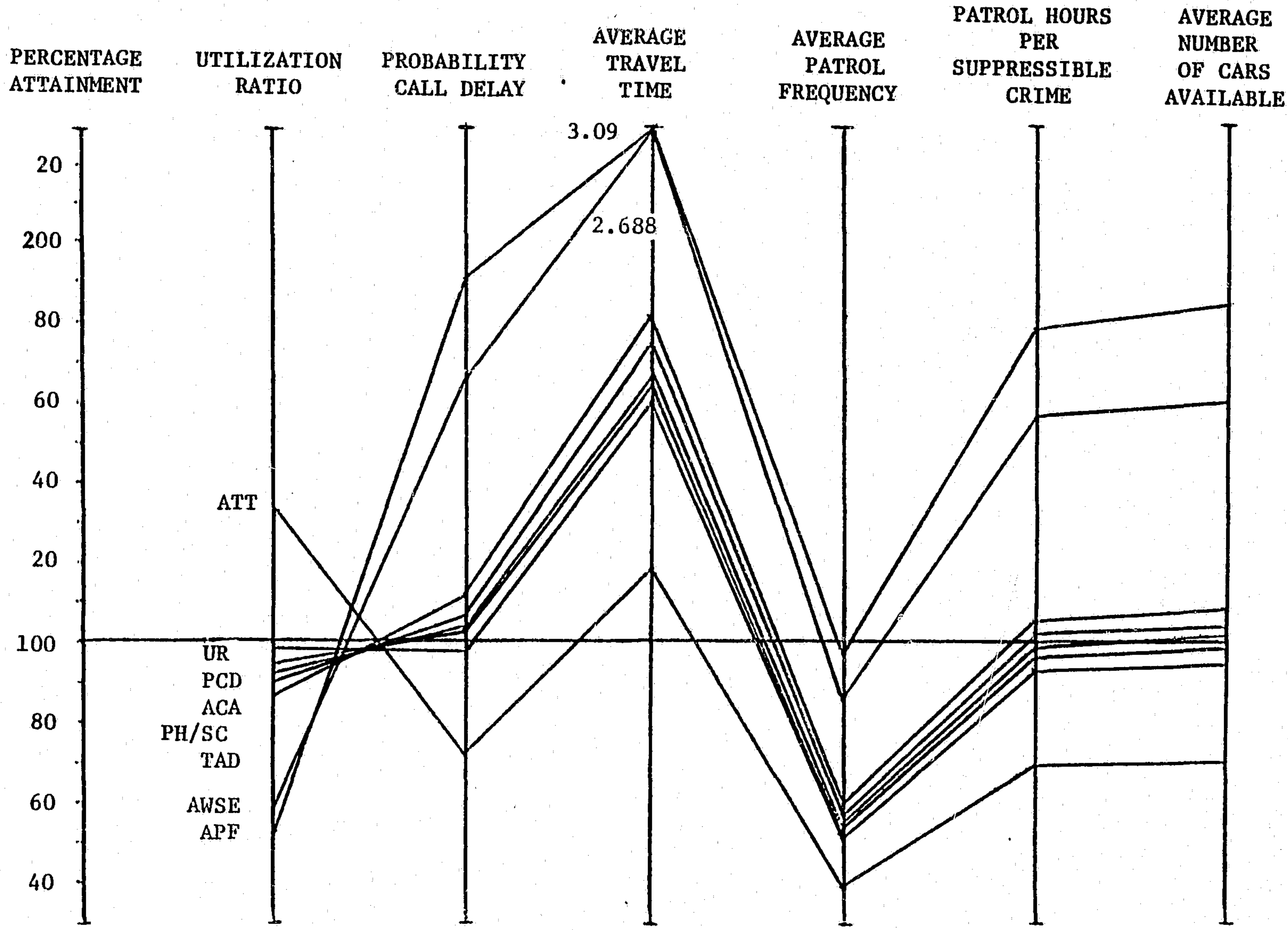

FIGURE 28 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 12

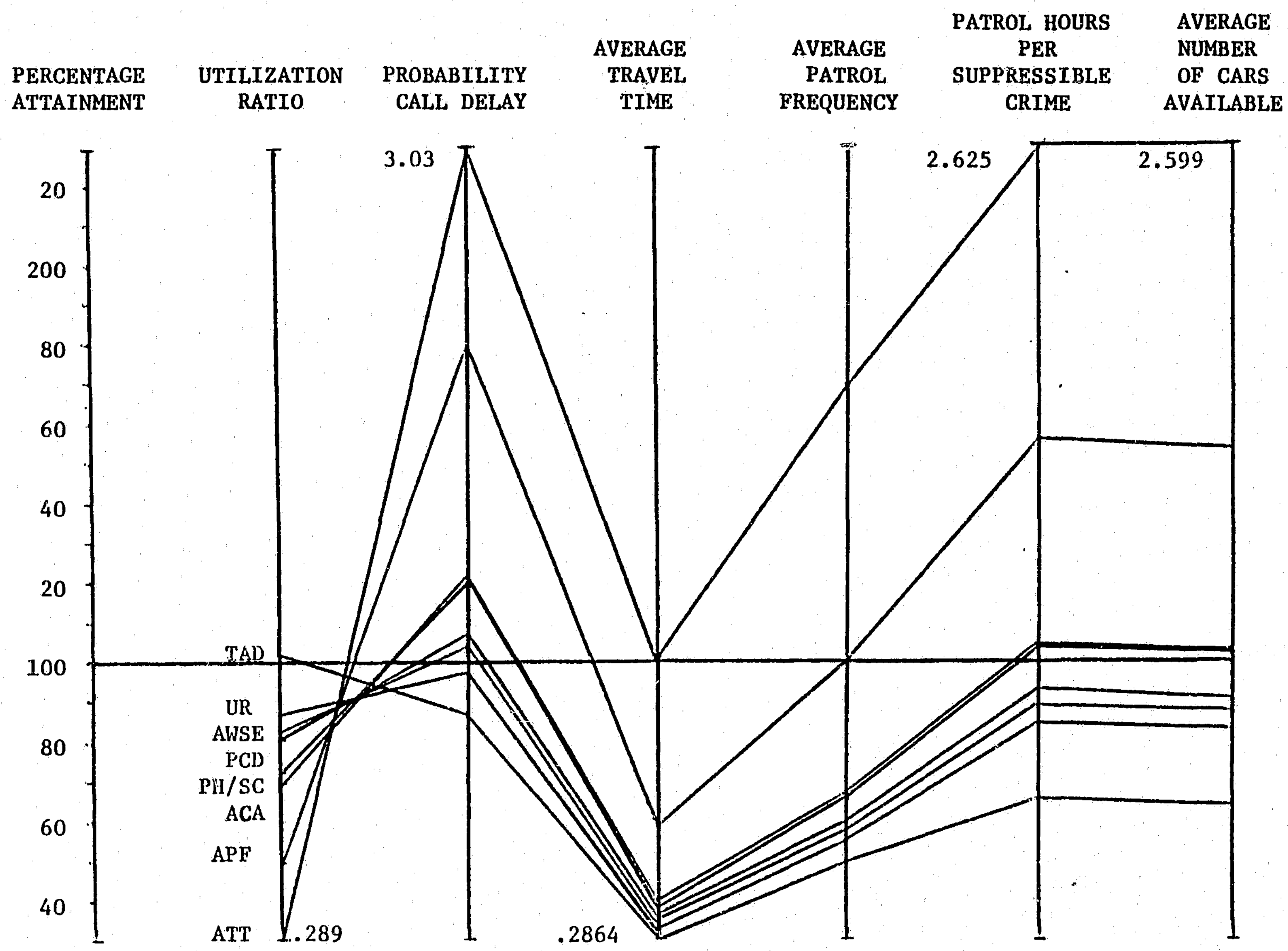

FIGURE 29 VALUE PATH ANALYSIS INITIAL GOAL PROGRAM RUNS: PRECINCT 13

APPENDIX E

RESULTS OF FINAL GOAL PROGRAMMING RUNS

Introduction

Appendix E presents the results obtained in the final goal program runs. There were actually two separate runs made with the preemptive weights exhibited in Table 20, Chapter V. As indicated by Table 56 and Table 57, the actual vehicle hours assigned across precincts are, for all practical purposes, identical. Because the assignment of actual vehicle hours was satisfactory to the Planning and Research Department and both sets of weights exhibited similar results, further goal program runs were unnecessary.

Tables 56 and 57 display, across the row for each precinct, the actual vehicle hours allocated for each watch during every day of an average week. The final two columns display the total average actual and effective hours allocated to each precinct on a per watch basis. At the bottom of each table are shown the preemptive weights used for that particular goal program run.

TABLE 56

ACTUAL VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER PRECINCT - FINAL GOAL PROGRAM RUN

Days	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Average	
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Act*	Eff*
Precinct 1	27.4	28.7	34.7	53.0	53.5	24.0	41.0	48.6	24.5	49.4	52.9	27.7	43.1	55.1	26.8	48.7	60.3	30.5	34.2	47.8	39.8	40.5	28.4
Precinct 4	32.5	44.9	43.6	45.6	68.7	26.8	36.0	57.6	27.4	41.9	59.0	28.5	39.4	59.8	29.5	46.2	65.2	34.5	39.4	59.8	55.4	44.8	31.4
Precinct 5	53.1	75.2	62.1	75.6	95.2	36.4	52.7	81.6	37.6	65.2	95.9	40.2	56.0	91.6	38.0	57.8	97.2	40.0	65.2	102.8	62.7	65.8	46.1
Precinct 6	27.3	40.2	35.9	38.4	48.1	24.0	26.6	42.6	24.0	29.0	43.6	24.0	27.1	41.1	24.0	32.0	51.6	26.6	27.2	47.9	29.7	33.8	23.7
Precinct 8	34.9	43.4	34.3	60.0	68.7	27.6	44.6	53.9	28.0	50.1	60.3	36.1	44.2	55.6	29.8	53.9	65.8	34.8	35.8	56.5	44.8	45.9	32.1
Precinct 11	24.0	28.7	31.3	47.8	52.7	24.0	30.3	47.6	24.0	30.7	43.7	25.1	32.1	51.0	24.0	34.7	54.1	24.0	28.5	44.6	33.6	35.1	24.5
Precinct 12	28.6	39.6	32.7	36.1	50.1	24.0	29.7	47.1	24.0	38.9	45.1	25.4	28.8	40.8	24.0	34.3	58.1	24.0	28.8	54.1	34.8	35.7	25.0
Precinct 13	36.4	53.3	39.0	59.5	132.3	24.0	39.0	65.8	24.0	49.1	70.0	24.0	45.4	61.8	24.0	51.8	71.1	46.4	45.2	98.5	42.0	52.5	36.7

	Weights	Normalized
Travel Time	1.0	.303
Utilization Ratio	.8	.2424
Average Patrol Frequency	.6	.1818
Average Number Cars Available	.4	.1212
All Other Performance Measures	.1	.0303

* Act = Actual
* Eff = Effective

TABLE 57

VEHICLE HOURS ALLOCATED PER WATCH PER DAY PER PRECINCT - FINAL GOAL PROGRAM RUN

Day	Sunday			Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Average	
Watch	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Act*	Eff*
Precinct 1	27.4	28.7	34.7	53.0	53.5	24.0	41.0	48.6	32.6	49.4	52.9	27.7	43.1	55.2	26.8	48.7	60.3	30.5	34.2	47.8	39.8	40.9	28.6
Precinct 4	32.5	44.9	43.6	45.6	68.7	26.8	36.0	57.6	27.4	41.9	59.0	28.5	39.4	59.8	29.5	46.2	65.2	34.5	39.4	59.8	55.4	44.8	31.4
Precinct 5	53.1	75.2	62.1	75.6	95.2	36.4	52.7	81.6	37.6	65.2	95.9	40.2	56.0	91.6	38.0	57.8	97.2	40.0	65.2	102.8	62.7	65.8	46.1
Precinct 6	28.7	40.2	35.9	38.4	67.4	24.0	28.0	42.6	24.0	30.2	43.6	24.0	28.5	41.1	24.0	32.0	72.2	27.5	28.6	67.1	30.9	37.1	26.0
Precinct 8	34.9	43.4	34.3	60.0	73.6	27.6	44.6	53.9	28.0	50.1	60.3	36.1	44.2	55.6	29.8	53.9	65.8	34.8	35.8	56.5	44.8	46.1	32.3
Precinct 11	24.0	28.7	31.3	47.8	52.7	24.0	30.3	47.6	24.0	30.7	44.9	25.1	32.1	51.0	24.0	37.4	54.1	24.0	28.5	45.8	36.2	35.4	24.8
Precinct 12	28.6	41.5	32.7	37.8	56.1	24.0	29.7	48.6	24.0	40.8	46.4	25.4	28.8	44.1	24.0	34.3	58.1	24.0	28.8	54.1	34.8	36.2	25.4
Precinct 13	36.4	53.3	39.0	59.5	132.3	27.1	39.0	111.6	24.5	49.1	118.1	34.2	45.4	61.8	31.7	51.8	120.0	46.4	45.2	121.1	42.0	61.4	43.0

	Weights	Normalized
Travel Time	1.0	.303
Utilization Ratio	.6	.1818
Average Patrol Frequency	.8	.2424
Average Number Cars Available	.4	.1212
All Other Performance Measures	.1	.0303

* Act = Actual
* Eff = Effective

Goal Attainment Measures

Table 58 and Table 59 present the percentage goal attainments for each performance measure obtained in running the goal model with the two sets of preemptive weights shown in Table 20, Chapter V. These tables correspond to Table 56 and Table 59, respectively. Each row represents the average percentage attainment for that particular performance measure averaged across all watches and all days for each precinct, given the weighting scale presented below the table. The last column displays an overall average attainment percentage across all precincts. Each of the values found in Table 58 and Table 59 were calculated in the same manner as those percentage attainment values exhibited in Appendix D and as were described in Section 5.3.2. Once again the Total Average Delay measure of performance is presented in minutes due to the piecewise approximation of this measure and the absence of a single goal level.

TABLE 58

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES

	Precincts 1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	.991	.858	.557	.773	.594	.929	.942	.386	.754
Probability Call Delayed	1.015	1.148	1.679	1.158	1.482	1.00	1.010	2.22	1.339
Average Travel Time	1.288	1.000	1.001	1.276	1.006	1.605	1.649	.733	1.195
Average Patrol Frequency	.735	.4898	.7527	.7872	.939	.521	.5257	1.236	.748
Patrol Hours Per Suppresible Crime	1.037	.8979	1.422	1.145	1.509	.960	.9535	1.923	1.231
Average Number Cars Available	.976	1.096	1.635	1.101	1.397	.974	.9822	1.901	1.258
Total Average Delay (Min)	9.7	6.1	3.2	5.6	3.6	7.6	7.0	3.6	5.8

PREEMPTIVE WEIGHTS

Travel Time = 1.0
Utilization Ratio = .6
Average Patrol Frequency = .8
Average Number Cars = .4
all other weights = .1

TABLE 59

PERCENTAGE ATTAINMENT OF PERFORMANCE MEASURES

	Precincts								
	1	4	5	6	8	11	12	13	Total Average Attainment
Utilization Ratio	.998	.858	.557	.847	.598	.940	.958	.452	.776
Probability Call Delayed	1.008	1.148	1.679	1.056	1.473	.988	.994	1.895	1.280
Average Travel Time	1.279	1.000	1.001	1.163	1.000	1.586	1.623	.626	1.159
Average Patrol Frequency	.7299	.4898	.7527	.7175	.9331	.5147	.5174	1.055	.714
Patrol Hours Per Suppressible Crime	1.0297	.8979	1.422	1.044	1.50	.9485	.9384	1.641	1.178
Average Number Cars Available	.9696	1.096	1.635	1.003	1.388	.9623	.9667	1.622	1.205
Total Average Delay (Min)	9.7	6.1	3.2	7.2	4.0	7.8	7.4	4.1	6.2

PREEMPTIVE WEIGHTS

Travel Time = 1.0
Utilization Ratio = .8
Average Patrol Frequency = .6
Average Number Cars = .4
all other weights = .1

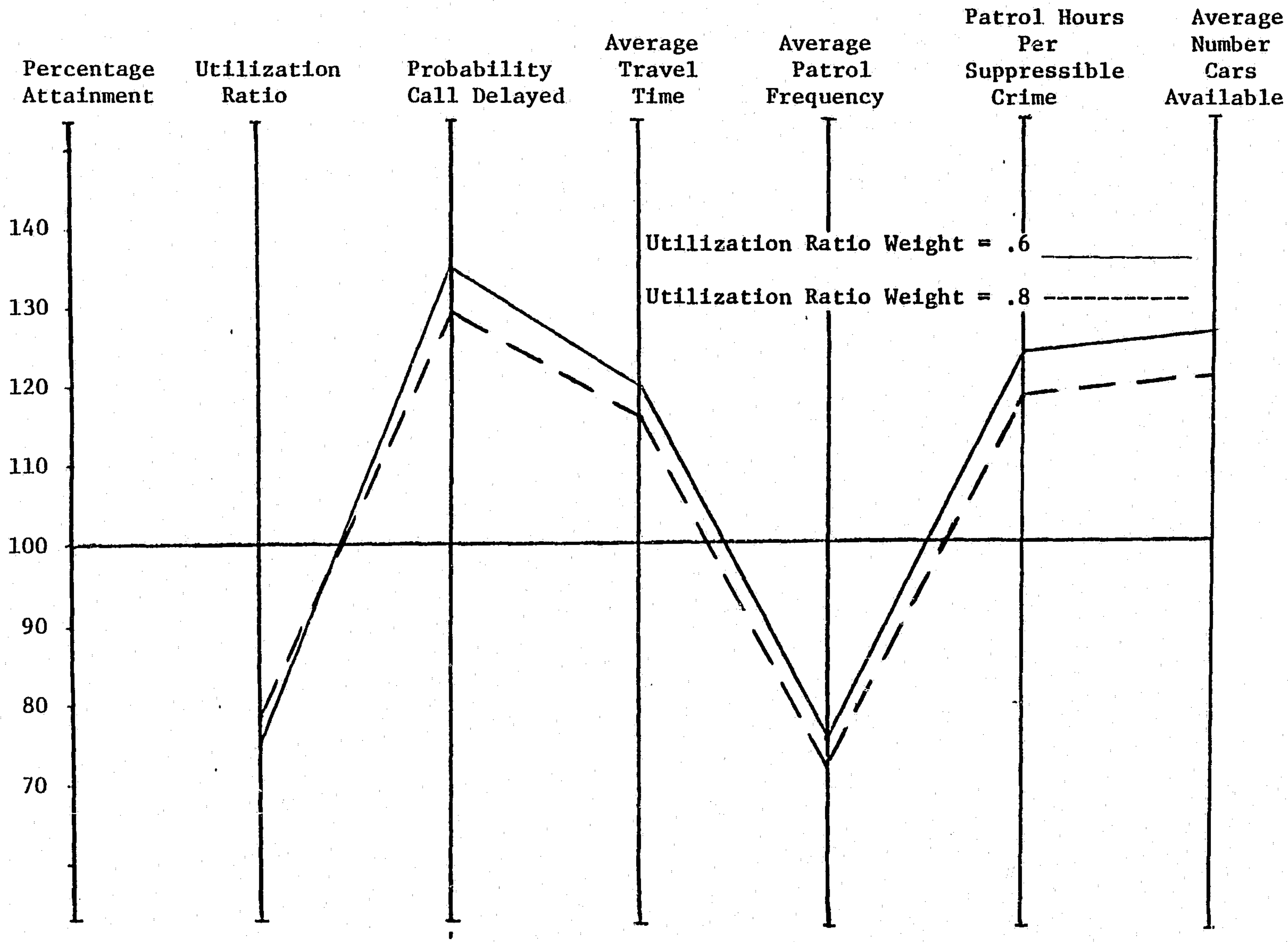

FIGURE 30 VALUE PATH ANALYSIS FINAL ALLOCATION AVERAGED OVER ALL PRECINCTS

Vehicle Schedules

Tables 60, 61, and 62 present vehicle schedules in terms of the number of vehicles assigned on a per watch per day basis for each precinct. Table 60 reflects the actual allocation of patrol vehicles which was present in Columbus, Ohio during Quarter Three, 1975. Table 61 exhibits the patrol vehicle schedule derived directly from transforming the vehicle hours assigned in the goal program results displayed in Table 57 into actual numbers of vehicles. The actual allocation of vehicles in Table 61 was adjusted by a member of the four man decision team from the Planning and Research Department to arrive at a feasible operating schedule of patrol vehicles across each precinct on a per watch per day basis. Table 62 reflects this smoothed vehicle allocation. Table 61 and Table 62 represent the final results obtained in employing the research methodology described in this work.

TABLE 60

ACTUAL COLUMBUS ALLOCATION

Precinct 1

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	5	6	6	6	6	6	5
Watch	2	7	7	8	8	8	8	8
	3	7	6	6	7	7	7	7

Precinct 4

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	6	6	6	6	6	6	6
Watch	2	7	7	8	8	8	8	8
	3	7	7	6	6	7	7	7

Precinct 5

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	6	6	6	6	6	6	6
Watch	2	8	8	8	8	8	8	8
	3	6	6	5	5	6	6	6

Precinct 6

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	5	5	5	5	5	5	5
Watch	2	7	7	7	7	7	7	7
	3	6	6	6	6	6	6	6

TABLE 60 (cont.)

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		Precinct 8						
	1	4	4	4	4	4	4	4
Watch	2	5	5	6	6	6	6	6
	3	5	4	4	5	5	5	5
		Precinct 11						
	1	5	5	5	5	5	5	5
Watch	2	8	8	8	7	7	8	8
	3	6	6	6	5	5	6	6
		Precinct 12						
	1	5	5	5	5	5	5	5
Watch	2	7	7	7	7	7	7	7
	3	5	5	5	5	5	5	5
		Precinct 13						
	1	4	4	4	4	4	4	4
Watch	2	6	6	6	5	5	6	6
	3	4	4	4	4	4	4	4

TABLE 61

ACTUAL GOAL PROGRAM ALLOCATION

Precinct 1

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	4	7	5	6	6	6	5
Watch	2	4	7	6	7	7	8	6
	3	5	3	3	4	4	4	5

Precinct 4

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	4	6	5	5	5	6	5
Watch	2	6	9	7	8	8	8	8
	3	6	4	4	4	4	4	7

Precinct 5

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	7	9	7	8	7	7	8
Watch	2	9	12	10	12	12	12	13
	3	8	5	5	5	5	5	8

Precinct 6

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	4	5	4	4	4	4	4
Watch	2	5	6	6	6	5	7	6
	3	5	3	3	3	3	4	4

TABLE 61 (cont.)

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					Precinct 8			
	1	5	8	6	7	6	7	5
Watch	2	6	9	7	8	7	8	7
	3	5	4	4	5	4	5	6
					Precinct 11			
	1	3	6	4	4	4	5	4
Watch	2	4	7	6	6	7	7	6
	3	4	3	3	3	3	3	4
					Precinct 12			
	1	4	5	4	5	4	5	4
Watch	2	5	7	6	6	5	8	7
	3	4	3	3	4	3	3	5
					Precinct 13			
	1	5	8	5	7	6	7	6
Watch	2	7	16	8	9	8	9	12
	3	5	3	3	3	3	6	6

TABLE 62

SMOOTHED GOAL PROGRAM ALLOCATION

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		Precinct 1						
	1	5	6	6	6	6	6	5
Watch	2	6	7	7	7	7	7	6
	3	5	4	4	4	4	4	5
		Precinct 4						
	1	5	5	5	5	5	5	5
Watch	2	8	8	8	8	8	8	8
	3	6	4	4	4	4	4	6
		Precinct 5						
	1	8	8	8	8	7	7	8
Watch	2	10	10	12	12	12	12	12
	3	8	5	5	5	5	5	8
		Precinct 6						
	1	4	4	4	4	4	4	4
Watch	2	6	6	6	6	6	6	6
	3	4	4	3	3	4	4	4

TABLE 62 (cont.)

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					Precinct 8			
	1	5	7	7	7	7	7	5
Watch	2	7	8	8	8	8	8	7
	3	5	4	4	5	5	5	5
					Precinct 11			
	1	4	5	5	5	5	5	4
Watch	2	6	7	7	7	7	7	6
	3	4	3	3	3	3	3	4
					Precinct 12			
	1	4	5	5	5	5	5	4
Watch	2	6	6	6	6	6	8	8
	3	4	4	4	4	3	3	4
					Precinct 13			
	1	6	7	7	7	7	7	6
Watch	2	9	9	9	9	9	9	9
	3	3	3	3	3	3	6	6

APPENDIX F

PERFORMANCE MEASURE RESULTS DERIVED FROM THE PATROL CAR ALLOCATION MODEL

The set of twenty-four tables presented here in Appendix F display the expected levels of performance associated with each measure of performance for the three patrol vehicle allocations of Table 60, Table 61, and Table 62 in Appendix E. The twenty-four tables are sectioned into three groups of eight tables each. The three groups correspond to the three allocation schemes; actual Columbus allocation, final goal program allocation, and the smoothed goal program allocation. The eight tables in each group represent the eight precincts involved in this research.

To derive the table values themselves, each allocation scheme was inputed into the Patrol Car Allocation Model and the simulation was performed. The expected levels of performance for each measure, as generated by the simulation run, were then transcribed into the tabular form displayed in this appendix.

TABLE 63

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 1

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.327	.534	.411	.500	.433	.489	.413	
	2	.229	.439	.346	.383	.394	.435	.337	.345
	3	.265	.206	.211	.211	.203	.232	.305	
	Average	.268	.395	.325	.359	.341	.383	.345	
Travel Time	1	2.3	2.5	2.2	2.4	2.2	2.4	2.4	
	2	1.7	2.1	1.8	1.9	1.9	2.0	1.8	2.0
	3	1.6	1.7	1.7	1.5	1.6	1.6	1.7	
	Average	1.8	2.2	1.9	2.0	1.9	2.0	1.9	
Patrol Hours Per Suppressible Crime	1	9.42	7.83	9.89	8.41	9.53	8.58	8.22	
	2	7.95	5.79	7.71	7.28	7.15	6.66	7.82	9.46
	3	14.40	13.34	13.25	15.46	15.62	15.06	13.62	
	Average	9.98	8.25	9.69	9.67	9.93	9.31	9.41	
Average Patrol Frequency	1	.63	.52	.66	.56	.63	.57	.55	
	2	1.00	.73	.79	.92	.90	.84	.99	.817
	3	.96	.89	.88	1.03	1.04	1.00	.91	
	Average	.86	.71	.84	.84	.86	.80	.81	
Average Number of Cars Available	1	2.35	1.96	2.47	2.10	2.38	2.15	2.06	
	2	3.78	2.75	3.66	3.46	3.40	3.16	3.71	3.07
	3	3.60	2.34	3.31	3.87	3.91	3.76	3.41	
	Average	3.24	2.68	3.15	3.14	3.23	3.02	3.06	
Probability Call Delayed	1	.120	.253	.116	.199	.152	.196	.151	
	2	.011	.151	.039	.095	.080	.143	.032	.103
	3	.031	.059	.039	.013	.037	.036	.078	
	Average	.052	.176	.067	.117	.096	.138	.081	
Average Total Delay	1	3.96	7.17	3.67	5.59	4.57	5.38	4.54	
	2	1.81	4.48	2.11	3.10	2.78	4.07	2.00	3.45
	3	1.80	2.33	2.03	1.59	1.89	1.88	2.48	
	Average	2.46	5.19	2.65	3.73	3.21	4.05	2.87	
Average Number of Cars Allocated	1	5.0	6.0	6.0	6.0	6.0	6.0	5.0	
	2	7.0	7.0	8.0	8.0	8.0	8.0	8.0	6.71
	3	7.0	6.0	6.0	7.0	7.0	7.0	7.0	
	Average	6.3	6.3	6.7	7.0	7.0	7.0	6.7	

TABLE 64

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 4

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.273	.385	.304	.353	.332	.391	.332	
	2	.317	.489	.356	.365	.371	.403	.370	.321
	3	.286	.176	.209	.218	.194	.226	.364	
	Average	.293	.348	.296	.317	.301	.340	.357	
Travel Time	1	2.7	2.9	2.8	2.8	2.8	3.0	2.8	
	2	2.5	3.0	2.4	2.4	2.5	2.5	2.4	2.5
	3	2.3	2.1	2.3	2.4	2.1	2.4	2.5	
	Average	2.5	2.8	2.5	2.5	2.5	2.6	2.6	
Patrol Hours Per Suppressible Crime	1	6.26	5.30	6.00	5.57	5.76	5.25	5.75	
	2	3.57	2.67	3.85	3.79	3.76	3.57	3.76	5.06
	3	7.18	8.29	6.81	6.74	8.10	7.78	6.39	
	Average	5.18	4.77	5.15	5.00	5.37	5.07	4.94	
Average Patrol Frequency	1	.54	.46	.52	.48	.50	.45	.50	
	2	.59	.44	.64	.63	.62	.59	.63	.57
	3	.62	.72	.59	.58	.70	.67	.55	
	Average	.59	.54	.58	.56	.61	.57	.56	
Average Number of Cars Available	1	3.05	2.58	2.92	2.72	2.81	2.56	2.80	
	2	3.35	2.51	3.61	3.56	3.52	3.34	3.53	3.23
	3	3.50	4.04	3.32	3.28	3.95	3.79	3.12	
	Average	3.30	3.04	3.28	3.19	3.43	3.23	3.15	
Probability Call Delayed	1	.056	.092	.065	.081	.062	.124	.063	
	2	.040	.167	.040	.041	.049	.068	.043	.076
	3	.093	.027	.056	.076	.027	.141	.164	
	Average	.064	.117	.051	.062	.048	.103	.091	
Average Total Delay	1	3.30	3.89	3.46	3.74	3.38	4.73	3.43	
	2	2.89	5.20	2.73	2.75	2.84	3.16	2.78	3.42
	3	3.23	2.29	2.86	3.21	2.29	4.52	4.64	
	Average	3.12	4.23	2.98	3.17	2.88	3.98	3.61	
Average Number of Cars Allocated	1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
	2	7.0	7.0	8.0	8.0	8.0	8.0	8.0	6.82
	3	7.0	7.0	6.0	7.0	7.0	7.0	7.0	
	Average	6.7	6.7	6.7	6.7	7.0	7.0	7.0	

TABLE 65

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 5

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.299	.430	.300	.369	.320	.327	.368	.331
	2	.314	.399	.342	.400	.387	.406	.429	
	3	.320	.190	.234	.246	.197	.205	.324	
	Average	.311	.345	.300	.350	.310	.322	.379	
Travel Time	1	3.7	4.0	3.6	3.8	3.7	3.7	3.8	3.5
	2	3.1	3.3	3.2	3.4	3.3	3.4	3.5	
	3	3.3	3.5	3.4	3.5	3.0	3.1	3.5	
	Average	3.3	3.6	3.4	3.6	3.4	3.4	3.6	
Patrol Hours Per Suppressible Crime	1	6.73	5.47	6.72	6.05	6.53	6.46	6.06	5.34
	2	4.52	3.96	4.34	3.95	4.04	3.92	3.76	
	3	6.53	7.78	6.13	6.03	7.71	7.63	6.49	
	Average	5.59	5.31	5.39	5.01	5.60	5.50	5.04	
Average Patrol Frequency	1	.52	.42	.52	.47	.51	.50	.47	.55
	2	.68	.60	.65	.60	.61	.59	.57	
	3	.51	.60	.48	.47	.60	.59	.50	
	Average	.57	.54	.55	.51	.57	.56	.51	
Average Number of Cars Available	1	2.94	2.39	2.94	2.65	2.86	2.83	2.65	3.07
	2	3.84	3.37	3.68	3.36	3.44	3.33	3.20	
	3	2.86	3.40	2.68	2.64	3.37	3.34	2.84	
	Average	3.21	3.05	3.10	2.88	3.22	3.16	2.90	
Probability Call Delayed	1	.060	.137	.047	.083	.057	.054	.085	.071
	2	.024	.057	.031	.066	.057	.070	.091	
	3	.096	.045	.101	.127	.028	.068	.152	
	Average	.058	.084	.051	.084	.051	.065	.106	
Average Total Delay	1	4.27	5.83	4.08	4.72	4.23	4.19	4.72	4.21
	2	3.30	3.80	3.42	3.96	3.81	4.01	4.40	
	3	4.29	3.97	4.71	5.33	3.20	3.88	5.47	
	Average	3.90	4.57	3.90	4.48	3.81	4.04	4.78	
Average Number of Cars Allocated	1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.6
	2	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
	3	6.0	6.0	5.0	5.0	6.0	6.0	6.0	
	Average	6.7	6.7	6.3	6.3	6.7	6.7	6.7	

TABLE 66

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 6

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.288	.389	.282	.306	.288	.322	.287	
	2	.276	.331	.294	.301	.283	.353	.329	.273
	3	.283	.169	.161	.172	.169	.216	.244	
	Average	.282	.293	.247	.260	.246	.299	.289	
Travel Time	1	2.4	2.6	2.4	2.4	2.4	2.5	2.4	
	2	2.0	2.1	2.0	2.0	2.0	2.1	2.1	2.11
	3	2.0	1.7	1.8	1.8	1.8	1.8	1.9	
	Average	2.1	2.2	2.1	2.1	2.1	2.1	2.1	
Patrol Hours Per Suppressible Crime	1	9.50	8.15	9.57	9.25	9.49	9.04	9.50	
	2	6.76	6.25	6.59	6.52	6.70	6.04	6.26	8.71
	3	11.47	13.30	13.43	13.25	13.30	12.54	12.10	
	Average	8.62	8.48	9.04	8.89	9.05	8.41	8.53	
Average Patrol Frequency	1	.66	.57	.67	.65	.66	.63	.66	
	2	.94	.87	.92	.91	.94	.84	.87	.81
	3	.80	.93	.94	.92	.93	.88	.84	
	Average	.80	.79	.84	.83	.84	.78	.79	
Average Number of Cars Available	1	2.49	2.14	2.51	2.43	2.49	2.37	2.49	
	2	3.55	3.28	3.46	3.42	3.52	3.17	3.29	3.05
	3	3.01	3.49	3.52	3.48	3.49	3.29	3.18	
	Average	3.02	2.97	3.16	3.11	3.17	2.95	2.99	
Probability Call Delayed	1	.082	.138	.065	.080	.063	.108	.072	
	2	.023	.041	.035	.029	.024	.045	.039	.052
	3	.093	.011	.022	.020	.028	.042	.044	
	Average	.063	.070	.042	.043	.037	.062	.049	
Average Total Delay	1	3.44	4.49	3.16	3.42	3.11	3.94	3.25	
	2	2.17	2.42	2.35	2.26	2.19	2.47	2.39	2.68
	3	3.08	1.82	1.96	1.95	2.05	2.27	2.28	
	Average	2.83	3.04	2.51	2.56	2.45	2.84	2.59	
Average Number of Cars Allocated	1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
	2	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.0
	3	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
	Average	6.0	6.0	6.0	6.0	6.0	6.0	6.0	

TABLE 67

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 8

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.302	.440	.392	.458	.403	.490	.326	
	2	.297	.462	.291	.337	.312	.396	.314	.318
	3	.206	.218	.214	.229	.189	.220	.282	
	Average	.259	.384	.298	.333	.295	.351	.307	
Travel Time	1	3.9	3.8	4.0	4.3	4.1	4.3	3.8	
	2	3.3	3.8	3.1	3.1	3.1	3.3	3.1	3.42
	3	2.8	3.3	3.1	2.8	2.8	2.9	3.0	
	Average	3.3	3.7	3.4	3.4	3.4	3.5	3.3	
Patrol Hours Per Suppressible Crime	1	8.23	8.26	7.17	6.39	7.03	6.01	7.95	
	2	5.46	4.07	6.44	6.02	6.25	5.73	6.23	7.41
	3	11.70	9.22	9.27	11.36	11.95	11.49	10.58	
	Average	7.75	6.44	7.34	7.47	7.89	7.26	7.77	
Average Patrol Frequency	1	.52	.52	.45	.40	.44	.38	.50	
	2	.67	.50	.79	.74	.77	.71	.77	.615
	3	.74	.58	.59	.72	.75	.73	.67	
	Average	.64	.53	.61	.62	.66	.60	.65	
Average Number of Cars Available	1	1.95	1.96	1.70	1.52	1.67	1.43	1.89	
	2	2.53	1.88	2.98	2.78	2.89	2.65	2.88	2.317
	3	2.78	2.19	2.20	2.70	2.84	2.73	2.51	
	Average	2.42	2.01	2.29	2.33	2.47	2.27	2.43	
Probability Call Delayed	1	.165	.194	.178	.274	.211	.284	.140	
	2	.064	.207	.048	.059	.050	.091	.059	.126
	3	.053	.153	.100	.059	.059	.093	.101	
	Average	.092	.192	.105	.133	.107	.159	.094	
Average Total Delay	1	6.53	7.06	6.90	10.60	8.01	10.24	5.99	
	2	3.97	7.14	3.54	3.72	3.57	4.30	3.67	5.5
	3	3.26	6.06	4.50	3.44	3.43	4.11	4.07	
	Average	4.55	6.92	4.94	6.01	5.06	6.33	4.40	
Average Number of Cars Allocated	1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
	2	5.0	5.0	6.0	6.0	6.0	6.0	6.0	4.8
	3	5.0	4.0	4.0	5.0	5.0	5.0	5.0	
	Average	4.7	4.4	4.7	5.0	5.0	5.0	5.0	

TABLE 68

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 11

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.240	.510	.362	.366	.381	.412	.340	
	2	.201	.336	.305	.329	.373	.355	.289	.304
	3	.283	.191	.181	.274	.209	.203	.304	
	Average	.237	.336	.281	.323	.327	.322	.307	
Travel Time	1	1.7	2.1	1.9	1.9	1.9	2.0	1.9	
	2	1.3	1.4	1.4	1.5	1.6	1.5	1.4	1.6
	3	1.4	1.4	1.3	1.5	1.5	1.4	1.5	
	Average	1.4	1.7	1.6	1.6	1.7	1.6	1.6	
Patrol Hours Per Suppressible Crime	1	8.51	5.49	7.15	7.10	6.93	6.58	7.40	
	2	7.30	6.07	6.35	5.37	5.02	5.90	6.50	7.18
	3	9.27	10.46	10.59	7.82	8.51	10.30	9.00	
	Average	8.12	7.06	7.65	6.44	6.41	7.21	7.38	
Average Patrol Frequency	1	.57	.37	.48	.47	.46	.44	.49	
	2	.96	.79	.83	.70	.66	.77	.85	.64
	3	.64	.73	.74	.54	.59	.72	.62	
	Average	.72	.63	.68	.57	.57	.64	.66	
Average Number of Cars Available	1	2.66	1.71	2.23	2.22	2.17	2.06	2.31	
	2	4.47	3.72	3.89	3.29	3.07	3.61	3.98	2.99
	3	3.01	3.40	3.44	2.54	2.77	3.35	2.92	
	Average	3.38	2.94	3.19	2.68	2.67	3.01	3.07	
Probability Call Delayed	1	.050	.272	.145	.130	.139	.195	.143	
	2	.005	.043	.029	.041	.080	.054	.018	.084
	3	.060	.046	.036	.084	.053	.048	.100	
	Average	.038	.132	.068	.080	.094	.098	.079	
Average Total Delay	1	2.25	7.31	4.24	3.73	3.84	5.38	4.10	
	2	1.33	1.82	1.64	1.89	2.54	1.98	1.50	2.8
	3	1.97	1.84	1.69	2.49	2.01	1.87	2.54	
	Average	1.81	3.94	2.50	2.63	2.86	3.05	2.55	
Average Number of Cars Allocated	1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
	2	8.0	8.0	8.0	7.0	7.0	8.0	8.0	6.1
	3	6.0	6.0	6.0	5.0	5.0	6.0	6.0	
	Average	6.3	6.4	6.3	5.7	5.7	6.3	6.3	

TABLE 69

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 12

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.331	.422	.348	.453	.336	.398	.333	
	2	.381	.377	.367	.350	.333	.433	.404	
	3	.360	.234	.231	.280	.204	.238	.386	.343
	Average	.334	.348	.321	.360	.296	.366	.378	
Travel Time	1	1.8	1.9	1.8	2.0	1.8	1.9	1.8	
	2	1.5	1.6	1.5	1.5	1.5	1.6	1.6	
	3	1.6	1.5	1.5	1.6	1.5	1.5	1.7	1.65
	Average	1.6	1.7	1.6	1.7	1.6	1.7	1.7	
Patrol Hours Per Suppressible Crime	1	7.20	6.22	7.02	5.89	7.15	6.48	7.19	
	2	5.24	4.79	4.87	5.00	5.13	4.35	4.58	
	3	6.64	7.95	7.98	7.46	8.26	7.90	6.37	6.01
	Average	6.09	5.97	6.21	5.86	6.45	5.81	5.70	
Average Patrol Frequency	1	.50	.43	.49	.41	.50	.45	.50	
	2	.71	.65	.66	.68	.70	.59	.62	
	3	.48	.57	.58	.54	.60	.57	.46	.557
	Average	.56	.55	.58	.54	.60	.54	.53	
Average Number of Cars Available	1	2.34	2.02	2.28	1.91	2.32	2.11	2.34	
	2	3.34	3.05	3.10	3.19	3.27	2.78	2.92	
	3	2.24	2.68	2.69	2.52	2.79	2.67	2.15	2.60
	Average	2.64	2.59	2.69	2.54	2.79	2.52	2.47	
Probability Call Delayed	1	.103	.179	.108	.199	.091	.142	.134	
	2	.038	.067	.061	.063	.047	.104	.080	
	3	.173	.095	.081	.140	.077	.088	.180	.104
	Average	.100	.112	.080	.131	.068	.113	.124	
Average Total Delay	1	3.07	4.66	3.16	5.06	2.83	3.85	3.76	
	2	1.80	2.23	2.12	2.18	1.92	2.79	2.35	
	3	4.20	2.75	2.42	3.63	2.41	2.61	4.31	3.0
	Average	2.94	3.19	2.51	3.57	2.32	3.09	3.31	
Average Number of Cars Allocated	1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
	2	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
	3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.7
	Average	5.7	5.7	5.7	5.7	5.7	5.7	5.7	

TABLE 70

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE ACTUAL COLUMBUS ALLOCATION OF PATROL VEHICLES: PRECINCT 13

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization	1	.242	.415	.268	.331	.309	.363	.319	
Ratio	2	.226	.353	.292	.363	.322	.321	.327	.288
	3	.237	.173	.154	.211	.197	.300	.270	
	Average	.234	.319	.246	.306	.280	.327	.309	
Travel Time	1	5.3	5.9	5.3	5.5	5.5	5.7	5.5	
	2	4.2	4.7	4.5	5.1	4.9	4.5	4.6	4.9
	3	4.6	4.3	4.2	4.4	4.4	4.9	4.7	
	Average	4.6	5.0	4.7	5.1	5.0	5.0	4.9	
Patrol Hours	1	7.39	5.70	7.13	6.52	6.73	6.18	6.64	
Per	2	5.65	4.72	5.17	3.88	4.12	4.96	4.91	5.67
Suppressible	3	7.12	7.72	7.90	7.37	7.49	6.53	6.81	
Crime	Average	6.46	5.74	6.36	5.43	5.64	5.67	5.83	
Average	1	.56	.44	.55	.50	.51	.47	.51	
Patrol	2	.86	.72	.79	.59	.63	.76	.75	.605
Frequency	3	.57	.62	.63	.59	.60	.52	.54	
	Average	.67	.59	.66	.56	.58	.58	.60	
Average Number	1	2.12	1.64	2.05	1.87	1.94	1.78	1.91	
of Cars	2	3.25	2.72	2.97	2.23	2.37	2.85	2.83	2.27
Available	3	2.14	2.32	2.37	2.21	2.25	1.96	2.04	
	Average	2.50	2.22	2.46	2.10	2.18	2.20	2.26	
Probability	1	.089	.205	.086	.127	.131	.168	.131	
Call Delayed	2	.021	.083	.054	.123	.084	.064	.086	.100
	3	.120	.057	.033	.075	.077	.185	.136	
	Average	.070	.123	.060	.114	.098	.129	.112	
Average Total	1	6.48	9.39	6.43	7.28	7.39	8.51	7.48	
Delay	2	4.38	5.58	5.02	6.68	5.83	5.23	5.80	6.31
	3	6.37	5.04	4.59	5.37	5.42	8.21	6.67	
	Average	5.58	6.87	5.36	6.58	6.25	7.06	6.51	
Average Number	1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
of Cars	2	6.0	6.0	6.0	5.0	5.0	6.0	6.0	4.6
Allocated	3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
	Average	4.7	4.7	4.7	4.3	4.3	4.7	4.7	

TABLE 71

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE
FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 1

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.409	.458	.494	.50	.433	.489	.413	
	2	.54*	.439	.462	.438	.45	.435	.449	
	3	.372	.60*	.60*	.370	.54*	.54*	.427	.441
	Average	.391	.449	.478	.436	.442	.462	.431	
Travel Time	1	2.7	1.9	2.6	2.4	2.2	2.4	2.4	
	2	2.9*	2.1	2.3	2.2	2.1	2.0	2.2	
	3	2.0	3.1*	3.1*	2.2	2.9*	2.9*	2.3	2.25
	Average	2.35	2.0	2.45	2.27	2.15	2.2	2.3	
Patrol Hours Per Suppressible Crime	1	6.62	12.69	7.09	8.41	9.53	8.58	8.22	
	2	3.5*	5.79	4.76	5.80	5.68	6.66	4.87	
	3	8.8	3.0*	3.0*	7.06	3.5*	3.5*	8.02	7.39
	Average	7.71	9.24	5.93	7.09	7.61	7.62	6.54	
Average Patrol Frequency	1	.44	.84	.47	.56	.63	.57	.55	
	2	.35*	.73	.60	.73	.72	.84	.62	
	3	.58	.20*	.20*	.47	.35*	.35*	.53	.625
	Average	.51	.785	.535	.59	.675	.71	.57	
Average Number of Cars Available	1	1.65	3.17	1.77	2.10	2.38	2.15	2.06	
	2	1.25*	2.75	2.26	2.76	2.70	3.16	2.31	
	3	2.2	1.0*	1.0*	1.77	1.25*	1.25*	2.01	2.35
	Average	1.93	2.96	2.02	2.21	2.54	2.66	2.12	
Probability Call Delayed	1	.25	.134	.248	.199	.152	.196	.151	
	2	.38*	.151	.157	.165	.142	.143	.14	
	3	.168	.40*	.40*	.205	.38*	.38*	.301	.180
	Average	.209	.143	.203	.190	.147	.170	.196	
Average Total Delay	1	8.2	3.85	7.12	5.59	4.57	5.38	4.54	
	2	13.5*	4.48	4.56	5.03	4.29	4.07	3.94	
	3	4.31	15.75*	15.75*	5.87	13.5*	13.5*	9.29	5.26
	Average	6.26	4.17	5.84	5.50	4.43	4.73	5.87	
Average Number of Cars Allocated	1	4.0	7.0	5.0	6.0	6.0	6.0	5.0	
	2	4.0	7.0	6.0	7.0	7.0	8.0	6.0	
	3	5.0	3.0	3.0	4.0	4.0	4.0	5.0	5.34
	Average	4.3	5.7	4.7	5.7	5.7	6.0	5.3	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 72

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE
FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 4

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.410	.385	.365	.424	.398	.391	.399	
	2	.370	.38	.407	.365	.371	.403	.37	.376
	3	.333	.307	.314	.525*	.339	.525*	.364	
	Average	.371	.357	.362	.395	.369	.397	.378	
Travel Time	1	3.7	2.9	3.2	3.3	3.2	3.0	3.2	
	2	2.9	2.4	2.7	2.4	2.5	2.5	2.4	2.9
	3	2.7	3.2	3.2	3.9*	3.2	3.9	2.5	
	Average	3.1	2.8	3.0	2.9	3.0	2.8	2.7	
Patrol Hours Per Suppressible Crime	1	3.39	5.3	4.56	4.13	4.32	5.25	4.32	
	2	2.82	4.17	3.10	3.79	3.76	3.57	3.76	4.21
	3	5.74	3.98	3.94	2.5*	3.8	2.5*	6.39	
	Average	3.98	4.48	3.87	3.96	3.96	4.41	4.82	
Average Patrol Frequency	1	.29	.46	.39	.36	.37	.45	.37	
	2	.47	.69	.52	.63	.62	.59	.63	.47
	3	.50	.34	.34	.25*	.33	.25*	.55	
	Average	.42	.50	.42	.50	.44	.52	.52	
Average Number of Cars Available	1	1.65	2.58	2.22	2.02	2.11	2.55	2.10	
	2	2.65	3.91	2.91	3.56	3.52	3.34	3.53	2.69
	3	2.80	1.94	1.92	1.5*	1.85	1.5*	3.12	
	Average	2.37	2.81	2.35	2.79	2.49	2.95	2.92	
Probability Call Delayed	1	.273	.092	.152	.183	.15	.124	.152	
	2	.091	.048	.079	.041	.049	.068	.043	.139
	3	.182	.277	.262	.37*	.28	.37*	.164	
	Average	.182	.139	.164	.112	.160	.096	.120	
Average Total Delay	1	6.53	3.89	5.45	6.16	5.23	4.73	5.36	
	2	9.71	2.73	3.48	2.75	2.84	3.16	2.78	5.29
	3	5.13	9.63	8.93	13.25*	9.46	13.25	4.64	
	Average	7.12	5.42	5.95	4.46	5.84	3.95	4.26	
Average Number of Cars Allocated	1	4.0	6.0	5.0	5.0	5.0	6.0	5.0	
	2	6.0	9.0	7.0	8.0	8.0	8.0	8.0	5.86
	3	6.0	4.0	4.0	4.0	4.0	4.0	7.0	
	Average	5.3	6.3	5.3	5.7	5.7	6.0	6.7	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 73

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLED: PRECINCT 5

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization	1	.256	.287	.257	.277	.274	.281	.276	
Ratio	2	.279	.266	.274	.266	.258	.270	.18*	.260
	3	.24	.228	.234	.246	.237	.246	.243	
	Average	.258	.260	.255	.263	.256	.266	.260	
Travel Time	1	3.3	2.9	3.2	3.1	3.3	3.3	3.1	
	2	2.9	2.5	2.7	2.5	2.5	2.5	2.45*	3.04
	3	2.6	4.1	3.4	3.5	3.4	3.6	2.7	
	Average	2.9	3.2	3.1	3.0	3.1	3.1	2.9	
Patrol Hours	1	8.33	10.27	8.32	9.25	8.13	8.06	9.26	
Per	2	5.35	7.26	5.98	7.25	7.34	7.21	12.4*	
Suppressible	3	9.73	6.18	6.13	6.03	6.11	6.03	9.69	7.68
Crime	Average	7.80	7.90	6.81	7.51	7.19	7.1	9.48	
Average	1	.65	.8	.65	.72	.63	.63	.72	
Patrol	2	.81	1.09	.9	1.09	1.11	1.09	1.25	.74
Frequency	3	.75	.48	.48	.47	.47	.47	.75	
	Average	.74	.79	.68	.76	.74	.73	.74	
Average Number	1	3.64	4.49	3.64	4.05	3.56	3.53	4.05	
of Cars	2	4.54	6.17	5.08	6.16	6.24	6.13	6.8*	4.16
Available	3	4.26	2.70	2.68	2.64	2.67	2.64	4.24	
	Average	4.26	4.45	3.8	4.28	4.16	4.1	4.15	
Probability	1	.025	.014	.019	.016	.023	.022	.017	
Call Delayed	2	.009	.002	.004	.003	.002	.003	.001*	.038
	3	.021	.109	.101	.127	.077	.144	.039	
	Average	.018	.042	.041	.049	.034	.056	.028	
Average Total	1	3.48	3.01	3.39	3.18	3.46	3.44	3.18	
Delay	2	2.94	2.48	2.74	2.49	2.47	2.5	2.3*	3.49
	3	2.77	5.46	4.71	5.33	4.22	5.95	3.03	
	Average	3.06	3.65	3.61	3.67	3.38	3.96	3.11	
Average Number	1	7.0	9.0	7.0	8.0	7.0	7.0	8.0	
of Cars	2	9.0	12.0	10.0	12.0	12.0	12.0	13.0	
Allocated	3	8.0	5.0	5.0	5.0	5.0	5.0	8.0	8.3
	Average	8.0	8.7	7.3	8.3	8.0	8.0	9.7	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 74

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 6

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.36	.389	.353	.383	.36	.403	.359	
	2	.386	.386	.343	.351	.396	.353	.384	.361
	3	.34	.338	.322	.344	.338	.324	.366	
	Average	.362	.371	.339	.359	.365	.36	.370	
Travel Time	1	2.8	2.6	2.8	2.8	2.8	2.9	2.8	
	2	2.6	2.3	2.3	2.3	2.6	2.1	2.3	2.57
	3	2.3	2.7	2.8	2.8	2.8	2.5	2.5	
	Average	2.6	2.5	2.6	2.6	2.7	2.5	2.5	
Patrol Hours Per Suppressible Crime	1	6.83	8.15	6.9	6.58	6.83	6.37	6.84	
	2	4.09	4.91	5.25	5.19	4.03	6.04	4.92	6.05
	3	8.8	5.3	5.43	5.25	5.3	7.21	6.77	
	Average	6.57	6.12	5.86	5.67	5.39	6.54	6.18	
Average Patrol Frequency	1	.48	.57	.48	.46	.48	.44	.48	
	2	.57	.69	.73	.72	.56	.84	.69	.536
	3	.61	.37	.38	.37	.37	.50	.47	
	Average	.55	.54	.53	.52	.47	.59	.55	
Average Number of Cars Available	1	1.79	2.14	1.81	1.73	1.79	1.67	1.79	
	2	2.15	2.58	2.76	2.72	2.12	3.17	2.59	2.03
	3	2.31	1.39	1.42	1.38	1.39	1.89	1.78	
	Average	2.08	2.12	2.00	1.94	1.77	2.24	2.05	
Probability Call Delayed	1	.185	.138	.155	.182	.152	.231	.168	
	2	.138	.093	.08	.069	.144	.045	.089	.175
	3	.197	.224	.294	.301	.346	.212	.227	
	Average	.173	.152	.176	.184	.214	.163	.161	
Average Total Delay	1	6.22	4.45	5.43	6.18	5.3	7.6	5.67	
	2	4.45	3.37	3.22	3.0	4.6	2.47	3.31	6.23
	3	5.72	7.82	11.6	11.33	14.41	7.19	7.14	
	Average	5.46	5.32	6.75	6.84	8.10	5.75	5.37	
Average Number of Cars Allocated	1	4	5	4	4	4	4	4	
	2	5	6	6	6	5	7	6	
	3	5	3	3	3	3	4	4	
	Average	4.7	4.7	4.3	4.3	4.0	5.0	4.7	4.5

TABLE 75

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE
FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 8

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.242	.275	.261	.262	.269	.280	.260	
	2	.232	.257	.250	.253	.267	.276	.269	.248
	3	.206	.218	.214	.229	.237	.220	.235	
	Average	.227	.250	.242	.248	.258	.259	2.55	
Travel Time	1	3.3	2.6	3.0	2.8	3.0	2.8	3.3	
	2	2.9	2.4	2.7	2.6	2.8	2.6	2.8	2.9
	3	2.8	3.3	3.1	2.8	3.3	2.9	2.6	
	Average	3.0	2.8	2.9	2.7	3.0	2.8	2.9	
Patrol Hours Per Suppressible Crime	1	11.18	17.10	13.07	15.23	12.93	14.86	10.9	
	2	6.98	10.13	7.95	9.05	7.77	8.76	7.74	10.91
	3	11.7	9.22	9.27	11.36	9.0	11.49	13.53	
	Average	9.95	12.15	10.10	11.88	9.90	11.70	10.72	
Average Patrol Frequency	1	.71	1.08	.83	.96	.82	.94	.69	
	2	.86	1.25	.98	1.11	.96	1.08	.95	.86
	3	.74	.58	.59	.72	.57	.73	.85	
	Average	.77	.97	.80	.93	.78	.92	.83	
Average Number of Cars Available	1	2.65	4.06	3.10	3.62	3.07	3.53	2.59	
	2	3.23	4.68	3.68	4.18	3.54	4.05	3.58	3.22
	3	2.78	2.19	2.20	2.70	2.14	2.73	3.21	
	Average	2.89	3.64	2.99	3.5	2.93	3.44	3.13	
Probability Call Delayed	1	.072	.018	.026	.023	.036	.022	.057	
	2	.022	.007	.019	.010	.020	.019	.024	.048
	3	.053	.153	.10	.059	.135	.093	.034	
	Average	.049	.059	.048	.031	.064	.045	.04	
Average Total Delay	1	4.13	2.75	3.2	2.97	3.36	2.96	3.92	
	2	3.10	2.46	2.90	2.62	2.92	2.75	2.97	
	3	3.26	6.06	4.50	3.44	5.37	4.11	2.91	3.46
	Average	3.50	3.76	3.53	3.01	3.88	3.27	3.27	
Average Number of Cars Allocated	1	5	8	6	7	6	7	5	
	2	6	9	7	8	7	8	7	6.2
	3	5	4	4	5	4	5	6	
	Average	5.3	7.0	5.7	6.7	5.7	6.7	6.0	

TABLE 76

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 11

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.400	.425	.452	.457	.477	.412	.424	
	2	.403	.384	.407	.383	.373	.406	.385	.408
	3	.424	.381	.362	.456	.349	.406	.47*	
	Average	.409	.397	.407	.432	.400	.408	.405	
Travel Time	1	2.4	1.8	2.3	2.3	2.3	2.0	2.2	
	2	2.1	1.6	1.8	1.7	1.6	1.7	1.7	2.0
	3	2.0	2.1	2.1	2.1	2.1	2.1	2.2*	
	Average	2.2	1.8	2.1	2.0	2.0	1.9	2.0	
Patrol Hours Per Suppressible Crime	1	4.03	7.73	4.91	4.86	4.64	6.58	5.16	
	2	2.73	4.92	4.07	4.23	5.02	4.75	4.22	4.56
	3	4.96	4.00	4.12	3.51	4.21	3.84	3.5*	
	Average	3.91	5.41	4.37	4.2	4.31	5.06	4.69	
Average Patrol Frequency	1	.27	.52	.33	.32	.31	.44	.34	
	2	.36	.64	.53	.55	.66	.62	.55	.41
	3	.34	.28	.29	.24	.29	.27	.33*	
	Average	.32	.48	.38	.37	.42	.44	.45	
Average Number of Cars Available	1	1.26	2.41	1.53	1.52	1.47	2.06	1.61	
	2	1.67	3.02	2.49	2.59	3.07	2.91	2.58	1.92
	3	1.61	1.30	1.34	1.14	1.37	1.25	1.5*	
	Average	1.51	2.24	1.79	1.75	1.97	2.07	2.10	
Probability Call Delayed	1	.277	.131	.291	.270	.286	.195	.285	
	2	.204	.083	.124	.092	.080	.101	.090	.233
	3	.291	.410	.382	.386	.283	.440	.25*	
	Average	.257	.208	.266	.249	.216	.245	.188	
Average Total Delay	1	9.29	3.51	9.94	8.19	8.47	5.38	9.53	
	2	5.64	2.53	3.34	2.79	2.54	2.88	2.63	9.97
	3	7.78	36.51	19.72	14.24	8.94	39.41	15.00*	
	Average	7.57	14.18	11.00	8.41	6.65	15.89	6.08	
Average Number of Cars Allocated	1	3	6	4	4	4	5	4	
	2	4	7	6	6	7	7	6	4.6
	3	4	3	3	3	3	3	4	
	Average	3.7	5.3	4.3	4.3	4.7	5.0	4.7	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 77

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 12

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.414	.422	.436	.453	.420	.398	.416	
	2	.446	.377	.428	.408	.466	.379	.404	.407
	3	.485*	.389	.385	.350	.339	.397	.386	
	Average	.43	.395	.416	.404	.408	.391	.402	
Travel Time	1	2.1	1.9	2.1	2.0	2.1	1.9	2.2	
	2	2.0	1.6	1.8	1.8	2.0	1.5	1.6	1.9
	3	2.2*	2.0	2.1	1.9	2.0	2.0	1.7	
	Average	2.1	1.8	2.0	1.9	2.0	1.8	1.8	
Patrol Hours Per Suppressible Crime	1	5.05	6.22	4.86	5.89	4.99	6.48	5.03	
	2	3.04	4.79	3.77	3.90	2.93	5.45	4.58	4.68
	3	3.40*	3.80	3.83	5.39	4.11	3.75	6.37	
	Average	4.05	4.94	4.15	5.06	4.01	5.23	5.33	
Average Patrol Frequency	1	.35	.43	.34	.41	.35	.45	.35	
	2	.41	.65	.51	.53	.40	.74	.62	.42
	3	.31*	.27	.28	.39	.30	.27	.46	
	Average	.38	.45	.38	.44	.35	.49	.48	
Average Number of Cars Available	1	1.64	2.02	1.58	1.91	1.62	2.11	1.64	
	2	1.94	3.05	2.40	2.49	1.87	3.48	2.92	1.99
	3	1.40*	1.28	1.29	1.82	1.39	1.27	2.15	
	Average	1.79	2.12	1.76	2.07	1.63	2.29	2.24	
Probability Call Delayed	1	.225	.179	.233	.199	.205	.142	.274	
	2	.196	.067	.130	.130	.225	.055	.080	.213
	3	.340*	.392	.368	.274	.332	.379	.180	
	Average	.211	.213	.244	.201	.254	.191	.178	
Average Total Delay	1	6.22	4.66	6.48	5.06	5.53	3.85	8.46	
	2	4.87	2.23	3.37	3.53	5.64	1.93	2.35	7.24
	3	13.75*	22.61	13.84	8.63	15.80	17.17	4.31	
	Average	5.55	9.83	7.90	5.74	8.99	7.65	5.04	
Average Number of Cars Allocated	1	4	5	4	5	4	5	4	
	2	5	7	6	6	5	8	7	4.7
	3	4	3	3	4	3	3	5	
	Average	4.3	5.0	4.3	5.0	4.0	5.3	5.3	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 78

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE FINAL GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 13

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.193	.207	.214	.189	.206	.209	.212	
	2	.194	*	.219	.201	.201	.214	.164	.209
	3	.190	.231	.205	.281	.263	.200	.180	
	Average	.192	.219	.213	.224	.223	.208	.185	
Travel Time	1	4.6	3.6	4.6	3.8	4.2	3.8	4.2	
	2	3.8	*	3.6	3.4	3.6	3.4	2.9	4.09
	3	4.0	5.2	5.0	5.4	5.4	3.7	3.6	
	Average	4.1	4.4	4.4	4.2	4.3	3.6	3.6	
Patrol Hours Per Suppressible Crime	1	9.82	15.44	9.57	13.82	11.60	13.49	11.51	
	2	6.87	*	7.61	8.75	7.78	8.61	12.22	9.56
	3	9.45	5.38	5.56	5.03	5.16	11.20	11.48	
	Average	8.71	10.41	7.58	9.20	8.18	11.10	11.74	
Average Patrol Frequency	1	.75	1.18	.73	1.06	.89	1.03	.88	
	2	1.05	*	1.16	1.34	1.19	1.32	1.87	.93
	3	.75	.43	.44	.40	.41	.89	.92	
	Average	.85	.81	.78	.93	.83	1.08	1.22	
Average Number of Cars Available	1	2.82	4.44	2.75	3.97	3.34	3.88	3.31	
	2	3.95	*	4.37	5.03	4.47	4.95	7.03	3.49
	3	2.84	1.62	1.67	1.51	1.55	3.36	3.44	
	Average	3.20	3.03	2.93	3.50	3.12	4.06	4.59	
Probability Call Delayed	1	.033	.005	.031	.005	.017	.009	.016	
	2	.007	*	.010	.003	.004	.005	.001	.047
	3	.050	.139	.091	.179	.180	.033	.019	
	Average	.030	.095	.044	.062	.067	.016	.012	
Average Total Delay	1	4.89	3.61	4.86	3.81	4.30	3.91	4.31	
	2	3.86	*	3.71	3.39	3.58	3.43	2.87	4.78
	3	4.50	7.82	6.44	8.79	8.97	3.96	3.72	
	Average	4.42	5.72	5.00	5.33	5.62	3.77	3.63	
Average Number of Cars Allocated	1	5	8	5	7	6	7	6	
	2	7	16	8	9	8	9	12	6.8
	3	5	3	3	3	3	6	6	
	Average	5.7	9.0	5.3	6.3	5.7	7.3	8.0	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 79

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 1

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization	1	.327	.534	.411	.50	.433	.489	.431	
Ratio	2	.267	.439	.396	.438	.450	.497	.449	.426
	3	.372	.54*	.317	.370	.54*	.54*	.427	
	Average	.319	.487	.375	.436	.442	.493	.431	
Travel Time	1	2.3	2.5	2.2	2.4	2.2	2.4	2.4	
	2	1.9	2.1	2.0	2.2	2.1	2.3	2.2	2.23
	3	2.0	2.9*	2.2	2.2	2.9*	2.9*	2.3	
	Average	2.1	2.3	2.1	2.3	2.15	2.35	2.3	
Patrol Hours	1	9.42	7.83	9.89	8.41	9.53	8.58	8.22	
Per	2	6.48	5.79	6.23	5.80	5.68	5.19	4.87	7.24
Suppressible	3	8.8	3.5*	7.65	7.06	3.5*	3.5*	8.02	
Crime	Average	7.83	6.81	7.92	7.09	7.61	6.89	6.54	
Average	1	.63	.52	.66	.56	.63	.57	.55	
Patrol	2	.82	.73	.79	.73	.72	.66	.62	.625
Frequency	3	.58	.35*	.51	.47	.35*	.35*	.53	
	Average	.68	.625	.62	.59	.675	.615	.57	
Average Number	1	2.35	1.96	2.47	2.10	2.38	2.15	2.06	
of Cars	2	3.08	2.75	2.96	2.76	2.70	2.46	2.31	2.36
Available	3	2.2	1.25*	1.91	1.77	1.25*	1.25*	2.01	
	Average	2.54	2.36	2.45	2.21	2.54	2.31	2.12	
Probability	1	.120	.253	.116	.199	.152	.196	.151	
Call Delayed	2	.030	.151	.077	.165	.142	.235	.14	.171
	3	.168	.38*	.212	.205	.38	.38	.301	
	Average	.110	.202	.135	.190	.147	.216	.196	
Average Total	1	3.96	7.17	3.67	5.59	4.57	5.38	4.54	
Delay	2	2.19	4.48	2.81	5.03	4.29	7.39	3.44	5.12
	3	4.31	13.5*	6.26	5.87	13.5*	13.5*	9.24	
	Average	3.54	5.83	4.25	5.50	4.43	6.39	5.87	
Average Number	1	5.0	6.0	6.0	6.0	6.0	6.0	5.0	
of Cars	2	6.0	7.0	7.0	7.0	7.0	7.0	6.0	5.59
Allocated	3	5.0	4.0	4.0	4.0	4.0	4.0	5.0	
	Average	5.3	5.7	5.7	5.7	5.7	5.7	5.3	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 80

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 4

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.328	.462	.365	.424	.398	.467	.399	
	2	.277	.428	.356	.365	.371	.403	.37	.379
	3	.333	.307	.314	.525*	.339	.525*	.424	
	Average	.313	.399	.345	.395	.369	.436	.398	
Travel Time	1	3.1	3.4	3.2	3.3	3.2	3.5	3.2	
	2	2.3	2.6	2.4	2.4	2.5	2.5	2.4	2.9
	3	2.7	3.2	3.2	3.9*	3.2	3.9*	3.0	
	Average	2.7	3.1	2.9	2.9	3.0	3.0	2.9	
Patrol Hours Per Suppressible Crime	1	4.83	3.86	4.56	4.13	4.32	3.81	4.32	
	2	4.32	3.42	3.85	3.79	3.76	3.57	3.76	4.11
	3	5.74	3.98	3.94	2.5*	3.8	2.5*	4.96	
	Average	4.96	3.75	4.12	3.96	3.96	3.69	4.35	
Average Patrol Frequency	1	.42	.33	.39	.36	.37	.33	.37	
	2	.72	.57	.64	.63	.62	.59	.63	.47
	3	.50	.34	.34	.25*	.33	.25*	.43	
	Average	.55	.41	.46	.50	.44	.46	.48	
Average Number of Cars Available	1	2.35	1.88	2.22	2.02	2.11	1.86	2.10	
	2	4.05	3.21	3.61	3.56	3.52	3.34	3.53	2.65
	3	2.8	1.94	1.92	1.5*	1.85	1.5*	2.42	
	Average	3.07	2.34	2.58	2.79	2.49	2.6	2.68	
Probability Call Delayed	1	.134	.206	.152	.183	.15	.253	.152	
	2	.019	.094	.040	.041	.049	.068	.043	.150
	3	.182	.277	.262	.37*	.28	.37*	.292	
	Average	.112	.192	.151	.112	.160	.161	.162	
Average Total Delay	1	5.04	6.53	5.45	6.16	5.23	9.10	5.36	
	2	2.43	3.55	2.73	2.75	2.84	3.16	2.78	5.51
	3	5.13	9.63	8.93	13.25*	9.46	13.25*	8.95	
	Average	4.2	6.57	5.70	4.46	5.84	6.13	5.70	
Average Number of Cars Allocated	1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
	2	8.0	8.0	8.0	8.0	8.0	8.0	8.0	5.87
	3	6.0	4.0	4.0	4.0	4.0	4.0	6.0	
	Average	6.3	5.7	5.7	5.7	5.7	5.7	6.3	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 81

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 5

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.224	.323	.225	.277	.274	.287	.276	.259
	2	.251	.319	.228	.266	.258	.270	.286	
	3	.24	.228	.234	.246	.237	.246	.243	
	Average	.238	.290	.229	.263	.256	.266	.268	
Travel Time	1	3.0	3.2	3.0	3.1	3.3	3.3	3.1	3.01
	2	2.7	2.8	2.4	2.5	2.5	2.5	2.5	
	3	2.6	4.1	3.4	3.5	3.4	3.6	2.7	
	Average	2.8	3.4	2.9	3.0	3.1	3.1	2.8	
Patrol Hours Per Suppressible Crime	1	9.93	8.67	9.92	9.25	8.13	8.06	9.26	7.69
	2	6.17	5.61	7.63	7.25	7.34	7.21	7.05	
	3	9.73	6.81	6.13	6.03	6.11	6.03	9.69	
	Average	8.61	6.82	7.89	7.51	7.19	7.1	8.7	
Average Patrol Frequency	1	.77	.67	.77	.72	.63	.63	.72	.77
	2	.93	.85	1.15	1.09	1.11	1.09	1.06	
	3	.75	.48	.48	.47	.47	.47	.75	
	Average	.82	.67	.80	.76	.74	.73	.84	
Average Number of Cars Available	1	4.34	3.79	4.34	4.05	3.56	3.53	4.05	4.31
	2	5.24	4.77	6.48	6.16	6.24	6.13	6.0	
	3	4.26	2.7	2.68	2.64	2.67	2.64	4.24	
	Average	4.61	3.75	4.5	4.28	4.16	4.1	4.76	
Probability Call Delayed	1	.011	.033	.008	.016	.023	.022	.017	.037
	2	.003	.01	.001	.003	.002	.033	.005	
	3	.021	.109	.101	.127	.077	.144	.039	
	Average	.012	.051	.037	.049	.034	.056	.020	
Average Total Delay	1	3.06	3.44	3.01	3.18	3.46	3.44	3.18	3.44
	2	2.70	2.87	2.41	2.49	2.47	2.5	2.55	
	3	2.77	5.46	4.71	5.33	4.22	5.95	3.03	
	Average	2.84	3.92	3.38	3.67	3.38	3.96	2.92	
Average Number of Cars Allocated	1	8.0	8.0	8.0	8.0	7.0	7.0	8.0	8.3
	2	10.0	10.0	12.0	12.0	12.0	12.0	12.0	
	3	8.0	5.0	5.0	5.0	5.0	5.0	8.0	
	Average	8.7	7.7	8.3	8.3	8.0	8.0	9.3	

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TABLE 82

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 6

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.36	.486	.353	.383	.36	.403	.354	
	2	.322	.386	.343	.351	.33	.412	.384	.358
	3	.42	.254	.322	.344	.254	.324	.366	
	Average	.367	.375	.339	.359	.315	.380	.370	
Travel Time	1	2.8	3.1	2.8	2.8	2.8	2.9	2.8	
	2	2.2	2.3	2.3	2.3	2.2	2.4	2.3	2.57
	3	2.9	2.3	2.8	2.8	2.4	2.5	2.5	
	Average	2.6	2.6	2.6	2.6	2.5	2.6	2.5	
Patrol Hours Per Suppressible Crime	1	6.83	5.48	6.9	6.58	6.83	6.37	6.84	
	2	5.42	4.91	5.25	5.19	5.36	4.71	4.93	6.10
	3	5.8	7.96	5.43	5.25	7.96	7.21	6.77	
	Average	6.02	6.12	5.86	5.67	6.72	6.10	6.18	
Average Patrol Frequency	1	.48	.38	.48	.46	.48	.44	.48	
	2	.76	.69	.73	.72	.75	.66	.69	.55
	3	.45	.56	.38	.37	.56	.50	.47	
	Average	.56	.54	.53	.52	.60	.53	.55	
Average Number of Cars Available	1	1.79	1.44	1.81	1.73	1.79	1.67	1.79	
	2	2.85	2.58	2.76	2.72	2.82	2.47	2.59	2.05
	3	1.67	2.09	1.42	1.38	2.09	1.89	1.78	
	Average	2.10	2.04	2.00	1.94	2.23	2.01	2.05	
Probability Call Delayed	1	.185	.285	.155	.182	.152	.231	.168	
	2	.057	.093	.08	.069	.059	.101	.089	.166
	3	.28	.098	.294	.301	.17	.212	.227	
	Average	.174	.159	.176	.184	.127	.181	.161	
Average Total Delay	1	6.22	9.2	5.43	6.18	5.3	7.6	5.67	
	2	2.79	3.37	3.22	3.0	2.85	3.48	3.31	5.95
	3	11.0	3.63	11.6	11.33	5.41	7.19	7.14	
	Average	6.67	5.4	6.75	6.84	4.52	6.09	5.37	
Average Number of Cars Allocated	1	4	4	4	4	4	4	4	
	2	6	6	6	6	6	6	6	4.6
	3	4	4	3	3	4	4	4	
	Average	4.7	4.7	4.3	4.3	4.7	4.7	4.7	

TABLE 83

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 8

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.242	.314	.224	.262	.230	.280	.260	
	2	.198	.289	.218	.253	.234	.276	.269	.243
	3	.206	.218	.214	.229	.189	.220	.282	
	Average	.215	.274	.219	.248	.218	.259	.270	
Travel Time	1	3.3	2.9	2.7	2.8	2.7	2.8	3.3	
	2	2.6	2.6	2.5	2.6	2.5	2.6	2.8	2.8
	3	2.8	3.3	3.1	2.8	2.8	2.9	3.0	
	Average	2.9	2.9	2.9	2.7	2.7	2.8	3.0	
Patrol Hours Per Suppressible Crime	1	11.18	14.15	16.02	15.23	15.88	15.86	10.[illegible]	
	2	8.49	8.61	9.46	9.05	9.28	8.76	7.74	11.20
	3	11.7	9.22	9.27	11.36	11.95	11.49	10.58	
	Average	10.46	10.66	11.58	11.88	12.37	11.70	9.74	
Average Patrol Frequency	1	.71	.89	1.01	.96	1.00	.94	.69	
	2	1.04	1.06	1.16	1.11	1.14	1.08	.95	.88
	3	.74	.58	.59	.72	.75	.73	.67	
	Average	.83	.84	.92	.93	.96	.92	.77	
Average Number of Cars Available	1	2.65	3.36	3.80	3.62	3.77	3.53	2.59	
	2	3.93	3.98	4.38	4.18	4.29	4.05	3.58	3.32
	3	2.78	2.19	2.20	2.70	2.84	2.73	2.51	
	Average	3.12	3.18	3.46	3.5	3.63	3.44	2.89	
Probability Call Delayed	1	.072	.038	.009	.023	.013	.022	.057	
	2	.008	.019	.008	.010	.008	.019	.024	.045
	3	.053	.153	.10	.059	.059	.093	.101	
	Average	.044	.070	.039	.031	.027	.045	.061	
Average Total Delay	1	4.13	3.24	2.74	2.97	2.81	2.96	3.92	
	2	2.69	2.77	2.57	2.62	2.58	2.75	2.97	3.36
	3	3.26	6.06	4.50	3.44	3.43	4.11	4.07	
	Average	3.36	4.02	3.27	3.01	2.94	3.27	3.65	
Average Number of Cars Allocated	1	5	7	7	7	7	7	5	
	2	7	8	8	8	8	8	7	6.3
	3	5	4	4	5	5	5	5	
	Average	5.7	6.3	6.7	6.7	6.7	6.7	5.7	

TABLE 84

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 11

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.300	.510	.362	.366	.381	.412	.424	
	2	.269	.384	.349	.329	.373	.406	.385	.383
	3	.424	.381	.362	.456	.349	.406	.47*	
	Average	.331	.425	.358	.384	.368	.408	.405	
Travel Time	1	2.0	2.1	1.9	1.9	1.9	2.0	2.2	
	2	1.6	1.6	1.6	1.5	1.6	1.7	1.7	1.9
	3	2.0	2.1	2.1	2.1	2.1	2.1	2.2*	
	Average	1.9	1.9	1.9	1.8	1.9	1.9	2.0	
Patrol Hours Per Suppressible Crime	1	6.27	5.49	7.15	7.10	6.93	6.58	5.16	
	2	5.02	4.92	5.21	5.37	5.02	4.75	4.22	5.17
	3	4.96	4.00	4.12	3.51	4.21	3.84	3.5*	
	Average	5.42	4.80	5.49	5.33	5.39	5.06	4.69	
Average Patrol Frequency	1	.42	.37	.48	.47	.46	.44	.34	
	2	.66	.64	.68	.70	.66	.62	.55	.46
	3	.34	.28	.29	.24	.29	.27	.33*	
	Average	.47	.43	.48	.47	.47	.44	.45	
Average Number of Cars Available	1	1.96	1.71	2.23	2.22	2.17	2.06	1.61	
	2	3.07	3.02	3.19	3.29	3.07	2.91	2.58	2.15
	3	1.61	1.30	1.34	1.14	1.37	1.25	1.5*	
	Average	2.21	2.01	2.25	2.22	2.20	2.07	2.10	
Probability Call Delayed	1	.125	.272	.145	.130	.139	.195	[illegible]	
	2	.034	.083	.059	.041	.080	.101	[illegible]	.198
	3	.291	.410	.382	.386	.283	.440	[illegible]	
	Average	.150	.255	.195	.186	.167	.245	[illegible]	
Average Total Delay	1	3.86	7.31	4.24	3.73	3.84	5.38	9.53	
	2	1.88	2.53	2.16	1.89	2.54	2.88	2.63	8.91
	3	7.78	36.51	19.72	14.24	8.94	39.41	15.0*	
	Average	4.51	15.45	8.71	6.62	5.11	15.89	6.08	
Average Number of Cars Allocated	1	4	5	5	5	5	5	4	
	2	6	7	7	7	7	7	6	4.9
	3	4	3	3	3	3	3	4	
	Average	4.7	5.0	5.0	5.0	5.0	5.0	4.7	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 85

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE
SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 12

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization Ratio	1	.414	.422	.348	.453	.336	.398	.416	
	2	.371	.440	.428	.408	.388	.379	.355	.381
	3	.485*	.292	.289	.350	.339	.397	.485*	
	Average	.393	.385	.355	.404	.354	.391	.385	
Travel Time	1	2.1	1.9	1.8	2.0	1.8	1.9	2.2	
	2	1.7	1.8	1.8	1.8	1.7	1.5	1.4	1.8
	3	2.2*	1.8	1.8	1.9	2.0	2.0	2.2*	
	Average	1.9	1.8	1.8	1.9	1.8	1.8	1.8	
Patrol Hours Per Suppressible Crime	1	5.05	6.22	7.02	5.89	7.15	6.48	5.03	
	2	4.14	3.69	3.77	3.90	4.03	5.45	5.68	5.17
	3	3.40*	5.87	5.90	5.39	4.11	3.75	3.40*	
	Average	4.60	5.26	5.56	5.06	5.10	5.23	5.36	
Average Patrol Frequency	1	.35	.43	.49	.41	.50	.45	.35	
	2	.56	.50	.51	.53	.55	.74	.77	.48
	3	.31*	.42	.43	.39	.30	.27	.31*	
	Average	.46	.45	.48	.44	.45	.49	.56	
Average Number of Cars Available	1	1.64	2.02	2.28	1.91	2.32	2.11	1.64	
	2	2.64	2.35	2.40	2.49	2.57	3.48	3.62	2.22
	3	1.40*	1.98	1.99	1.82	1.39	1.27	1.40*	
	Average	2.14	2.12	2.22	2.07	2.09	2.29	2.63	
Probability Call Delayed	1	.225	.179	.108	.199	.091	.142	.274	
	2	.087	.140	.130	.130	.104	.055	.040	.171
	3	.340*	.200	.181	.274	.332	.377	.340*	
	Average	.156	.173	.140	.201	.176	.191	.157	
Average Total Delay	1	6.22	4.66	3.16	5.06	2.83	3.85	3.46	
	2	2.61	3.66	3.37	3.53	2.90	1.93	1.73	5.51
	3	13.75*	5.87	4.77	8.63	15.80	17.17	13.75*	
	Average	4.42	4.73	3.77	5.74	7.18	7.65	5.10	
Average Number of Cars Allocated	1	4	5	5	5	5	5	4	
	2	6	6	6	6	6	8	8	5.0
	3	4	4	4	4	3	3	4	
	Average	4.7	5.0	5.0	5.0	4.7	5.3	5.3	

*Asterisks indicate values estimated from performance measure trade-off curves due to the lack of actual data. These values were not used in the calculation of the average values.

TABLE 86

EXPECTED PERFORMANCE MEASURE LEVELS FOR THE SMOOTH GOAL PROGRAM ALLOCATION OF PATROL VEHICLES: PRECINCT 13

Performance Measure	Watch	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Average
Utilization	1	.161	.237	.153	.189	.176	.209	.212	
Ratio	2	.151	.235	.195	.201	.179	.214	.218	.210
	3	.316	.231	.205	.281	.263	.200	.180	
	Average	.209	.234	.184	.224	.206	.208	.203	
Travel Time	1	4.1	3.9	3.7	3.8	3.8	3.8	4.2	
	2	3.3	3.5	3.4	3.4	3.3	3.4	3.4	4.0
	3	5.5	5.2	5.0	5.4	5.4	3.7	3.6	
	Average	4.3	4.2	4.0	4.2	4.2	3.6	3.7	
Patrol Hours	1	12.26	13.00	14.44	13.82	14.04	13.49	11.51	
Per	2	9.31	8.38	8.82	8.75	8.94	8.61	8.57	9.65
Suppressible	3	4.79	5.38	5.56	5.03	5.16	11.20	11.48	
Crime	Average	8.79	8.92	9.61	9.20	9.38	11.10	10.52	
Average	1	.94	.99	1.01	1.06	1.07	1.03	.88	
Patrol	2	1.42	1.28	1.35	1.34	1.38	1.32	1.31	.97
Frequency	3	.38	.43	.44	.40	.41	.89	.92	
	Average	.91	.90	.96	.93	.95	1.08	1.04	
Average Number	1	3.52	3.74	4.15	3.97	4.04	3.88	3.31	
of Cars	2	5.35	4.82	5.07	5.03	5.17	4.95	4.93	3.64
Available	3	1.44	1.62	1.67	1.51	1.55	3.36	3.44	
	Average	3.44	3.39	3.63	3.50	3.59	4.06	3.89	
Probability	1	.010	.012	.002	.005	.006	.009	.016	
Call Delayed	2	.001	.007	.003	.003	.001	.005	.009	.047
	3	.259	.139	.091	.179	.180	.033	.019	
	Average	.090	.053	.032	.062	.062	.016	.015	
Average Total	1	4.14	3.99	3.72	3.81	3.81	3.91	4.31	
Delay	2	3.27	3.49	3.39	3.39	3.32	3.43	3.50	4.92
	3	12.08	7.82	6.44	8.79	8.97	3.96	3.72	
	Average	6.50	5.10	4.52	5.33	5.37	3.77	3.84	
Average Number	1	6	7	7	7	7	7	6	
of Cars	2	9	9	9	9	9	9	9	6.5
Allocated	3	3	3	3	3	3	6	6	
	Average	6.0	6.3	6.3	6.3	6.3	7.3	7.0	

END