Optimal distribution policy for mobile police patrols

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OPTIMAL DISTRIBUTION POLICY FOR MOBILE POLICE PATROLS

by

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ABSTRACT

The operations of the mobile resources of Durham County Constabulary have been studied with particular reference to their function of responding to calls for service, both emergency and otherwise. Data collected during two three-month survey periods a year apart has been analysed to determine the main quantitative aspects of mobile police performance and to evaluate the demand for and the service provided by these resources.

The effects of organisational changes made between the two survey periods have been assessed in terms of these measures of performance. Significant changes in some aspects of the service provided were recorded.

Mathematical models of these measures of police performance have been tested and found to be generally applicable to the Durham Constabulary situation. They have been used to explain some of the observed changes and to form a basis for the evaluation of various policies for allocating mobile resources to optimise performance.

Various possible objectives for mobile police resource allocation have been considered and their consequences on allocation and on patrol car organisation evaluated. A conflict between certain allocation objectives under Durham Constabulary conditions has been indicated.

An allocation of mobile resources to satisfy specified service capabilities in areas of mixed urban/rural characteristics has been recommended and its implications considered.

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CONTENTS

CHAPTER I

INTRODUCTION

In recent years there have been a number of investigations into aspects of police work in the U.K., U.S.A., and elsewhere. Those with relevance to the present study will be described here. While the details they give are in each case specific to the force being investigated, the ideas are of general application.

The results of surveys and of experiments concerned with the dual role of the police force in preventing offences and in responding to calls for service are described in section 1.1.

In addition, methods of allocation have been described based on assumed or measured effects and on specified objectives. These are described in section 1.2.

The conclusions from previous work and its bearing on the present study are summarised in section 1.3.

1.1. Experimental Work in the Police Service

1.1.1. Experiments in Durham and elsewhere - effect of police on traffic.

First Durham Experiment

During the period August 1967 to September 1968 a joint team from Durham Constabulary and Durham University carried out a study into the effects of police patrol levels and tactics on the accident rate on certain major trunk roads in the Durham Police Area.

The aim of this project was to investigate the relationship (if any) between the level of police patrol activity on these trunk roads and the accident rate recorded on the same roads in the same period with the initial hypothesis that there was such an effect for the accident rate per unit traffic flow. This in its turn implied that other variables (weather, modifications in road conditions due to engineering) would enter only as secondary effects. Important experimental variables became

(a) intensity of patrolling, and

(b) traffic flow,

and the function to be investigated was

(c) accident rate.

When the study had been completed the Project Report (9) concluded that

(i) there was no detectable relationship between the level of police patrolling and the accident rate on trunk roads,

(ii) there was some evidence of a rise in reported non-injury accidents in the presence of increased patrolling.

Conclusion (ii) reflected the fact that during increased patrolling police patrols had been more likely to come across damage only accidents which would not otherwise have been brought to the attention of the police.

Since accidents are distributed approximately according to a Poisson distribution, with the size of sample involved in this experiment a decrease of approximately one third would have been required for significance, hence the reported failure to obtain a significant change is not surprising.

Other findings were

(iii) the actual levels of motor patrol reported were low. The average patrol strength per twelve mile stretch of road did not exceed one, and was for considerable periods as low as one-twelfth. In particular the patrolling level achieved was lower than expected due to police time spent on such activities as writing up reports and taking refreshments.

(iv) The daily variation in reported patrol strength was out of phase with the variation in accident rate and traffic flow, in that relative to accident rate excessive reported patrol frequencies were recorded between 1 a.m. and 7 a.m. and low levels of patrol were reported between 5 p.m. and 11 p.m.

The report also found considerable shortcomings in the traffic flow data available. It went on to recommend that the allocation of available patrol strength by shift should be re-examined in the light of the local diurnal variation in traffic flow and accident rate. The report also recommended that in any future experiments involving measurements of police activity, or of other parameters as a function of such activity, in as far as was consistent with operational requirements, the senior police officer assigned to the experiment should have direct operational command of the part of the force taking part in the experiment. This recommendation reflected the difficulty of ensuring adequate completion of forms, a feature also reported by the Lancaster investigators (4).

Second Durham Experiment

Since the negative results of the first experiment might have been due to the small accident sample obtained during the limited time and extent of the experiment, further experimental work was carried out to investigate the effect of police patrolling on particular aspects of driver behaviour. Comparisons were made between the situations where the available patrol strength was deployed uniformly and where it was deployed in a pulsed manner, involving alternate three day bursts of high and low police activity with the same overall level of effort.

The measures of driver behaviour used were

(a) mean and variance of speed distribution in a derestricted zone. (Heavy goods, light commercial, and private motor cars separately.)

(b) The same in a 30 m.p.h. restricted zone.

(c) Percentage of drivers overtaking on a narrow undulating stretch of road.

(d) Percentage of drivers giving precedence to pedestrians at a designated crossing.

These measures were chosen because they were as far as possible objective and quantitative, related in some degree with accidents, and capable of producing large samples in a short time.

Preliminary experiments showed that the presence of a police motorcycle patrol on a short stretch of road (four miles of carriageway) affected driver behaviour in that

(1) the mean speed of the traffic flow in a restricted speed zone was lowered, and

(2) a higher proportion of drivers gave precedence to pedestrians at crossings.

However from the main experiment carried out between March and July, 1969, (10) it was concluded that, as measured by the four characteristics of driver behaviour described

(i) there was no evidence of any difference in the short term between uniform and pulsed patrolling, and

(ii) there was no evidence of any difference between the days when a pulse was in operation and when a pulse was not in operation.

These conclusions indicated that, in the short term, heavy police coverage had no detectable effect on driver behaviour, except possibly in the immediate vicinity of a police vehicle.

Other Experimental Work

The findings of the second Durham Experiment were to a certain extent at variance with the findings of published reports of related work carried out elsewhere.

A detailed study by Biss (2) quotes similar experiments, on accident rates and aspects of driver behaviour, carried out in Slough (1955-57), Wisconsin (1955-59), Indiana (1962), California (1964), England (1964-5), S.W.England (1965), Sweden (1965), Yorkshire (1967-68), and London (1968).

The sum total of these reports suggests that very large increases in police activity, coupled with publicity of the increases, do lead to a significant decrease in the number of accidents and to a decrease in average speed, which is possibly significant. It is suggested that any effect on the motoring public of increased apparent police activity is detected after months, rather than days, and is possibly transmitted via the effect of prosecutions rather than by the visual impact of the increased police activity.

1.1.2 Experiments in Urban Areas - effect of police on crime

Beat Patrol Experiment

In 1964 the Home Office Police Research and Development Branch initiated a series of experiments to measure the effectiveness of foot patrols (see Turner (22), (23), and (24)).

The aim of the main 'Beat Patrol Experiment' was to discover some of the basic relationships between the number of men employed on foot patrols and the number of crimes committed at different times of day. A 'Latin Square' experiment was used, in which different combinations of beat manpower and times of day were tested in small experimental areas in four cities (Cardiff, Manchester, Newcastle, and Sheffield) at different times of the year over one year from December, 1965, to December 1966. The results were compared with those from control areas to determine the effect in terms of extra crimes prevented and detected.

The subsequent report (3) found that for preventable indictable crime the evidence supported the hypothesis that 'any preventive effect gained by patrolling is achieved with one man per beat and any increase in manpower above this level (up to four men per beat) does not result in any further crimes being prevented'. This finding was supported by the significant result that the crime level for one man per beat was 30% reduced compared with the crime level for no men per beat.

The report concluded that 'the relevance of these results to strategic and tactical deployment of manpower is important. The thesis is held by a section of the police service that increasing the level of foot patrols in general will result in a reduction in crime. This thesis is rebutted by the results of this experiment.'

Other Experimental Work.

Definite quantitative evidence of the effect of police on crime, and in particular of the role of the preventive patrol is difficult to find. To the author's knowledge there is no published evidence of any long term experiment on preventive patrol which has demonstrated a significant effect for enhanced patrol levels.

The Chicago study (7), which defined the preventive patrol function as the taking of police initiative against crime, calculated that the probability of space-time coincidence of police and criminal event was small (for example, 0.02 for a street robbery) and concluded that further work was necessary before the use of scarce police resources in the preventive patrol mode could be rejected or supported.

A brief summary by Turner (25) quotes several small-scale experiments carried out in England, similar to the Beat Patrol Experiment, on the effect of police on crime and criminal activity.

Set against the findings of the Beat Patrol Experiment are the findings of experiments in Liverpool, Leeds, and Kirkby suggesting that providing the increases in patrol activity are publicised, high levels of prevention can be achieved.

Overall the available evidence suggests that increases in police activity are not sufficient by themselves to effect any noticeable changes in criminal behaviour, but that when they are used in conjunction with widespread advance publicity campaigns their effect is enhanced sufficiently for a change to be detectable.

1.1.3 Measurements of Police Response.

Chicago.

The Police Department in Chicago (see (7) and (26)) has paid much attention to its functions of preventive patrol and response and to the problem of most beneficially allocating available manpower and resources between these two activities, according to specified measures of performance. Though the operations of the Chicago Police are on a different scale of magnitude from those of the British forces mentioned, as shown by the figures which follow, the underlying problems are similar.

The fundamental assumption behind the role of preventive patrol is that police presence acts to deter crime, although no specific experimental evidence is cited in support of this. Information is however available on the response to calls for service, involving both the activities of the communications centre, and the field response.

The communications centre handles as inputs, demands for service (three million calls in 1968) and information requests from citizens and policemen (one million in the same year), and as outputs car assignments and information. Cars were despatched to just under two million of the calls for service in 1968. Observations in the centre determined that the average time required for incoming calls to be serviced was 82 seconds, and the average time taken to assign a car was just under 15 seconds, resulting in an average handling time of 97 seconds.

The field response involves the activities performed by a police unit between its assignment to an incident and its resumption of normal patrol, including travelling time on route to the incident from the location at time of assignment and service time at the incident scene. Total response time includes communications centre handling time and field response travelling time.

During a one week survey in August 1968, involving approximately 10,000 calls for service daily, service time and car utilisation was measured.

A small response time survey (454 observations) was also performed.

Service time averaged 40 minutes, and assists (to other police units) averaged 30 minutes. Utilisation, defined as the percentage of total duty time spent on calls for service and assists, varied from 21 to 55 per cent, according to shift and day of week, and averaged approximately 40 per cent. Response time was found to have a mean of 7.68 minutes, standard deviation of 5.65 minutes, and a mode of 4.0 minutes, when the average availability was 35 per cent.

Lancaster

The work described in the Lancaster report (4) was undertaken in this division of the Lancashire Constabulary. Data on various aspects was collected over the period May to December 1967.

This division was one of fifteen in the Constabulary and covered 220 square miles mainly of a rural nature with a population of 125,000. Special patrols were responsible for policing of the A6 trunk road and M6 motorway. A standard unit beat policing scheme was in operation, and was supplemented by divisional and traffic patrol groups, the latter organised at County Constabulary level.

Information on the following aspects was collected for the study.

(a) Urgent incidents reported, and

(b) operational duties worked.

Data required for (a) was obtained from the incident report forms, while details of (b) were extracted from the police duty state records.

Additional data on the duty time of panda vehicles and traffic patrols spent on various activities was collected. For the non-traffic personnel the information was collected by the station sergeant, who radioed the men at quarter-hour intervals. The traffic patrols were themselves required to complete a form hourly giving details of their activities. This arrangement was found to have serious shortcomings and the results for traffic patrols were disregarded on the grounds of complete lack of realism. Results showed that 60% of panda car duty time was spent on patrol.

In the Lancaster sub-division urgent incidents, excluding traffic offences, totalled 1190 for the seven month period studied, an average of 5.6 incidents per day. Half of these were discovered by patrols and the remainder reported by the public. At the same time an average patrol strength of 6.5 panda cars on duty was maintained. Thus on average the daily incident/panda car hour ratio was 0.036.

1.2 Allocation and objectives in the Police Service

Mathematical techniques of allocation either suitable for, adaptable to, or specially designed for police resource allocation are considered in reports from Baltimore (1), Chicago (7), Lancaster (4), St. Louis (19), and by Gass (12), and Larson (16) amongst others.

These techniques, together with examples of their practical application are considered here. It should be noted that the main source of differences between methods of allocation arises from varying attitudes on the part of the investigators as to the most desirable police achievements and hence the form of the objective function to be optimised. Thus Chicago and Baltimore used an equalised workload criterion for their police resource allocation algorithms, an approach considered in greater detail by Gass, Larson considered system response time, and Lancaster used a composite measure of effectiveness comprising results reflecting particularly crime prevention and detection achievements.

1.2.1 Mathematical Techniques of Allocation

Mathematical Programming

One set of allocation techniques is that of mathematical programming, including linear programming, together with its integer programming, and chance-constrained (stochastic) programming refinements, and non-linear and dynamic programming.

The general programming problem is to maximise or minimise the objective function

$$z = f(x_1, \ldots, x_n) \qquad (1)$$

for n variables $x_1, \ldots, x_n$ which satisfy the m inequalities or equations

$$g_i(x_1, \ldots, x_n) \{\leq, =, \geq\} b_i, \quad i = 1,\ldots,m \qquad (2)$$

where the b_i are assumed to be known constants. The restrictions (2) are the constraints on the problem.

The exact form of any programming problem depends upon the specified functions $g_i(x_1, \ldots, x_n)$, $i = 1,\ldots,m$ and $f(x_1, \ldots, x_n)$. For example, in the linear programming problem below

$$g_i(x_1, \ldots, x_n) = \sum_{j=1}^{n} a_{ij} x_j , \quad i = 1,\ldots,m$$

and

$$f(x_1, \ldots, x_n) = \sum_{j=1}^{n} c_j x_j ,$$

where the a_{ij} and c_j are known constants

Linear Programming

The standard linear programming problem is to maximise or minimise the linear function

$$z = \sum_j c_j x_j$$

for the x_j, subject to the constraints

$$\sum_j a_{ij} x_j \leq b_i , \quad i = 1,\ldots,m$$

and

$$x_j \geq 0 , \qquad j = 1,\ldots,n$$

where the a_{ij}, b_i and c_j are given constants.

Linear programming is applicable to situations where there are n competing activities, whose levels are represented by decision variables x_j, $j = 1,\ldots,n$. For example x_j could represent the number of man-hours assigned to a specific police activity j. Then z (the objective function) represents the overall measure of effectiveness, for example, total number of crimes prevented, and c_j is the decrease in this overall measure, that is, the number of crimes that would be prevented, by unit increase in x_j. The m numbers b_i represent the scarce resources to be allocated, for example the total man-hours and patrol cars available. The first m linear inequalities then represent constraints on the m resources, a_{ij} being the amount of resource i required by each unit of activity j, for example if x_j is the number of man-hours required for a particular patrol activity j and resource b_i is the number of patrol cars available, then a_{ij} is the number of patrol cars required by each unit of man-hours x_j for patrol activity j. The left side of each of these resource constraints then represents the total amount of the respective resource used by all n activities. Finally the constraints, $x_j \geq 0$, state that none of the n activities can be operated at a negative level.

Certain assumptions need to be satisfied for linear programming to be applicable to a problem of this type. First the parameters (c_j, a_{ij} , b_i) must be known, and this implies that the objective function is a deterministic linear function in the decision variables x_j.

In most allocation problems it certainly will not be true that the marginal measure of effectiveness, c_j , will be constant over the entire range of levels of each activity j. For example, the criminal activity on a particular beat may not decrease at a constant rate for each additional patrol car assigned to that beat (if indeed it decreases at all, see above). In other allocation problems there is a fixed return or cost associated with any activity operated at a positive level independent of the level of the activity.

For many allocation problems the above assumptions may be too strong, although the linear programming solution may still give satisfactory optimal decisions if the optimal values of the decision variables are not too sensitive to errors in the parameters.

Integer Linear Programming

In the linear programming formulation of the allocation problem above, the decision variables x_j are allowed to take non-integral values. Practical considerations often require integer solutions (e.g. number of men assigned, number of patrol cars allocated).

The linear programming formulation is readily adapted to the integer linear programming problem, which is to optimise the objective function

$$z = \sum_j c_j x_j$$

subject to

$$\sum_j a_{ij} x_j \leq b_i , \quad i = 1,\ldots,m$$

$$x_j \geq 0 , \quad j = 1,\ldots,n$$

and x_j integral, $j = 1,\ldots,n$ by imposing the additional constraints that the decision variables x_j, $j = 1,\ldots,n$ take on only integral values.

Chance-Constrained Programming

The deterministic linear programming model requires that all constraints hold with probability one. For chance-constrained programming the model is adapted so that the constraints

$$\sum_j a_{ij} x_j \leq b_i , \quad i = 1,\ldots,m$$

are replaced by

$$P \left\{ \sum_j a_{ij} x_j \leq b_i \right\} \geq \alpha_i$$

where the α_i's are numbers between zero and one but in most applications would be close to one. Hence, $1 - \alpha_i$ represents the allowable 'risk' or the probability that the activity levels take on values such that

$$\sum_j a_{ij} x_j > b_i .$$

This formulation covers the situation where some or all of the parameters (c_j, a_{ij}, b_i) are not known with certainty but are random variables with known probability distributions. The objective is then to optimise

$$E\left\{\sum_j c_j x_j\right\}$$

subject to the constraints

$$P\left\{\sum_j a_{ij} x_j \leq b_i\right\} \geq \alpha_i , \quad i = 1,\ldots,m$$

and

$$x_j \geq 0 , \qquad j = 1,\ldots,n .$$

The 'E' notation in the objective function represents taking the expected value of the objective function, so the measure of effectiveness is an average or expected measure.

Since all of the parameters in a linear programming model have to be estimated the chance-constrained linear programming models are more realistic than their deterministic equivalents. For example, the men available, cars available, demand for service, can be very difficult to estimate with a 'high confidence' and it may be more desirable to assume that these positive and negative resources are random variables. Using this method the possible values of the parameters are weighted by probability distributions to obtain a more realistic allocation model. Further details of this technique are included in Charnes and Cooper (6).

Dynamic Programming

Dynamic programming is a computational technique which is used to solve decision problems involving a sequence of interrelated decisions.

There is no general technique as in the case of linear programming and each dynamic resource allocation problem usually requires special formulation. The technique is most effective when used for allocation problems with few resource constraints.

For example the nonlinear programming problem

$$\sum_{j=1}^{n} a_j x_j \leq b \, , \quad a_j > 0, \quad j = 1,\ldots,n$$

$$x_j \geq 0 \, , \quad j = 1,\ldots,n$$

all x_j integral

maximise

$$z = \sum_{j=1}^{n} f_j(x_j)$$

with only one resource constraint can be considered to be an allocation problem in which there is a single limited resource, and x_j is the quantity of resource to be allocated to activity j. Then $f_j(x_j)$ can be thought of as the return from activity j when x_j units of the resource are allocated to it.

If then $\Lambda_k(\xi)$ and $\hat{x}_k(\xi)$ are defined so that

$$\Lambda_k(\xi) = \max_{x_1,\ldots,x_k} \sum_{j=1}^{k} f_j(x_j) \qquad k = 1,\ldots,n$$

and $\hat{x}_k(\xi)$ is the value(s) of x_k for which

$$\Lambda_k(\xi) = f_k[\, \hat{x}_k(\xi)]$$

that is, $\hat{x}_k(\xi)$ is a value of x_k which maximises $f_k(x_k)$ when x_k can assume the values $0,1,\ldots,[\xi/a_k]$, then $\Lambda_k(\xi)$ is the maximum return from the first k activities when a total quantity ξ of the resource is available for allocation to these activities and $\hat{x}_k(\xi)$ is the optimal value for x_k when there are only k activities and a quantity ξ of the resource is available for allocation to these activities.

Regarded as a n-stage problem, the dynamic programming approach, where at stage j the decision made is how much resource to allocate to activity j, that is, x_j is selected, solves successively the one-stage, two-stage, ... problems until all n stages are included, so for k stages the solution is obtained by using the k - 1 stage solution and adding the k^{th} stage. The optimal values of the x_j, $j = 1,\ldots,k$, depend on ξ, the total quantity of the resource which is available for allocation to the k stages.

As many resource allocations in the police system involve interrelated decisions similar in structure to the above problem the techniques of dynamic programming should prove useful in obtaining solutions to some of these allocation problems. Further details of these techniques can be found in Hadley (13).

<u>Warehouse Location</u>

The warehouse location problem is analogous to many problems in the police system such as the structuring of beats, location of patrol cars, and allocating of man-hours to preventive patrol and calls for service. The problem is to locate a specified number of warehouses (patrol cars, men, determining beat structure) and assign customers (calls for service, expected calls for service, expected crimes by beat for each shift) such that the total cost of servicing (travel time, negative of the crime prevented) is minimised.

A general formulation of the warehouse location problem is as follows. Consider a distribution of warehouses j (police patrols) and outlets k (demands for service). The problem is to specify the location of the warehouses and to allocate x_{jk} customers at outlet k to be supplied with service from warehouse j in such a way that the service demands at the outlets are satisfied, that is

$$\sum_{j} x_{jk} = b_k \qquad (1)$$

where b_k is the demand at outlet k.

There may be a further constraint so that the service capacity of each warehouse is not exceeded, so if

$$\sum_{k} x_{jk} = z_j \qquad (2)$$

then $$z_j \leq a_j, \quad \text{for all } j$$

where a_j is the capacity of warehouse j.

The objective function may be dependent on the z_j as well as on the x_{jk}, this would reflect different service efficiencies at the warehouses, as in the commercial case where warehousing and ordering costs are known to depend on z_j^q, where $q = \frac{1}{2}$ from standard inventory theory.

In any case the final requirement is to optimise a function $c(x_{jk})$ subject to restrictions (1), (2). The function may be linear or non-linear and the solutions may be restricted to be integral.

The exact optimal solution is difficult to obtain for this problem. A heuristic-analytic or heuristic technique of solution may be necessary. These are discussed in Feldman, Lehrer and Ray (11), and Kuehn and Hamburger (15).

Queueing Theory

Queueing theory is one technique that has already been applied to some problems in the police service, see St. Louis (19). Most of the reported work concerns the application of the theory to the study of behaviour characteristics of operations in the police service involving congestion (for instance, arrivals of calls for service). Only limited use of optimisation in the study of stochastic processes in the police service has been made, but if the behaviour of a process is known it would be possible to impose on it either a minimum requirement or an optimisation procedure.

The basic process assumed by queueing models is that units requiring service (beats, locations, crimes in progress) are generated at random over time by an input source. These units enter the system (calls placed) and join a queue. At certain points in time a member of the queue is selected for service by a service rule (certain types of calls for service are processed first). The required service is then performed for the unit by the service mechanism (calls despatched) after which the unit leaves the queueing system.

Applications of queueing models require the estimation of the parameters in the model, in particular the distribution of the arrivals for service and the service mechanism.

Queueing situations requiring decision making arise in many areas in the police system. For instance, the number of despatchers in the control room and the number of men or cars available to answer calls for service, are both sets of 'servers' in the queueing model. The demands on them arrive at random, their work involves servicing these demands and also other work, the time taken to service a demand has a distribution which can be measured. The efficiency of the system may then be measured by

(a) time of response to the demand, that is, time to pass on a call, time to reach the incident (waiting time in the queueing model), or

(b) internal properties of the system such as the proportion of time occupied in service, or length of a busy period.

These decisions involve the question of the appropriate level of service to provide in the police system. Decisions regarding the amount of service capacity involve two considerations. One is the cost of providing the service and the other is the cost involved in waiting for that service. These two considerations are conflicting in many of the decisions faced in allocation models of this type. The objectives of reducing service costs imply that a minimal acceptable level of service has to be maintained, on the other hand, long waiting times are undesirable which recommends a high level of service.

Since there are costs and benefits to be received by each proposed police activity the use of queueing optimisation models may be very beneficial in the design and control of such activities if the appropriate cost and return functions can be determined.

1.2.2. Specific Police Applications

Practical applications of the above techniques will now be considered

Warehouse Location - Gass

Gass's formulation of the patrol beat determination problem (12) was based on the recommendation of the International Association of

Chiefs of Police (IACP). This suggested that the total crime workload in each zone of a city should be measured by combining the weighted workloads for each of its constituent census tracts (to measure the workload for a tract, weights were given to the various incidents to yield a total weighted workload, these weights were supposed to reflect the seriousness of an incident and the time required to service it) and then by some heuristic procedure the tracts should be combined to form k contiguous beats each having approximately the same relative workload.

Thus the major problem discussed by Gass was as follows. Given k patrol units to be assigned during a shift, how should the k corresponding patrol beats be determined so that

(a) each patrol unit will, on the average, have the same workload, and

(b) the area of a patrol beat is structured to allow for efficient patrol and response tactics.

Clearly it was not desirable to have two disconnected regions in the same beat, but some definition of 'efficient' was required. Gass noted that the problem was analogous to the warehouse location problem and defined it as follows.

Let

k = number of patrol beats to be assigned,

n = number of census tracts in the city,

$$x_{ij} = \begin{cases} 1, & \text{if tract } T_j \text{ assigned to beat about tract } T_i, \\ 0, & \text{otherwise,} \end{cases}$$

c_j = the weighted crime workload in T_j, for example, if I_{pj} = level of crime incident p in T_j, then

$$c_j' = \sum_p w_p I_{pj}$$

where w_p is the weight of the p^{th} incident.

$$c = \sum_1^n c_j = \text{total weighted crime in the city.}$$

c/k = average weighted crime per beat.

a = factor for minimum allowable crime in a beat with respect to average crime per beat,

b = factor for maximum allowable crime in a beat with respect to average crime per beat,

d_{ij} = distance between centres of T_i and T_j census tracts,

$d_{ij}^2 c_j$ = 'moment of inertia' of the weighted crimes in T_j about the centre of tract T_i.

The measure of effectiveness considered by Gass was

$$\sum_i \sum_j d_{ij}^2 \, c_j \, x_{ij}$$

which he interpreted as the total 'moment of inertia' of the weighted crimes about the k centres.

The model was

$$\text{minimise} \quad \sum_{i=1}^n \sum_{j=1}^n d_{ij}^2 \, c_j \, x_{ij}$$

subject to

$$\sum_{i=1}^n x_{ij} = 1 \ , \qquad j = 1,\ldots,n$$

$$\sum_{i=1}^{n} x_{ii} = k$$

$$\sum_{j=1}^{n} c_j \, x_{ij} \geq \frac{ac}{k} \, x_{ii} \, , \qquad i = 1,\ldots,n$$

$$\sum_{j=1}^{n} c_j \, x_{ij} \leq \frac{bc}{k} \, x_{ii} \, , \qquad i = 1,\ldots,n$$

$$x_{ij} = 0 \text{ or } 1.$$

The restrictions on the decision variables x_{ij} made this model an integer linear programming problem. In fact Gass did not solve the integer programming problem but applied the heuristic procedure of Hess, et al. (14).

For the problem Gass considered for the City of Cleveland, using data from the 1966 report of the Police Department, there were a total of k = 58 beats and n = 205 census tracts to assign. In his computations five measures of the workload were considered for a census tract, namely, number of index crimes, population, area, level of crime multiplied by the population and the level of crime multiplied by the area, and the effect of using each was compared.

One of the problems encountered by Gass was that due to a lack of data, the measure and weighting scheme proposed by the IACP could not be evaluated. Gass planned to imbed the police beat algorithm within a geographical crime information system with graphical inputs and outputs which would enable the proper man-machine interaction to be brought to bear on the heuristic-analytic type of decision model that he had developed.

The Gass model is an example of the integer linear programming formulation of the warehouse location problem approach to an allocation model for the police system with an equalised workload objective.

The Chicago assignment, see Chicago (7) and Wilson (26), was also equalised workload, considered as being largely comprised of calls for service. An appropriate workload was assumed to be four calls per shift per beat car with one hour devoted to each call. This loading left approximately four hours for preventive patrol during a tour of duty. The weightings used were again intended to reflect seriousness and service time of each call for service category. Beats were then determined by use of the weighted workload criterion, see also Baltimore (1), with the recognition that beats in a peripheral district may become too large under this sole criterion for adequate police service in terms of response time and preventive patrol, in which case extra beats, in excess of those required on the workload criterion, may be needed. The solution was obtained by trial and error methods.

The final Chicago report found that while the weightings were supposed to reflect seriousness, and more importantly, service time requirements of a call, an inverse relationship between seriousness and service time was often observed. Thus a patrolman initially despatched to the scene of a serious incident was often quickly replaced by a member of a specialised squad, for example, a detective. It was also found that assumed average service time was 50% in excess of the observed value of forty minutes.

A more relevant objective was suggested to be the minimisation of some function of response time coupled with the maximisation of the probability of halting or preventing a crime through selective preventive or tactical patrol.

The problem of time distribution of effort was also mentioned and it was postulated that in scheduling duty shifts it was desirable to match the demand pattern as closely as possible, so that a penalty would be incurred if either too many or too few operators were provided, that is, the principle should be equalised workload overall. Solutions of these problems were also provided by trial and error.

Dynamic Programming - Larson

Larson (16) considered one aspect of the police system manpower problem, the determination of hourly demand for certain police personnel. The model was used to determine the demand for personnel throughout a 24 hour day. His models allowed for widely fluctuating rates of calls for service and still aimed at providing a constant level of service to the public. The types of personnel considered were radio-despatchable patrolmen and the associated support personnel (complaint clerks and despatchers) in the communications centre.

Larson interpreted the service level as an indicator of police accessibility to the public and chose system response time as his allocation criterion, assuming that the police administration desired to maintain a certain level of service to the public. The service level was defined in terms of average delays incurred, the relative numbers of various types of calls, and the costs per unit of delay, the last of which could depend upon the priority of the call for service. The numerical value of the service level was left as a police policy decision. However the delay in any response was supposed determined by the number of personnel allocated to that activity, and the requirement was to define an allocation which would achieve the desired service with a minimum total level of manpower.

Larson used a dynamic programming formulation for the problem as follows.

Let

I = number of activities to which personnel are to be allocated in the system,

N_i = number of police personnel assigned to the i^{th} activity, $i = 1,\ldots,I$,

N_i^{o} = minimum allowable number of personnel who can be assigned to the i^{th} activity, $i = 1,\ldots,I$,

N_i^* = optimal number, to be determined, of personnel assigned to the i^{th} activity, $i = 1,\ldots,I$,

J = total number of priority classes for calls,

λ_j = average number of j-priority calls received per hour,

w_j = cost per minute of delay incurred during response to a j-priority call, $j = 1,\ldots,J$,

$\bar{T}_{ij}(N_i)$ = average delay incurred by j-priority calls at activity i, with N_i personnel assigned, $i = 1,\ldots,I$, $j = 1,\ldots,J$.

For example, in the Boston study by Larson, the i subscripts referred to the following activities,

$i = 1$, complaint clerk processing

$i = 2$, despatching

$i = 3$, patrol car travelling.

Then the expected total delay cost incurred during an hour was

$$c = \sum_{j=1}^{J} w_j \lambda_j \sum_{i=1}^{I} \bar{T}_{ij}(N_i) \quad .$$

Larson next defined the normalised mean response time as

$$n_j = \frac{w_j \lambda_j}{\sum_{k=1}^{J} w_k \lambda_k}$$

where

$$\sum_{j=1}^{J} n_j = 1 .$$

The n_j's were normalised weighting factors for the various priority level delays.

The service level, that is, the normalised mean delay per call, was then defined as

$$\bar{T} = \frac{c}{\sum_{k=1}^{J} w_k \lambda_k}$$

$$= \sum_{j=1}^{J} n_j \sum_{i=1}^{I} \bar{T}_{ij} (N_i) \quad .$$

The problem was

$$\text{minimise} \quad \sum_{i=1}^{I} N_i$$

subject to the constraint that $\bar{T}$ is less than or equal to a specified service level T^o and that

$$N_i \geqslant N_i^{\,o}, \qquad i = 1,\ldots,I.$$

The dynamic programming formulation of this problem was then stated as follows.

Let

$\bar{T}_i(N)$ = minimum achievable normalised mean delay time per call through the i^{th} activity of the system with N personnel optimally allocated through the i^{th} activity. Then the problem can be stated as

$$\bar{T}_i(N) = \min_{N_i^o \leq N_i \leq N_i'} \left\{ \sum_{j=1}^{J} n_j \, \bar{T}_{ij}(N_i) + \bar{T}_{i-1}(N-N_i) \right\}$$

$$i = 1,\ldots,I, \qquad \text{where}$$

$$N_i^o \leq N$$

$$N_i' = N - \sum_{j=1}^{i-1} N_j^o$$

$$\bar{T}_o(N) \equiv 0.$$

This minimum cost equation can be interpreted as, the minimum achievable delay through the i^{th} activity is the minimum of the sum of the delay incurred at the i^{th} activity with N_i personnel assigned and the minimum achievable delay for the remaining i-1 activities with $N - N_i$ personnel assigned. This equation was solved recursively for N_i and the optimal results were tabled.

The output of Larson's model was a table of numbers with one row for each hour of the day and each column associated with a class of personnel. The entries in each row were the minimum numbers of personnel, by type, which should be assigned during the hour to achieve the desired service level. Larson did not consider constraints on the length or starting time of shifts in his model. Hence the entries in the tables are the demands for, rather than the allocations of, police personnel. The table can be used to construct shift assignments based on the numbers representing the derived demand for personnel. The Larson model could clearly be made more realistic by adding constraints in respect of length and starting time of a tour of duty.

The Larson model is an example of a dynamic programming model of the police allocation problem with a minimum system response time objective.

Queueing Theory - Chicago

Chicago (7), and St. Louis (19), used a queueing model to design their response force, for this was seen as offering the advantage of treating demands for service and police response as part of a stochastic process. The objective of the model was to minimise response time, by minimising expected average delay before a car was available for assignment within any given sector.

Assumptions made included those of Poisson input of service calls, negative exponential service time distribution and multiple parallel channels as it was the policy that if a beat officer was busy, an adjoining beat car would answer a call in that beat, but not in a beat in another district as interdistrict despatching was not generally allowed, so for the queueing model each district had c parallel channels servicing all its calls where c represented the number of beat cars.

The notation used was

λ = mean arrival rate

μ = mean service rate per channel

c = number of cars for answering calls

n = number of calls in the district system

ρ = utilisation factor for district ($\lambda/c\mu$)

p_n = the steady state, time independent, probability that there are n calls in the system

$p(0)$ = probability of no waiting

$p(> 0)$ = probability of any waiting

$p(> t)$ = probability of waiting greater than time t

L = average number of calls in queue awaiting service

w = average waiting time in the system.

If $\rho < 1$, then by standard queueing theory for the M/M/c queue, see Cox and Smith (8),

$$p_0 = \frac{1}{\sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!} + \frac{(c\rho)^c}{c!(1-\rho)}}$$

gives the probability that there are no calls receiving or waiting for service, and the number of calls waiting for an available car is

$$L = \frac{\rho(c\rho)^c}{c!(1-\rho)^2} p_0 .$$

The probability of a delay in finding an available car is

$$p(> 0) = \frac{(c\rho)^c}{c!(1-\rho)} p_0$$

and of a delay greater than t is

$$p(> t) = \exp\{-c\mu t(1-\rho)\} \quad p(> 0)$$

and the expected waiting time, excluding waiting time in service is

$$w = \frac{L}{\lambda} .$$

The effect of a priority discipline was compared with the first come - first served discipline. It was noted that crimes and traffic accidents accounted for less than 30% of the total calls resulting in the despatch of a beat car to a complainant, which indicated a two-priority class with 30% of calls treated as priority-one calls. In normal operating conditions the priority system was not found to offer any major savings, but when less than normal levels of cars were available the two-priority system was shown to be worthwhile.

Low mean service time, or a decrease in the number of calls to which a car was despatched, were shown to offer the greatest overall savings under normal conditions.

The initial assumptions made were tested using collected data and the negative exponential service time distribution was shown to be unreliable.

A hand graphical method for estimating the number of response units required to deal with any specified rate of arrival of calls for service per hour was presented using mean service times of 20, 30, 40, and 50 minutes.

Use of the queueing model technique was extended to cover another aspect of response force efficiency. This involved the probability of apprehending a criminal at or near the scene of crime, depending upon the number of police units responding within a given number of minutes under the trapping and search procedure Operation Blue Fence/Rake.

In Chicago once the strength of the patrol force was determined by the queueing model, it was then allocated by the equalised weighted workload criterion described above.

Allocation - Lancaster

The Lancaster work (4) was primarily concerned with the patrol deployment problem, which was briefly defined as the determination of the numbers and types of patrols that should be deployed at different places and times, in order to maximise the overall 'effectiveness' of the patrolling force. The investigation sought to judge effectiveness by reference to a wide range of police achievements.

To construct an overall measure of police effectiveness required the means for combining outputs from various measures of police achievement into a single measure of performance. The method adopted was to conduct a value judgement survey in which police sergeants and higher ranks rated a wide variety of incidents according to the value of

(a) preventing, and

(b) detecting

such an incident, both activities being considered to have good, but possibly differing values in terms of police achievement. These values were aggregated to indicate as a measure of effectiveness the function

20 (number of indictables prevented) +

$20k_1$ (number of indictables detected) +

5 (number of non-indictables prevented) +

$5k_2$ (number of non-indictables detected) +

10 (number of accidents prevented) +

$2k_3$ (number of traffic offences detected) +

10 (number of thousand man-hours congestion prevented) +

$1k_4$ (number of emergencies handled),

where the k_i were the ratios of the detection to prevention values and 10 units of effectiveness corresponded approximately to the value of preventing a typical larceny.

This measure of effectiveness suffers from

(i) the uncertainty in the k_i, value ranges being suggested as

$$0.4 \leqslant k_1 \leqslant 4.0, \quad 0.4 \leqslant k_2 \leqslant 4.0 ,$$

$$0.04 \leqslant k_3 \leqslant 0.40, \quad 0.7 \leqslant k_4 \leqslant 1.0,$$

(ii) the uncertainty in the numerical constants in the measure, which were qualitatively determined, and

(iii) the impossibility of measuring prevented crimes, the only reliable crime figures are those for recorded crime.

The patrol deployment problem was isolated from other areas of total police resource allocation and was regarded as existing at three levels.

(1) Total resources (money, manpower, equipment) to be used for patrolling established for whole county.

(2) These resources then divided between various operational groups in the county (that is, between divisions, sub-divisions, and traffic groups).

(3) Each operational unit then has to deploy its given resources between patrol types and between different places and times.

Level (3) was dealt with in detail.

The approach adopted was to compute the deployment pattern that maximised the effectiveness measure, using the appropriate mathematical techniques which, depending upon the nature of the objective function obtained, were found to be those of non-linear programming and queueing theory, subject to the resource and other constraints that existed. The technique was completed by developing models for predicting the outputs that would be obtained with any given deployment, these outputs then being incorporated into the overall efficiency measure.

Each model was concerned with the performance of patrols within some region, and attempted to estimate how performance would be affected by variations in the numbers of the different types of patrols deployed and by changes in the patrol effort allocated to different times of day. All were developed for general areas, with the exception of the response time model, which was specifically developed for urban areas. The specifications of these models were as follows.

Patrol Readiness Model

Readiness was defined as the probability that at least one patrol car was immediately available. It was divided into non-emergency and emergency readiness where the difference was the fraction of emergency incidents that could be handled immediately only by diverting a patrol car from a non-urgent activity.

The basic time period was taken to be four hours, in phase with the shift system, and the number of patrols of the s^{th} type on duty during this period was denoted by m_s, f_s denoted the fraction of the period that patrols of type s were on duty in a section.

Let

A_1 = time on urgent non-generated activities,

A_2 = time on urgent generated activities,

A_3 = time on non-urgent non-generated activities,

A_4 = time on non-urgent generated activities,

A_5 = time spent patrolling.

$A_{1s}, A_{2s}, \ldots, A_{5s}$ represented the corresponding total times for the m_s patrols of the s^{th} type

$$A = \sum_{i=1}^{5} A_i = \sum_{s} 4m_s f_s$$

$$A_s = \sum_{i=1}^{5} A_{is} = 4m_s f_s .$$

It was supposed that A_1 and A_3 were independent of the patrol deployment, but that A_2, A_4, and A_5 depended on both the number and types of patrol on duty. Since the majority of urgent generated activity concerned incidents discovered on patrol, it was supposed that

$$A_{2s} = a_{2s}(A_{2s} + A_{5s})$$

where a_{2s} was constant for all deployments. Since the bulk of the non-urgent generated activity consisted of taking refreshments, and other functions linked to a particular patrol tour, it was also supposed that

$$A_{4s} = a_{4s} A_s$$

where a_{4s} was fixed for all patrol allocations.

These equations were not considered sufficient to determine the total amount of time devoted to urgent generated activities, which depended on the amount of time spent patrolling, which in turn depended on how the non-generated work was divided between patrols. To reflect the tendency to assign more non-generated work to some patrols than to others, it was supposed that this work was distributed so that

$$A_{1s} + A_{3s} \;\alpha\; m_s k_s$$

where the constants k_s were in proportion to the loadings of non-generated work on different patrol types.

To derive an expression for readiness in terms of patrol strengths and activity levels the patrol situation was identified with a queueing process in which the patrols were servers and the activities were customers. Patrol types were dealt with similarly, and the notation used was

n = number of patrols in a section,

r = number of patrols available,

λ = mean arrival rate for non-generated customers,

$r\lambda'$ = mean arrival rate for generated customers,

μ = mean service rate for all customers.

Input was assumed to be Poisson, and the distribution of service time was taken to be negative exponential.

If x denoted the numbers of customers in the queue at any time, including those being served, the probability densities of transition to a queue with $x \pm 1$ customers were

$$x \to x+1 \quad \lambda_x = \begin{cases} \lambda + (n-x)\lambda', & x < n \\ \lambda, & x \geq n \end{cases}$$

$$x \to x-1 \quad \mu_x = \begin{cases} x\mu, & x < n \\ n\mu & x \geq n . \end{cases}$$

The steady state distribution of queue size for this queueing system was given by standard theory, see Cox and Smith (8), as

$$p(x) = \frac{\lambda_0 \lambda_1 \ldots \lambda_{x-1}}{\mu_1 \mu_2 \ldots \mu_x} p(0)$$

where $p(x)$ was the probability that there were x customers in the queue including those being served. When the values for λ_x, μ_x were entered, the probability that not all servers were busy, was shown to be

$$R = \frac{1 + \frac{(\rho+n\rho')}{1!} + \ldots + \frac{(\rho+n\rho')\ldots(\rho+2\rho')}{(n-1)!}}{1 + \frac{(\rho+n\rho')}{1!} + \ldots + \frac{(\rho+n\rho')\ldots(\rho+2\rho')}{(n-1)!} + \ldots + \frac{(\rho+n\rho')\ldots(\rho+\rho')n}{n!(n-\rho)}}$$

where $\rho = \frac{\lambda}{\mu}, \quad \rho' = \frac{\lambda'}{\mu}$.

R was taken to be the required patrol readiness.

The traffic intensities ρ, and ρ' were interpreted as

ρ = expected total service given to non-generated customers by all servers per unit of elapsed time,

ρ' = mean service given to generated customers by one server per unit of free time.

Therefore to evaluate emergency readiness they were taken as

$$\rho = \frac{A_1}{4}, \quad \rho' = \frac{A_2}{A - A_1 - A_2}$$

and for non-emergency readiness

$$\rho = \frac{A_1 + A_3}{4}, \quad \rho' = \frac{A_2 + A_4}{A_5} .$$

The model was then used with the data collected to give patrol readiness figures for the Lancaster section. Average non-emergency readiness was found to be 98.8% and emergency readiness was practically 100%, reflecting the lack of congestion (compare Chicago).

It was concluded that patrol readiness considerations only mildly restricted the way in which patrols could be deployed.

Response Time Model

This model was developed specifically for urban areas, with the assumption that response time was proportional to distance involved, and was concerned with response time detections which were taken to be apprehending a criminal at the scene of crime.

Let

k = the fraction of crimes reported whilst the criminal was still at or near the scene,

$f(t)$ = the density function of the time available to get to the scene if an arrest was to be secured,

$G(t)$ = the distribution function of the time taken for the first patrol to reach the scene,

then assuming that one patrol was capable of making any arrest, the probability of achieving a response time detection in respect of an arbitrary reported crime was

$$\int_0^\infty k\, f(t)\, G(t)\, dt.$$

It was assumed that $f(t)$ was negative exponentially distributed

$$f(t) = \lambda e^{-\lambda t}$$

so the problem was to compute $G(t)$.

Let

n_s = number of patrols of s^{th} type on duty in a section at a particular time,

P_{ri} = probability that the r^{th} patrol is on the i^{th} sub-beat at a random instant whilst available,

Q_j = probability that a crime occurs in the j^{th} sub-beat, strictly given that the crime is reported early enough to make a response time detection feasible,

t_{rij} = response time for r^{th} patrol from sub-beat i to sub-beat j.

P_{ri} depended on the patrol deployment, but Q_j and t_{rij} were assumed effectively independent of it. It was assumed that if patrols of the s^{th} type spent a proportion p_{si} of 'available' time on the i^{th} beat, $\sum_i p_{si} = 1$, then the same fractions would hold for all other deployments. Where patrols of a given type operated independently over a shared area it was assumed that

$$P_{ri} = P_{si} \quad \text{(if patrol r of } s^{th} \text{ type).}$$

Otherwise, if n_s patrols of the s^{th} type divide the total area between them, each being responsible for patrolling a sub-beat, then

$$P_{ri} \propto \begin{cases} n_s P_{si} , & \text{if patrol r of } s^{th} \text{ type and works sub-beat i,} \\ 0 , & \text{otherwise,} \end{cases}$$

the constant of proportionality being chosen so that

$$\sum_i P_{ri} = 1.$$

The probability that the response time to sub-beat j was less than T, given that the patrol was available, for the r^{th} patrol was

$$\sum_{(i \,:\, t_{ij} \leq T)} P_{ri} \quad .$$

Regarding a patrol as usefully available only when actually patrolling, the probability of being available was

$$a_r = \frac{A_{5s}}{4n_s} , \quad \text{if patrol r of } s^{th} \text{ type.}$$

The overall probability of the r^{th} patrol having a response time less than T was therefore

$$G_{rj}(T) = a_r \sum P_{ri} ,$$

the summation again being over sub-beats i with $t_{ij} \leq T$.

Calculations were found to show that although the different patrols were not strictly independent as far as availability was concerned, they were approximately so when readiness was high, provided that the bulk of the activity was not non-generated. Hence the approximate probability that the best response time to the j^{th} sub-beat was less than T was

$$G_j(T) = 1 - \prod_{r=1}^{n} \{1 - G_{rj}(T)\}$$

where

$$n = \sum_s n_s$$

and on averaging over all sub-beats j

$$G(t) = \sum_j Q_j \, G_j(t) \quad .$$

As this formula was found to be very time-consuming to compute, an approximation was developed for the case where crime and beats were distributed symmetrically about a town centre. Then the probability of a patrol arriving at the scene of a crime within time t was written as

$$1 - \prod_i \{1 - P_i(t)\}^{n_i} \quad ,$$

n_i = number of patrols of i^{th} type on duty within a section,

$P_i(t)$ = probability of a patrol of i^{th} type reaching scene within time t, averaged over all patrols of i^{th} type and all patrol and crime positions.

Using collected data with this model gave an estimated number of potential detections of 36.6 per year assuming that the criminal remained at or near the scene for 15 minutes. If this were reduced to 3 minutes, the potential detections dropped to 18 per year, with the normal patrol level. Alternatively, with an average patrol level, the estimated number of response time detections was 15 per 500 reported incidents.

It was concluded that opportunities to make response time detections were not a major factor affecting patrol deployment.

Patrol Discoveries Model

This model was developed to predict how the number of results stemming from patrol discoveries of incidents would vary with the pattern of patrol deployment. It was based on the assumption that this number was proportional to the amount of time the patrol was free from other work, and thus patrolling, and that the probability of two patrols independently making the same discovery was negligible.

The model assumed that the rate at which a patrol made discoveries whilst patrolling could be expressed as the product of a patrol specific figure and multiplicative factors which took into account the time of day and the region in which the patrol was operating.

In the model the number of 'good results' achieved during a specified (4-hour) period of the day in a specified section was written as

$$4 \sum_{i} n_i \, a_i \, \beta_i \, \gamma \, \delta \quad ,$$

n_i = number of patrols of i^{th} type on duty within section,

a_i = proportion of time for which the patrols of i^{th} type on patrol,

$$\left(= \frac{A_{5i}}{4n_i} \right),$$

β_i = rate at which patrols of i^{th} type made patrol discoveries, averaged over all sections and time periods being considered,

γ = multiplier for particular section,

δ = multiplier for particular time of day.

Using available data, the number of additional discovered results per extra patrol year (250 - 8 hour tours) were calculated for all patrol types, assuming that this extra patrol would not engage in any non-generated work. These numbers varied from 22.8 for a divisional patrol, and 33.2 for a panda car, to 190.9 for a traffic patrol car, although the latter included 180 traffic offences, 118 of which were for heavy radar-trap activity.

Large variations in discovery rates were detected between different types of area and different times of the day. It was suggested that deployment of more patrols in late evening was indicated, and that substantial gains could be made by transferring patrols from rural to urban areas.

The Lancaster work was primarily concerned with developing methods that could be used to deploy patrols more effectively, and did not reach the stage of determining optimum deployment patterns. *

1.3. Conclusions from Previous Work

The basic systems problem for mobile police patrols, as considered by all investigators concerned with the mobile police system, can be formulated as follows.

* but see section 6.1 .

Given a number of mobile resources of varying types with the corresponding manpower, how can they be allocated in the most beneficial manner by time and place, taking into account

(1) preventive function, and

(2) response function.

Measures of effectiveness which have been used or developed as objective functions for allocation purposes in the police field include

equalised workload,

minimum response time,

patrol readiness,

response time detections,

patrol discoveries,

and many variants of the above.

Information on demand and performance is necessary for any system of allocation and so attention has been devoted to the collection of detailed data on incidents comprising the police workload, and on activities undertaken by police mobile resources.

Within this framework the main distinctions between specific attempts at solution of the patrol deployment problem concern the interpretation of the relative desirability of the two main objectives of police mobile patrolling.

Any solution of this problem depends upon a knowledge, or facility for prediction, of the interactions between patrol distribution in time and space and the ability of the patrols to deter and respond. Thus, whichever measure of effectiveness is chosen, it is necessary to link it by some means, via collected data, or a mathematical model, or a combination of these, to the deployment of the patrols.

The purpose of the present work was to consider the operations of mobile patrols in County Durham, to collect information on the demands made upon them and on their response to these demands, to investigate the relationship between the way in which patrols were allocated and operated, and their effectiveness as measured in various ways, and finally to attempt to distinguish measures of effectiveness, and methods of allocation based on these, which would be appropriate to a large county police force under present conditions.

Accordingly, late in 1968, some members of the University Mathematics Department, who had been concerned with the work involved in the joint Durham projects (9, 10) drew up a programme for a preliminary investigation of the traffic division of County Durham, to be carried out early in 1969.

CHAPTER II

DURHAM COUNTY CONSTABULARY

2.1 Geographical Summary

The area within the jurisdiction of the Durham County Constabulary includes land characteristics ranging from the densely populated Tyneside and Wearside conurbations in the north to the sparsely populated moors of Weardale in the west.

Overall the Constabulary is responsible for policing an area of 594,000 acres (928 square miles), mostly of a rural nature, with a population of 1,515,000.

Major roads within the county, including the A1(M) motorway and the A19 trunk road, had a total classified mileage of 1642.

2.2 Operational Structure and Control

At the beginning of this investigation (January 1969) the Constabulary was divided into sub-units for the purposes of administration and operational control as shown in Figure 2.1. The eight divisions, A, B, C, D, E, F, G, and H were each subdivided to provide 22 subdivisions, A1, A2, ..., H2, and each of these subdivisions was then further subdivided to provide sections and beat areas.

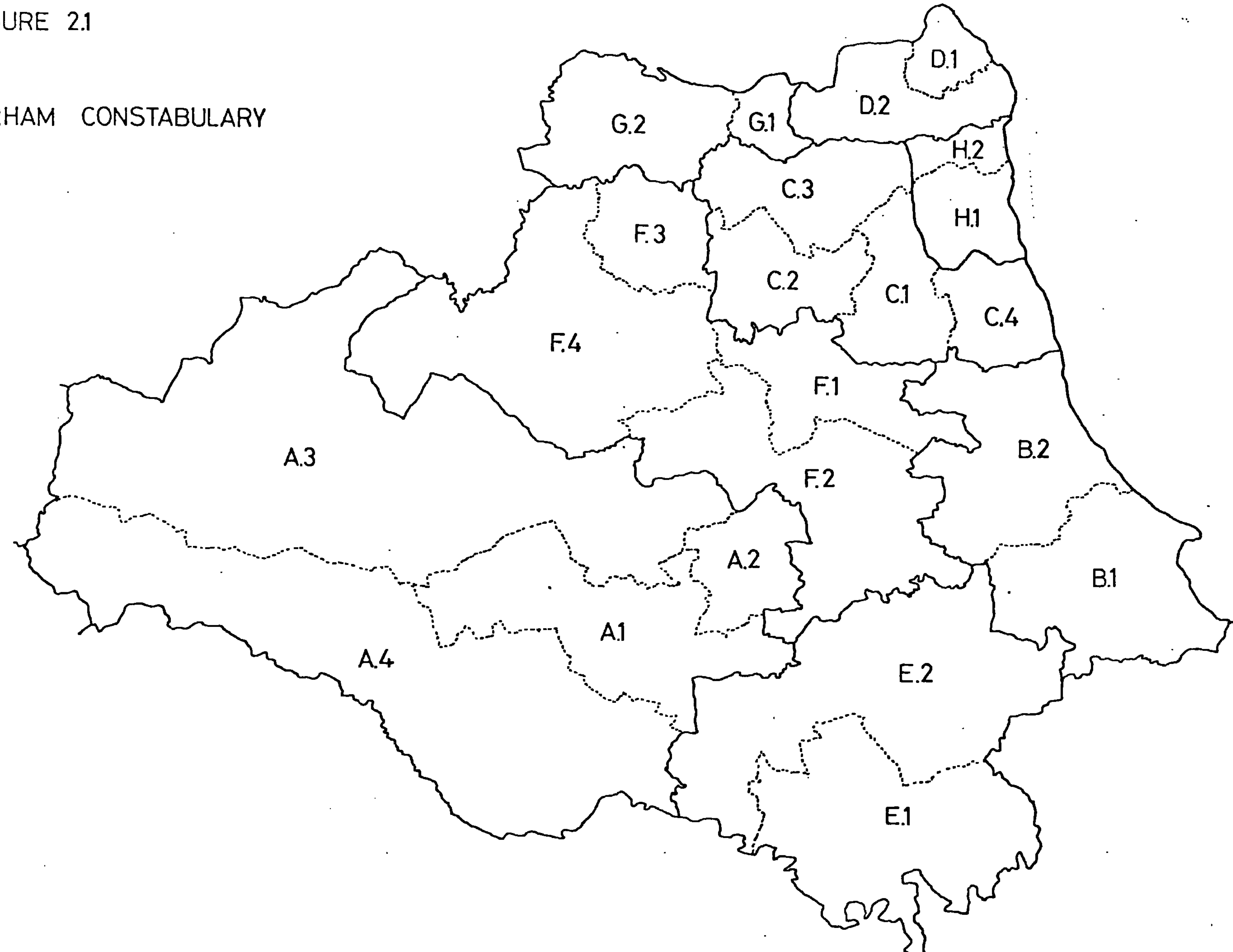
2.3 Mobile Units

Equipment, Function and Control

By the beginning of 1969 the unit beat policing mode of local patrol had been introduced into the Durham area and the following types of mobile units existed.

FIGURE 2.1

DURHAM CONSTABULARY



(i) Headquarters Traffic Patrols.

(ii) Divisional Motor Patrols.

(iii) Divisional and Subdivisional panda vehicles.

(iv) Specialised mobile squads.

Headquarters traffic patrols were commanded by the Chief Superintendent of Traffic and patrolled motorways, trunk and primary routes. As a traffic unit their prime function was the enforcement of traffic legislation, the detection of traffic offences, and road safety in all its aspects.

Divisional motor patrols were under the command of their respective Divisional Chief Superintendents. Their function was that of highly trained mobile policemen whose bias changed by time of day, at peak traffic times they were traffic patrols but during the early hours of the morning, when traffic flow was minimal, their prime function was one of crime prevention.

The vehicles used by the patrols in categories (i) and (ii) were usually high performance saloon cars carrying a range of equipment designed to deal with traffic incidents. Each car was equipped with a very high frequency (vhf) radio set with which it was in two-way communication with Headquarters control room and, in the case of divisional motor patrols, via a talk-through facility, with divisional control room.

These cars were one or two men crewed according to the time of day, the nature of the area patrolled, and the nature of the activities undertaken. Generally at night they were doubled crewed. The view was held by most officers, including the more senior commanding officers, that police presence had a large preventive effect, and the allocation and utilisation of the available motor patrol resources was based upon this view.

Divisional and sub-divisional panda vehicles were used by local beat policemen for patrol purposes. In urban areas, these vehicles were organised under the unit beat policing scheme (with a backing-up service provided by resident constables on foot patrol), and were controlled by a sergeant in divisional or sub-divisional control room. In rural areas these vehicles provided transport for a resident constable with responsibility for policing a rural beat, often large and lightly populated, for which motor transport was essential.

The vehicles used were usually small utility vans, occasionally a motor-cycle for a rural beat, carrying no specialised equipment. For communication purposes drivers used their personal radio sets operated on an ultra high frequency (uhf) to maintain two-way contact with their controlling officers in divisional or sub-divisional control rooms.

These panda vehicles were usually crewed by one man, but it was common practice for two-man crews to operate in 'rougher' urban areas for the half-shift 22.00 - 02.00.

Specialised mobile squads existed to undertake tasks for which specially equipped vehicles and highly trained personnel were required. The Special Incident Squad commanded by Detective Chief Superintendent C.I.D. Headquarters was made up of shooting brakes carrying a large amount of specialised equipment, manned by officers highly trained in scientific and mechanical examinations. Tasks undertaken by this squad included attending the scene of all fatal and serious traffic accidents, and making scientific investigations at the scene of robberies and break-ins.

Other specialised squads were the dog section, including dog vans, dogs, and their handlers, a river unit, composed of radio controlled launches, and associated mini-van, a frogman's unit, a motor-cycle patrol force for varied duties such as escort of wide loads, and a number of vehicles for the use of supervisory or senior officers. In addition there were prison vans, landrovers, a mobile police station, and a breakdown vehicle. All the vehicles in the specialised squads were equipped with vhf radio.

The distribution of the category (i), (ii), and (iii) vehicles and of the special incident squad vehicles, dog section vehicles, and motor-cycle patrols in category (iv) in 1969 is shown in Table 2.1.

Table 2.1

Police Mobile Strength 1969

Division	H.Q. Traffic Patrols	Divisional Motor Patrols	Panda Vehicles	Special Incident Squad Vehicles	Dog Section Vehicles	Motor Cycle Patrols
A		5	19		2	
B		6	15		2	
C		7	16		2	
D		6	14		2	
E		6	16		1	
F		8	14		2	
G		8	18		2	
H		6	14		1	
Head-quarters	18			10	8	16
Total	18	52	126	10	22	16

Communications

As mentioned above, the police vehicles in Durham were controlled using two distinct radio links.

Panda vehicles were not equipped with radio (except those in 'A' division, see below), but the officers manning them were equipped with personal radios operating on uhf wavelengths. Thus equipped they were in two-way contact with their supervisory officers in divisional or sub-divisional control rooms. These radios had an effective range of two to three miles without repeaters, in hilly terrain, or in the larger sub-divisions, they were ineffective. Accordingly panda vehicles in 'A' division were equipped with vhf radio sets. If they were not within uhf radio range of their divisional or sub-divisional control room, then they were able to maintain contact with H.Q. control room by using their vhf radio, otherwise 'A' division panda vehicles operated in the same manner as other panda vehicles.

Some specialist vehicles, for example, dog section vans, were allocated to a division, in which case the crews had both personal uhf radios, and vhf radios and were in a position to operate in both uhf and vhf communication mode provided that they were within receiving and transmitting range of the appropriate divisional or sub-divisional control room.

2.4 Emergency Call System

All '999' emergency telephone calls made in the Durham Constabulary area requiring police attention were handled centrally. These calls were routed by the G.P.O. to County Police Headquarters Control Room in Durham City. They were tape-recorded there and, in addition, the officer handling the call entered details of it on a hand written log sheet.

The officer could then take action in various ways. He could decide to

(a) assign the task to one or more vhf radio controlled patrol cars or other suitable mobile units (this included all vehicles of type (i) and (ii), and some type (iv) vehicles), or

(b) contact the relevant divisional or sub-divisional control room and have the task assigned to one or more panda vehicles (that is, type (iii) vehicles), or

(c) do both (a) and (b).

An electronic memory (see Appendix) was available in H.Q. Control Room to store information on the availability status of vhf radio controlled patrol cars and other vhf radio controlled vehicles, classified by type of vehicle, last known status, and last known location in terms of division and sub-division.

If the initial decision by a control room officer was (a), then the memory was interrogated and a suitable vehicle, if one was shown to be available, was despatched to the incident. If a vehicle was not available this was recorded on the log sheet and the task was reassigned to the relevant division as in (b).

If the initial decision was (b), then a telephone call, giving full details of the emergency call, was made to the relevant divisional, or, if possible, directly to the relevant sub-divisional, control room. 15 of the 22 sub-divisions could be contacted directly from H.Q. for 24 hours daily (A1, A2, B1, B2, C1, C2, C4, D1, D2, E1, F1, F2, G1, G2, and H1). The other seven were manned for limited hours only. When a sub-divisional control room was not manned, the relevant divisional control room was responsible for supervision of the panda vehicles in that sub-division.

2.5 Initial Investigation

The role of the police motor patrols in Durham Constabulary at the time of the setting-up of the initial investigation, 1968/9, was seen to be, to enforce the Road Traffic Acts, to deter crime by patrolling, and to respond to a wide variety of incidents, including accidents and crimes.

It was with this response function that the present investigation was mostly concerned.

To a large extent information on these incidents arises from calls made by members of the public, particularly important in terms of urgency, being those calls made using the '999' emergency service. It was therefore felt advisable to investigate the police system relating to the response to these calls in order to obtain some measure of the effectiveness of the response.

The use of non-generated workload arising from the servicing of '999' calls had the advantage that these calls formed an unbiased sample of the workload on the police created by the public, which was not true of the work self-generated by the mobile police (when the crews detected, or actively searched for, certain offences while patrolling) this being usually dealt with by themselves. This workload was biased as it was dependent on the policy of both the police force and the individual police officers (for example, blitz activity using radar traps for speeding offences, inspections on tyres, lights).

A short preliminary study of H.Q. Control Room in late 1968 revealed that the number of '999' calls was substantial (running at 100 ± 20 per day), and that tasks arising from the servicing of such calls could be regarded as representative of demands on the police by the public, covering a wide variety of incidents and being representative of the total non-generated workload undertaken by the mobile patrols, with the exception of certain special duties such as prison and wide load escorts.

The aims of the initial investigation were

(i) to study the operation of the motor patrol force in relation to its function of response to '999' calls,

(ii) to study the response of local forces (that is, panda vehicles controlled by divisional and sub-divisional control rooms) to such calls, and

(iii) to consider improvements in command, control, and allocation.

CHAPTER III

1969 STUDY

As described in Chapter II the '999' emergency call system involves the following features.

(i) Demand for Service

The emergency incident demand indicates the servicing requirements of the public as notified to the police by the emergency telephone service. These requirements may be specified by the temporal and spatial distribution of emergency incidents.

(ii) Service Facilities

The service that can be provided depends upon

(a) location of police mobile resources, and

(b) availability of these resources.

The service provided may be measured by

(c) response time.

Response time to an incident is the interval elapsing between the receipt of the incoming emergency call at H.Q. Control Room and the arrival of the first assigned police vehicle at the scene of the incident, and

(d) service time.

Service time for an emergency incident is the overall time that a police vehicle is involved with the incident, from its despatch to the incident until its resumption of normal patrol duties.

3.1 <u>Data Collection</u>

Information on the above aspects of the emergency call system was collected as follows.

1. For the three month period 5th January to 31st March a coded copy of the H.Q. Control Room log sheet relating to every '999' call in the Durham Constabulary area was obtained.

Each incident record contained the following details, day, month, year, time of day, location (by division/ sub-division, for example A1) and type of incident (coded into the five broad categories, traffic incidents, assistance to public, offences against property, offences against person, domestic and public disturbance), console number in H.Q. Control Room at which incoming call was handled, call-sign, location and time (when detailed) of vehicle (if vhf) despatched, and sequel of incident.

2. For a sample fortnight from the 2nd to the 15th February additional data, not usually recorded, was specially requested, namely the arrival time of a vehicle at the scene of an incident and the time at which it resumed patrolling duties after attending to the incident.

For the sample fortnight these times were entered on the H.Q. Control Room log sheet if a vhf vehicle was despatched, or on a special form (Form DU/DC 3) if a panda vehicle was despatched.

3. For the same fortnight the memory unit in H.Q. Control Room (see Appendix) was interrogated and the following details were recorded on a special form.

(a) The number of vhf vehicles available in all sub-divisions, every half-hour, and

(b) the number of vhf vehicles in all states (see Appendix) in all sub-divisions a half-hour after shift changes (that is, at 00.30, 06.30, 08.30, 10.30, 14.30, 16.30, 18.30, 22.30).

DU/DC 3

RECORD OF '999' CALLS ATTENDED BY VEHICLES
DETAILED FROM DIVISIONAL OR SUB DIVISION H.Q.

1. Time Call Received at Divisional or Sub Divisional Control ____________________

2. Time Vehicle Despatched ____________________

3. Location at time of despatch (Sub. Div. Area) ____________________

____

____

4. Type of vehicle ____________________

5. Time vehicle arrived at incident ____________________

6. Time vehicle resumed patrol after incident ____________________

7. Sequel ____________________

____

____

____

Concurrently the same information was collected for panda vehicles. As a memory unit was not available in divisional control rooms the information was recorded by the supervisory officers on the same form, using their knowledge of the number of vehicles on duty, and of the activities that were undertaken by these vehicles obtained via their personal (uhf) radio link.

The information contained on the coded log sheets formed the basis of the 1969 study and was supplemented by the additional information which was requested as described in (2) and (3) above.

3.2 Results

3.2.1 Emergency Incident Demand

During the 86 days of the study a total of 9569 incidents were reported via the emergency call service in the Durham Constabulary area. Figure 3.1 shows the overall diurnal variation in the number of emergency incidents for this period. The average daily number of emergency incidents was 111, so that on average there was an emergency incident every 13 minutes.

The variation in demand by day of week is shown in Figure 3.2. The average demand for each weekday is detailed for the quarters 00.01 to 06.00, 06.01 to 12.00, 12.01 to 18.00, and 18.01 to 24.00. The figure shows that there was a regular daily pattern of demand, with slight modifications at the weekend in the first and second quarters of Saturday and Sunday, the level of which varied according to the day of the week between an average of 94 incidents on Wednesday and an average of 144 incidents on Saturday.

Consideration of the diurnal variation in emergency incidents for the most densely populated sub-division D1 with 21 persons per acre and

Figure 3.1

EMERGENCY INCIDENTS:CLASSIFIED BY HOUR OF DAY

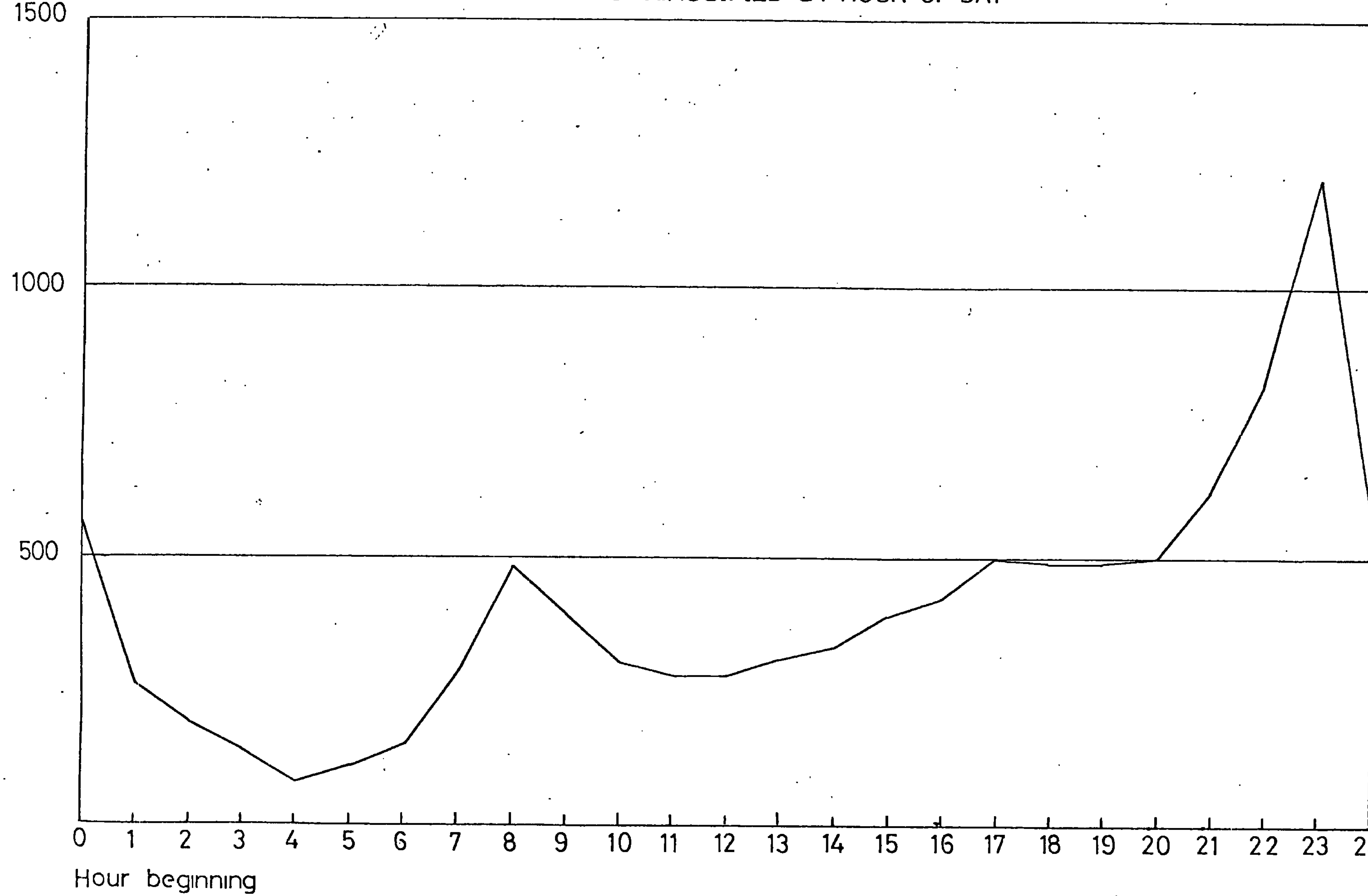


Table 3.1

Emergency Incidents: Classified by Hour of Day

Hour Beginning	Division								Total
	A	B	C	D	E	F	G	H	
00.01	27	95	53	79	60	46	86	114	560
01.00	11	48	21	42	22	27	35	52	258
02.00	10	23	16	34	21	19	22	44	189
03.00	3	21	24	14	15	17	17	25	136
04.00	6	8	16	10	5	10	18	11	84
05.00	11	18	12	12	8	18	15	14	108
06.00	3	23	20	23	10	13	28	29	149
07.00	9	56	28	34	34	38	42	49	290
08.00	23	79	48	72	44	53	64	92	475
09.00	20	57	33	47	40	44	61	86	388
10.00	19	52	24	37	30	19	53	68	302
11.00	13	39	24	44	24	25	43	72	284
12.00	14	42	23	35	32	19	47	63	275
13.00	21	54	20	56	27	27	48	59	312
14.00	18	40	33	59	28	30	46	77	331
15.00	21	53	29	63	52	33	63	72	386
16.00	36	53	31	67	55	29	56	94	421
17.00	27	67	32	87	41	55	89	106	504
18.00	27	62	51	76	50	44	94	90	494
19.00	23	82	33	57	50	49	82	116	492
20.00	30	71	46	83	49	45	75	99	498
21.00	39	102	40	112	61	56	84	123	617
22.00	35	149	50	115	93	77	109	189	817
23.00	76	253	109	154	108	113	147	239	1199
Totals	522	1547	816	1412	959	906	1424	1983	9569

Figure 3.2

EMERGENCY INCIDENTS: CLASSIFIED BY DAY OF WEEK

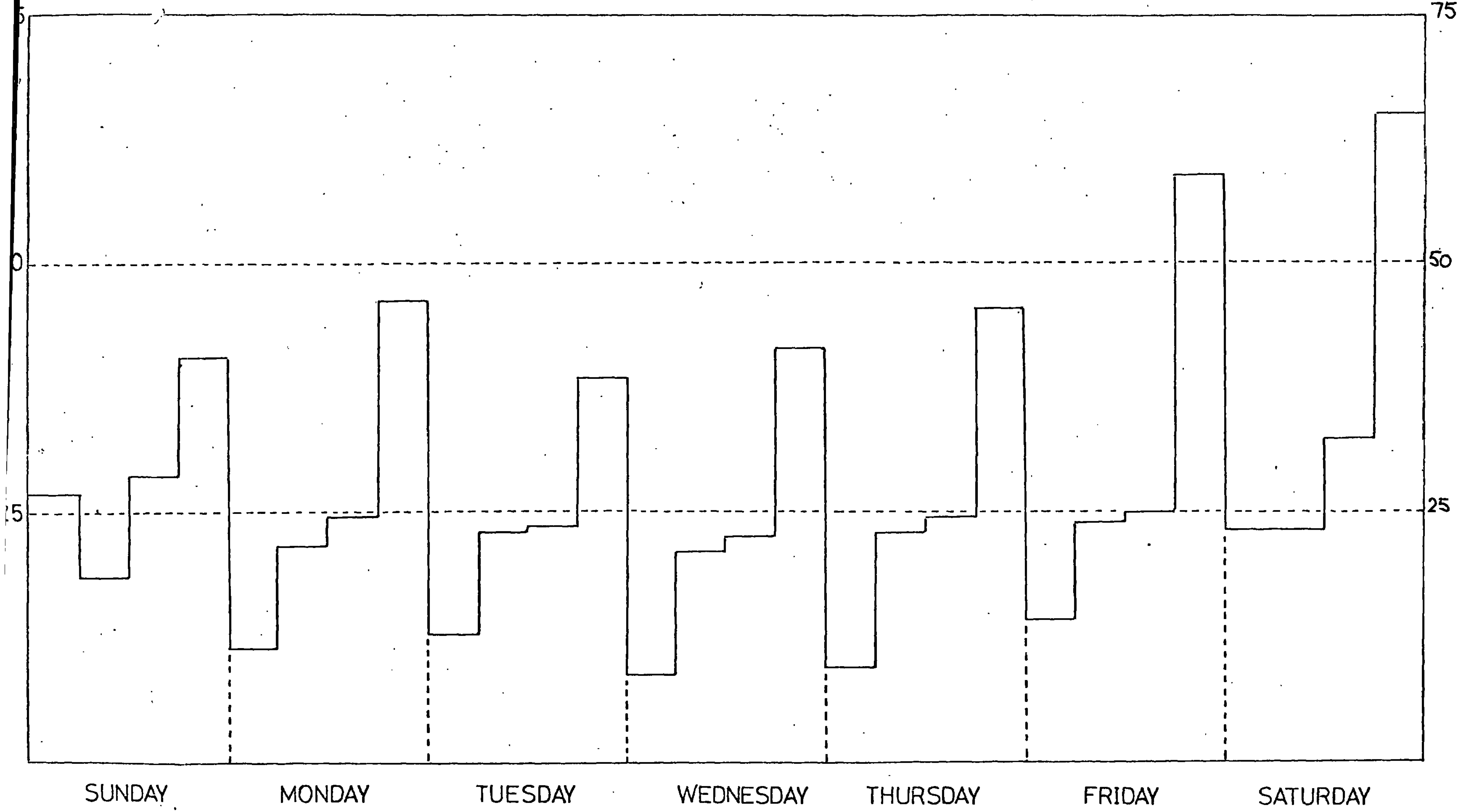


Table 3.2

Emergency Incidents: Classified by Day of Week

Averaged over Study Period

Day of Week	Quarter of Day				Total
	First	Second	Third	Fourth	
Sunday	26.8	18.6	28.5	40.5	114.4
Monday	11.5	21.5	24.4	46.2	103.6
Tuesday	13.2	22.8	23.5	38.5	98.0
Wednesday	8.8	20.8	22.7	41.3	93.6
Thursday	9.6	22.9	24.6	45.4	102.5
Friday	14.7	23.8	25.1	59.2	122.8
Saturday	23.5	23.5	32.6	64.8	144.4

the least densely populated sub-division A3 with 0.3 persons per acre, showed that not only were the incident levels markedly different (average emergency incidents daily being 11.9 in D1 compared with 0.8 in A3) but also that the hourly variation in incidents showed a completely different pattern in that A3 had no pronounced build-up of incidents corresponding to times of mass movement such as morning and late afternoon rush hours, and late evening closing time as observed in the pattern for D1, which closely resembled the overall pattern illustrated in Figure 3.1

3.2.2 Response

3.2.2.1 Type of Vehicle Used

Initial attention to an emergency incident was provided by either

(i) a patrol car or other vhf radio controlled vehicle, or

(ii) a panda vehicle.

The decision to despatch either a vhf or a panda vehicle was at the discretion of H.Q. Control Room personnel and no rigorous procedure was laid down for this selection.

Table 3.3 contains a breakdown of emergency incidents, divided into those initially attended by vhf vehicles under H.Q. Control and those initially attended by panda vehicles under divisional or sub-divisional control, and also classified by type of incident. This table shows that overall vhf vehicles initially attended 1536 (16%) of the 9569 incidents. The remaining 8033 (84%) were initially attended by panda vehicles.

The breakdown by type of incident shows that the proportion of incidents dealt with by vhf vehicles varied from 47% for traffic incidents (Type 1) to 9% for assistance to public incidents (Type 3).

Table 3.3

Emergency Incidents: Classified by Type of Vehicle Used

Type of Vehicle	Type of Incident											
	1	% of Total	3	% of Total	6	% of Total	7	% of Total	8	% of Total	Total	% of Total
Vhf	429	47.1	277	8.8	563	15.3	13	22.8	254	14.4	1536	16.1
Panda	481	52.9	2888	91.2	3106	84.7	44	77.2	1514	85.6	8033	83.9
Totals	910	100.0	3165	100.0	3669	100.0	57	100.0	1768	100.0	9569	100.0
% of Total	9.5		33.1		38.3		0.6		18.5		100.0	

Type

1. Traffic.
3. Civil. Assistance to Public.
6. Break-in, burglary, alarm, vehicle theft.
7. Severeassault, rape, serious crime.
8. Domestic .

One possible explanation for the high proportion of traffic incidents dealt with by vhf vehicles was that patrol cars were equipped with warning signs, hazard lights, and other basic equipment required for this type of incident. By contrast the panda vehicles contained a minimum of equipment as their basic purpose was to provide transport for a beat policeman.

Vhf vehicles initially attended 23% of the serious incidents (Type 7), including offences such as rape and severe assault, for which a vhf vehicle was desirable in view of the greater experience and enhanced training of their crews. Panda vehicles initially attended the great majority (91%) of the assistance to public incidents. Only 9% were initially attended by vhf vehicles. These incidents were most suitably dealt with at divisional or sub-divisional level by local beat police officers, that is, by using a panda vehicle.

A detailed breakdown of the vhf vehicles used for the emergency incidents is included in Table 3.4. This shows that 1345 of the 1536 incidents initially attended by vhf radio controlled vehicles were dealt with by a divisional motor patrol car within its own division, 88 incidents were dealt with by H.Q. traffic patrol vehicles, 91 incidents were dealt with by serious incident squad and dog section vehicles, and 12 incidents were dealt with by divisional motor patrol cars from another division, illustrating a low level of interdivisional despatching. These figures also illustrate the role of the specialised mobile squads as follow-up vehicles.

3.2.2.2 Vehicle Availability

Vhf Vehicles.

The hourly variation in the average number of vhf vehicles on patrol recorded during the fortnight study is shown in Figure 3.3.

Table 3.4

Vhf Vehicles used: Classified by Division of Incident

Division of Incident	Divisional Motor Patrol								Headquarters Traffic Patrol	Special Incident Squad	Dog Section	Total
	A	B	C	D	E	F	G	H				
A	126				1					1		128
B		200				1			12	6	9	228
C		1	158				1		18	4	7	189
D				166					3	3	11	183
E	2				119				20	3	10	154
F	1				1	164	1		26	10	10	213
G			1				239		4	3	8	255
H			1	1				173	5	3	3	186
Totals	129	201	160	167	121	165	241	173	88	33	58	1536

FIGURE 3.3

AVAILABLE VHF VEHICLES : CLASSIFIED BY HOUR OF DAY

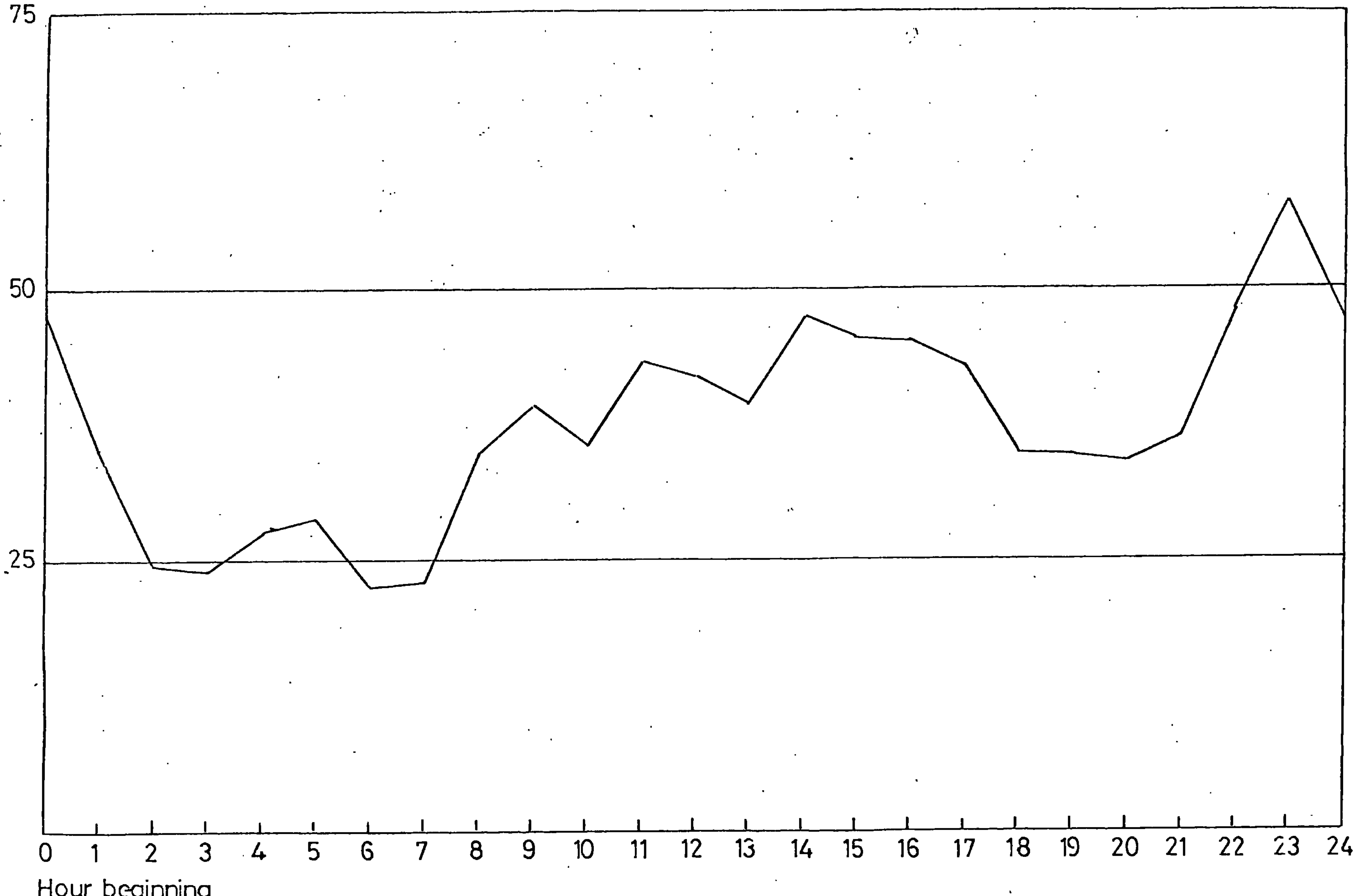


Table 3.5

Vhf Vehicles on Patrol: Classified by Hour of Day

Averaged Over Fortnight

Hour Beginning	Day of Week							Overall
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
00.01	46.25	44.25	47.75	53.00	48.25	43.25	50.50	47.61
01.00	32.00	33.50	34.00	42.25	36.50	28.50	37.50	34.89
02.00	24.00	22.75	28.25	29.50	23.00	16.75	25.75	24.29
03.00	27.25	20.50	24.00	31.25	23.75	17.25	22.25	23.75
04.00	30.25	25.25	29.25	34.25	26.75	18.75	28.50	27.57
05.00	31.50	27.50	27.50	34.75	29.75	19.50	29.50	28.57
06.00	23.00	22.00	23.75	25.00	24.25	15.25	23.00	22.32
07.00	24.50	22.00	25.50	27.00	25.50	14.75	22.50	23.11
08.00	35.50	34.50	36.25	39.25	36.75	27.00	34.75	34.86
09.00	35.50	40.75	41.25	44.75	39.50	35.00	40.75	39.64
10.00	35.00	35.75	35.00	36.75	33.75	34.00	37.25	35.36
11.00	42.50	41.50	40.50	49.00	44.25	41.50	46.75	43.71
12.00	46.75	39.00	40.25	34.50	46.00	40.50	47.50	42.07
13.00	36.25	35.75	35.25	44.25	42.25	37.50	46.00	39.61
14.00	44.25	47.50	48.50	50.25	47.75	41.75	51.50	47.36
15.00	45.00	45.50	50.00	43.25	42.25	41.00	50.00	45.29
16.00	45.25	52.75	49.25	47.75	33.25	39.50	52.00	45.68
17.00	37.75	47.00	49.00	49.00	39.25	38.00	39.50	42.79
18.00	34.00	35.25	40.25	38.25	33.75	29.25	35.00	35.11
19.00	38.00	33.25	40.75	34.25	34.50	29.50	35.50	35.11
20.00	37.25	36.25	41.50	28.00	34.50	30.00	32.75	34.32
21.00	38.00	42.75	38.50	36.75	36.75	29.50	35.25	36.79
22.00	49.00	57.75	51.00	42.75	48.50	41.25	50.00	48.61
23.00	60.50	64.00	59.75	62.50	53.75	49.75	58.75	58.43
Overall	37.47	37.79	39.04	39.93	36.85	31.63	38.86	37.37

The time variations shown were considered to be representative of the fluctuations that actually occurred but it was considered unwise to put any emphasis on the absolute number of vehicles recorded as it was subsequently found that during the period of the survey there was a certain background level of 'available' vehicles which would not normally have been considered as suitable for despatch to an emergency incident. This discrepancy arose from the manner in which data was input to the memory unit (see Appendix).

Panda Vehicles

The availability study of panda vehicles, for the purposes of which special forms were filled in by divisional control rooms, was abandoned when obvious discrepancies and sketchiness of returns was detected, an experience also recorded by the Lancaster investigators(4). These shortcomings were attributed to a failure in divisional control rooms to maintain updated records of panda vehicle location and status.

No Car Available

On a number of occasions an emergency incident arose to which the personnel in H.Q. Control Room wished to despatch a vhf vehicle but when the memory unit was interrogated it was found that no vhf vehicle was available in the location of the incident. These incidents were recorded by the operator concerned as 'no car available'.

Although not precisely defined, location was usually taken to be the sub-division in which the incident was reported. The practice on such occasions was to assign the task to divisional or sub-divisional control room so that a panda vehicle could be despatched to the incident, and possibly also despatch a vhf vehicle from a neighbouring sub-division.

The diurnal variation in the number of incidents for which 'no car available' was recorded is shown in Figure 3.4. Overall 570 (6%) of the 9569 incidents were recorded as 'no car available', a daily average of 6.6. Comparison of Figure 3.4 with the demand pattern as illustrated in Figure 3.1 showed that not all of the peaks of 'no car available' coincided with times at which heavy demand was experienced so that the latter did not always account for 'no car available'.

Comparison of the 'no car available' pattern with the vhf vehicle availability pattern illustrated in Figure 3.3 showed that there was a slight correlation between the times when the number of available vhf vehicles dropped and the times when 'no car available' reached a peak. It was suggested that these drops in vhf vehicle numbers were caused by shift changes and refreshment breaks. Specifically, comparison of the two patterns shown in Figures 3.3 and 3.4 indicated that the peak of 'no car available' reports at 02.00 corresponded with a 50% decrease in the number of available vhf vehicles, at the time of a refreshment break. Similarly at 07.00 the peak in 'no car available' reports corresponded with a low vehicle availability figure, possibly due to shift changes at 06.00 and 08.00.

3.2.2.3 Response Time

Total response time to an emergency incident is made up of

(a) handling time, and

(b) travelling time.

Handling time is the time that elapses while a call is dealt with

Figure 3.4

NO CAR AVAILABLE INCIDENTS: CLASSIFIED BY HOUR OF DAY

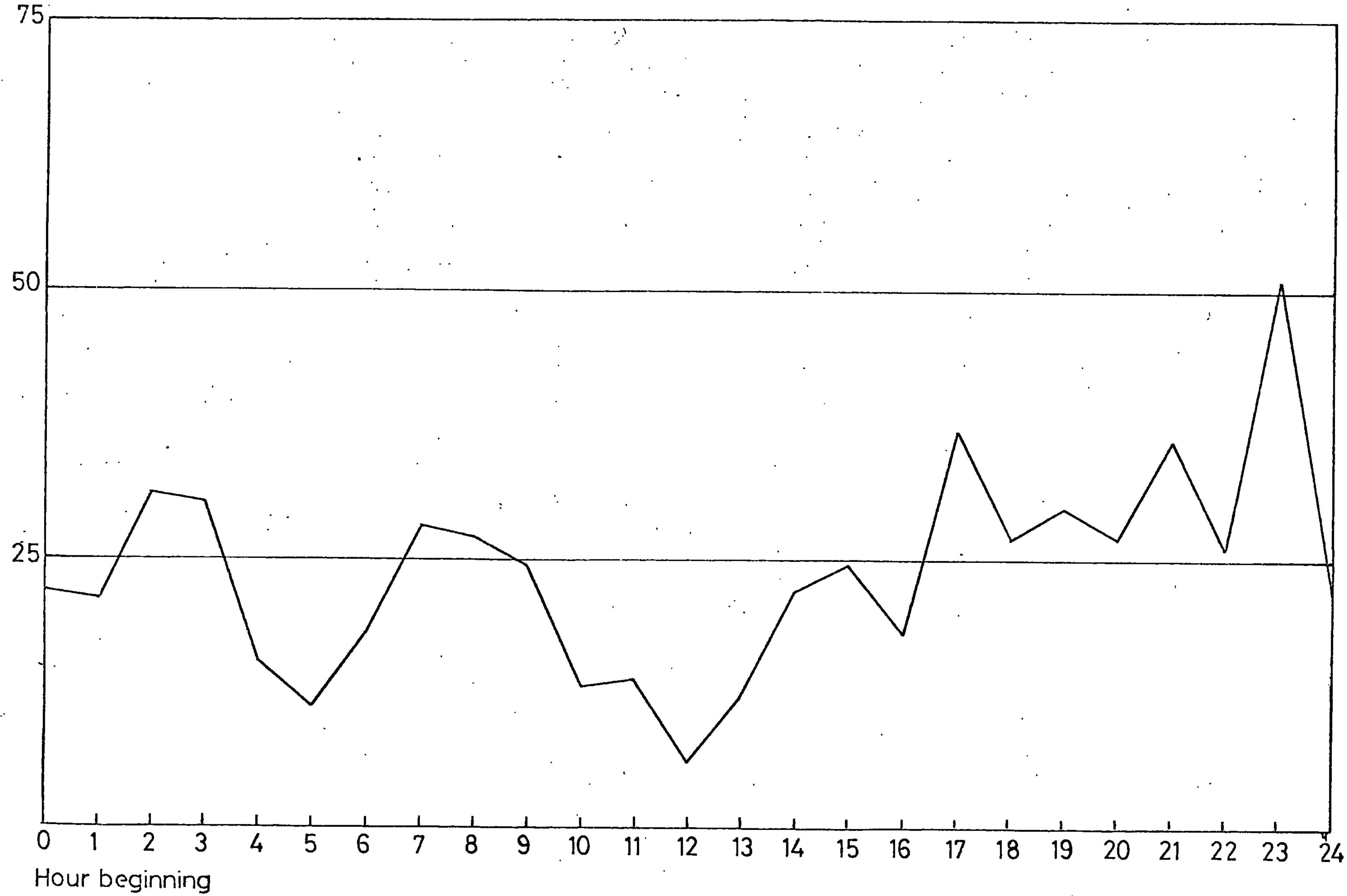


Table 3.6

No Car Available Incidents: Classified by Hour of Day

Hour beginning	Division								Total
	A	B	C	D	E	F	G	H	
00.01	2	4	5	1	1	4	2	3	22
01.00	-	9	3	1	2	3	-	3	21
02.00	1	4	2	4	2	10	2	6	31
03.00	1	2	5	4	2	4	6	6	30
04.00	1	2	6	-	-	2	2	2	15
05.00	1	-	4	2	-	4	-	-	11
06.00	-	2	5	1	1	2	3	4	18
07.00	-	3	6	3	4	4	5	3	28
08.00	-	5	7	4	5	2	2	2	27
09.00	1	2	2	8	2	4	4	1	24
10.00	-	4	3	-	1	1	3	1	13
11.00	1	3	3	-	2	2	1	2	14
12.00	-	1	1	1	1	-	1	1	6
13.00	1	1	1	2	1	2	2	2	12
14.00	3	2	6	1	1	2	2	5	22
15.00	4	6	4	1	3	2	3	1	24
16.00	2	1	2	4	1	4	1	3	18
17.00	4	8	3	1	1	8	7	5	37
18.00	3	2	11	1	3	2	3	2	27
19.00	1	4	8	2	2	-	5	8	30
20.00	2	8	3	2	-	4	4	4	27
21.00	2	6	3	9	3	5	2	6	36
22.00	1	3	3	4	3	3	6	3	26
23.00	2	13	10	4	2	9	4	7	51
Totals	33	95	106	60	43	83	70	80	570

in H.Q. Control Room, and for some calls in divisional or sub-divisional control room. It is the interval between the receipt of an incoming emergency call at H.Q. Control Room and the despatch of a vehicle to the incident, and is one measure of the efficiency of H.Q. and divisional control rooms.

Travelling time is the interval between the despatch of a vehicle and its arrival at the scene of an incident, and is one measure of the effectiveness of the allocation of police mobile resources.

Together handling time and travelling time make up overall response time, the measure of service that the public are most aware of, and one measure of the overall effectiveness of the police emergency response service.

The results of the fortnight study of response time are summarised in Table 3.7.

Complete response time information was obtained for 783 (53%) of the 1488 incidents recorded during the fortnight. The breakdown of response time by division and type of vehicle is included in Table 3.8.

Table 3.8

Response Time: Classified by Division

Division	Type of Vehicle				Overall	
	Vhf		Panda			
	Mean	Sample size	Mean	Sample size	Mean	Sample size
A	23.4*	9	12.0	18	15.8*	27
B	8.1	30	12.4	117	11.5	147
C	10.5	22	12.2	59	11.8	81
D	6.2	20	10.3	114	9.7	134
E	5.9	11	10.0	88	9.6	99
F	10.8	17	12.5	55	12.1	72
G	6.3	17	12.0	111	11.3	128
H	7.2	17	12.4	78	11.5	95
Overall	9.0	143	11.6	640	11.1	783

All times in minutes

* These figures are distorted by the effect of one long response time on a small sample.

Table 3.7

Response Characteristics: Classified by Type of Vehicle

Type of Vehicle	Handling Time				Travelling Time				Response Time			
	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size
Vhf	1.5	1.8	0.2	143	7.5	9.5	0.8	143	9.0	10.0	0.8	143
Panda	5.9	6.5	0.3	640	5.7	6.4	0.3	640	11.6	9.9	0.4	640
Overall	5.1	6.2	0.2	783	6.0	7.1	0.3	783	11.1	10.0	0.4	783

All times in minutes

This shows that the panda vehicle response time performance was reasonably consistent over all divisions. The response time performance of vhf vehicles showed a large degree of variation between an average of 5.9 minutes in E division and 10.5 minutes in C division, excluding the exceptionally large value recorded for A division.

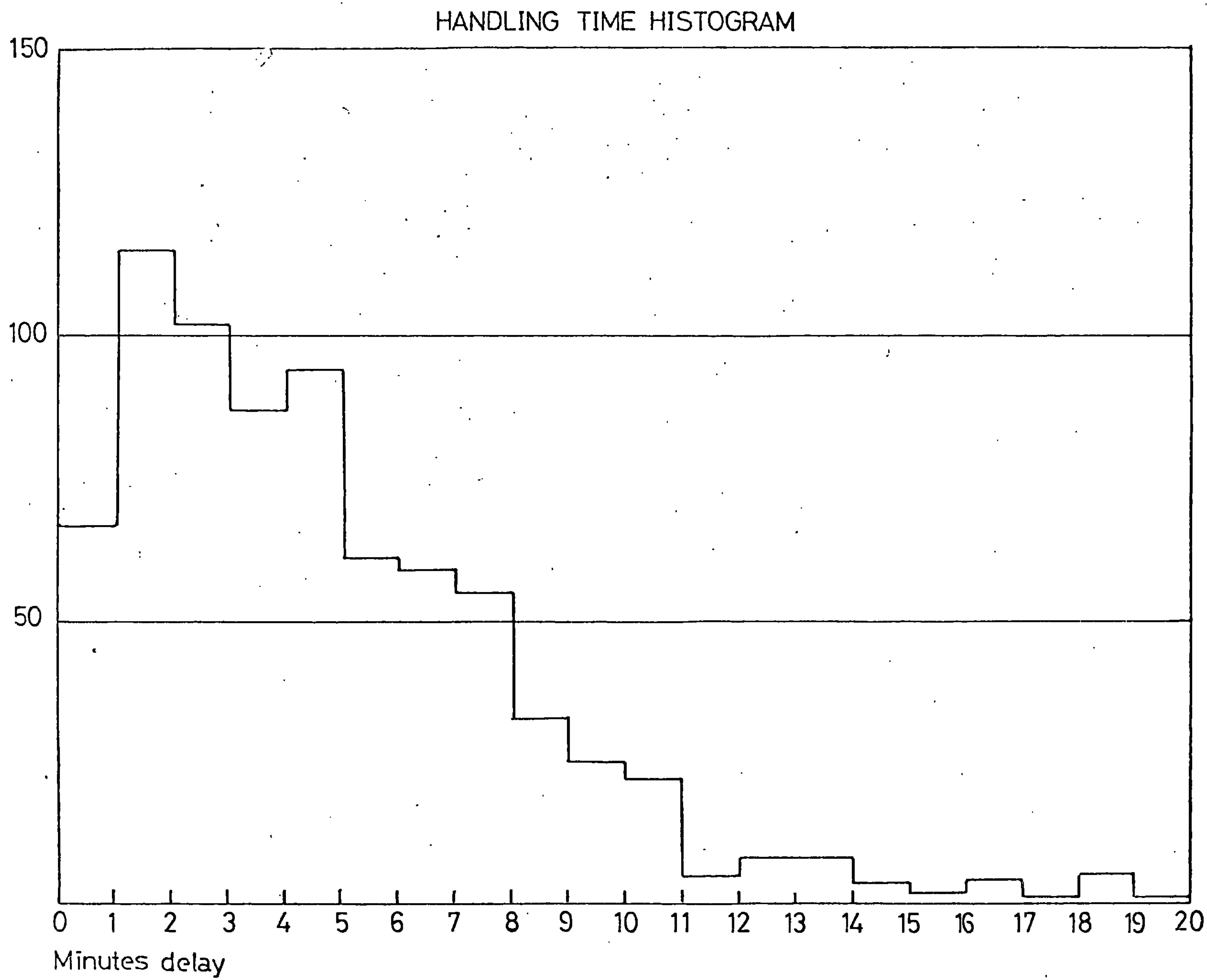
The distributions of handling time, travelling time, and response time for all incidents are illustrated in Figures 3.5, 3.6, and 3.7. The response time distribution had a mean of 11.1 minutes with a standard deviation of 10.0 and a modal value of 9 minutes. Handling time had a mean of 5.1 minutes with a standard deviation of 6.2 minutes and a mode of 1 minute. Travelling time had a mean of 6.0 minutes with a standard deviation of 7.1 minutes and a mode of 3 minutes.

The breakdown of response characteristics by type of vehicle, included in Table 3.7, shows that the average response time for panda vehicles of 11.6 minutes was 2.6 minutes longer than that for vhf vehicles. In fact the average travelling time for panda vehicles was 1.8 minutes shorter than that for vhf vehicles but this was detracted from by an average handling time of 5.9 minutes, some 4.4 minutes longer than that for vhf vehicles despatched directly by H.Q. Control Room. This delay was attributed to the need for a telephone call from H.Q. Control Room to divisional or sub-divisional control room, to relay details of an emergency incident, before a panda vehicle could be despatched.

Service Time

Service time for an incident included travelling time on route to the incident and time spent at the incident scene. The latter aspect

Figure 3.5



HANDLING TIME HISTOGRAM
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Minutes delay

Figure 3.6

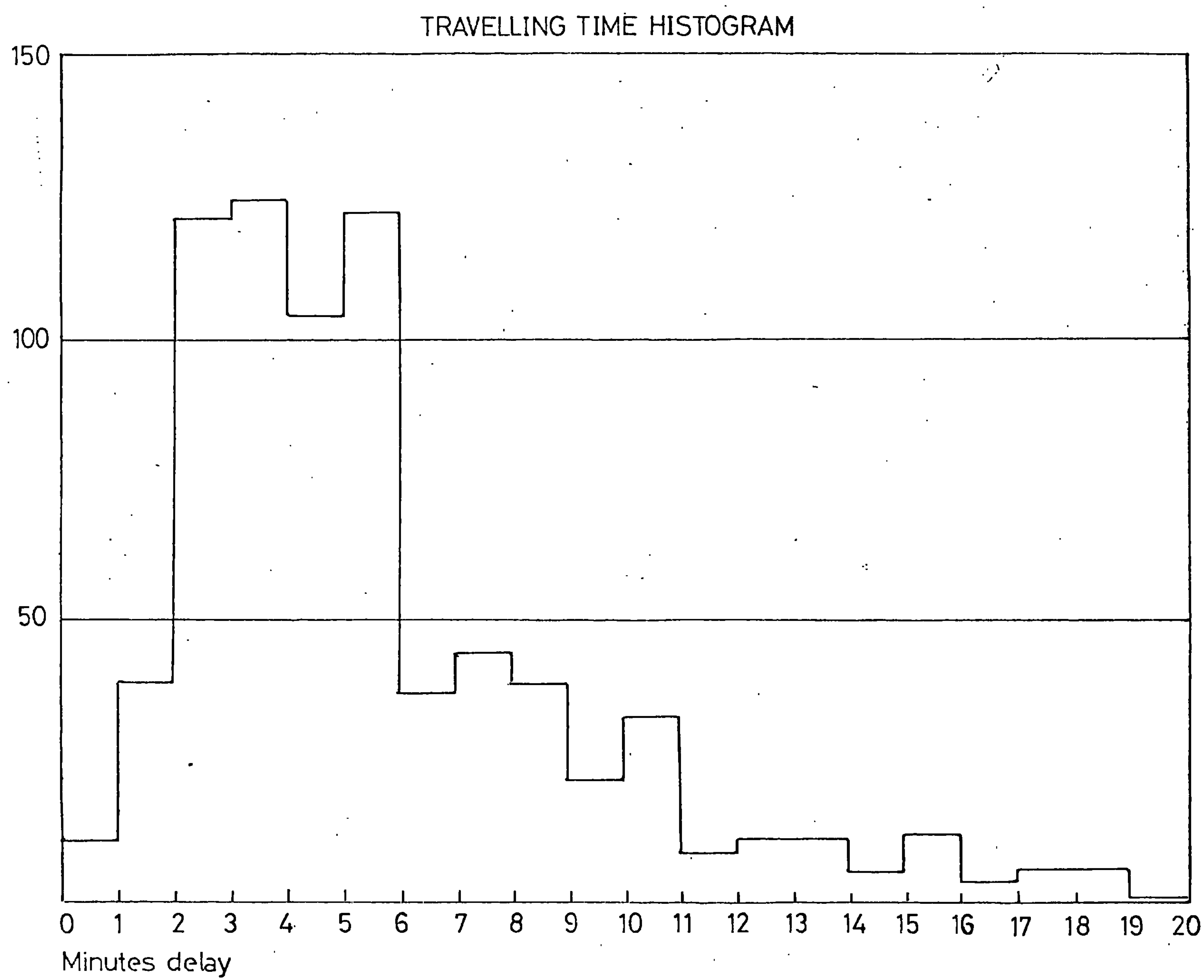

TRAVELLING TIME HISTOGRAM
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Minutes delay

Figure 3.7

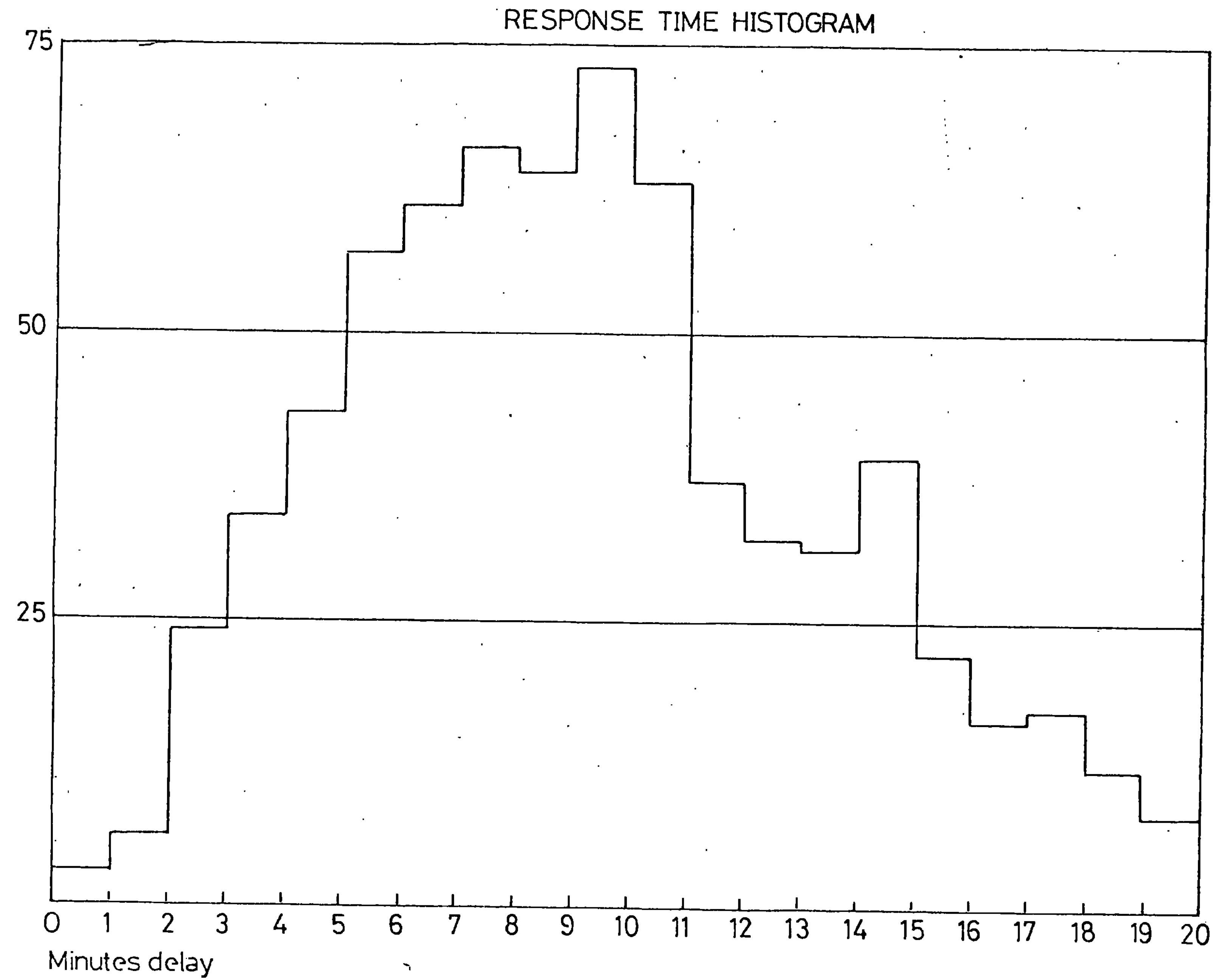

RESPONSE TIME HISTOGRAM
75
50
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Minutes delay

Table 3.9

Response Characteristics: Classified by Length of Delay

Length of Delay	Frequency		
	Response Time	Handling Time	Travelling Time
Minutes			
0	3	67	11
1	6	115	39
2	24	102	121
3	34	87	124
4	43	94	104
5	57	61	122
6	61	59	37
7	66	55	44
8	64	33	39
9	73	25	22
10	63	22	33
11	37	5	9
12	32	8	11
13	31	8	11
14	39	4	6
15	22	2	12
16	16	4	4
17	17	1	6
18	12	5	6
19	8	1	1
20	9	-	3
Over 20	66	25	18

was investigated for response time data collected on the 1st February immediately prior to the fortnight study of response time. The results of this small one day study are included in Table 3.10.

Table 3.10

Time at Incident Scene: Classified by Type of Vehicle

Type of Vehicle	Mean	Sample Size
Vhf	21.5	19
Panda	29.1	90
Overall	27.7	109

All times in minutes.

Combined with the mean travelling times from the full response time study these incident scene times indicated a mean service time of 29.0 minutes for vhf vehicles and 34.8 minutes for panda vehicles with an overall mean service time of 33.7 minutes per emergency incident.

Service time depended upon the type of task that had to be undertaken at the incident scene, the amount of assistance that was available, and any congestion that was present in the police response service, and was not seen as an important measure of the effectiveness of initial police response to emergency incidents.

Reliability of Response Time Data

It was requested that all times were given to the nearest minute. When the returns were processed slight time discrepancies between H.Q.

and divisional control room forms were detected for some incidents to which a panda vehicle had been despatched arising from the use of unsynchronised clocks. For these incidents all times were referred to the H.Q. clock, facilitated by the practice of recording the time of a message from H.Q. Control Room to divisional or sub-divisional control room on both the communications forms used.

A more serious possible source of error was that there was no means by which cross-checking could be performed on time of vehicle arrival at the scene of an incident, and time at which a vehicle resumed patrol. The irregularities in the histograms in Figures 3.5, 3.6, and 3.7 suggested that some of the vehicle despatch and arrival times had been rounded off to the nearest five, ten, or fifteen minutes. It was thought that this rounding-off of times occurred when personnel in H.Q. or divisional control room entered them on the relevant form some time after the information had been received from the vehicle concerned.

3.2.2.4 Other Aspects of the Response Function

Handling of Incoming Calls in H.Q. Control Room

During preliminary observation of H.Q. Control Room it was observed that during busy periods the duty inspector and sergeant were obliged to act as telephonists. As these officers should have been acting in a supervisory manner, helping other control room personnel to deal with incidents, it was desirable that they should not have answered calls themselves. This aspect of operations in H.Q. Control Room was recorded on an incident log sheet, as the officer handling a call was identified by the console number recorded.

The hourly variations in emergency calls handled by the H.Q. Control Room duty inspector and sergeant are shown in Figure 3.8. This shows that the ideal situation was almost achieved. For example, the inspector answered an average of 4.6 calls a day, or under one call every five hours, with a peak in the hour beginning 21.00 of 0.6 calls an hour, a rate which should not have interfered too greatly with his supervisory role. A similar situation was seen to have existed for the duty sergeant who answered an average of 13.3 calls a day, or just over one call every two hours, with a peak rate of 1.7 calls an hour in the hour beginning 23.00. Most of the emergency calls (84%) were handled by the other duty personnel in H.Q. Control Room who were experienced traffic and communications officers, known as traffic handlers. This was in accordance with operational requirements.

Multiple Vhf Vehicle Response

It was observed that for some incidents more than one vhf vehicle had been recorded on the incident log sheet as having attended the incident. Such multiple attendances could have arisen in one of the following ways.

(a) more than one vhf vehicle was initially despatched to an incident because each vehicle was equally favourably placed in the required area, or

(b) the first vehicle on the scene decided further assistance was necessary and radioed H.Q. Control Room to request the despatch of additional vhf vehicles as required.

The maximum number of vhf vehicles despatched to an incident was ten for an incident of arson at a farm in E division. The first vehicle on the scene was an E division motor patrol car, and this was

Figure 3.8

EMERGENCY CALLS HANDLED BY H.Q. CONTROL ROOM INSPECTOR + SERGEANT: CLASSIFIED BY HOUR OF DAY

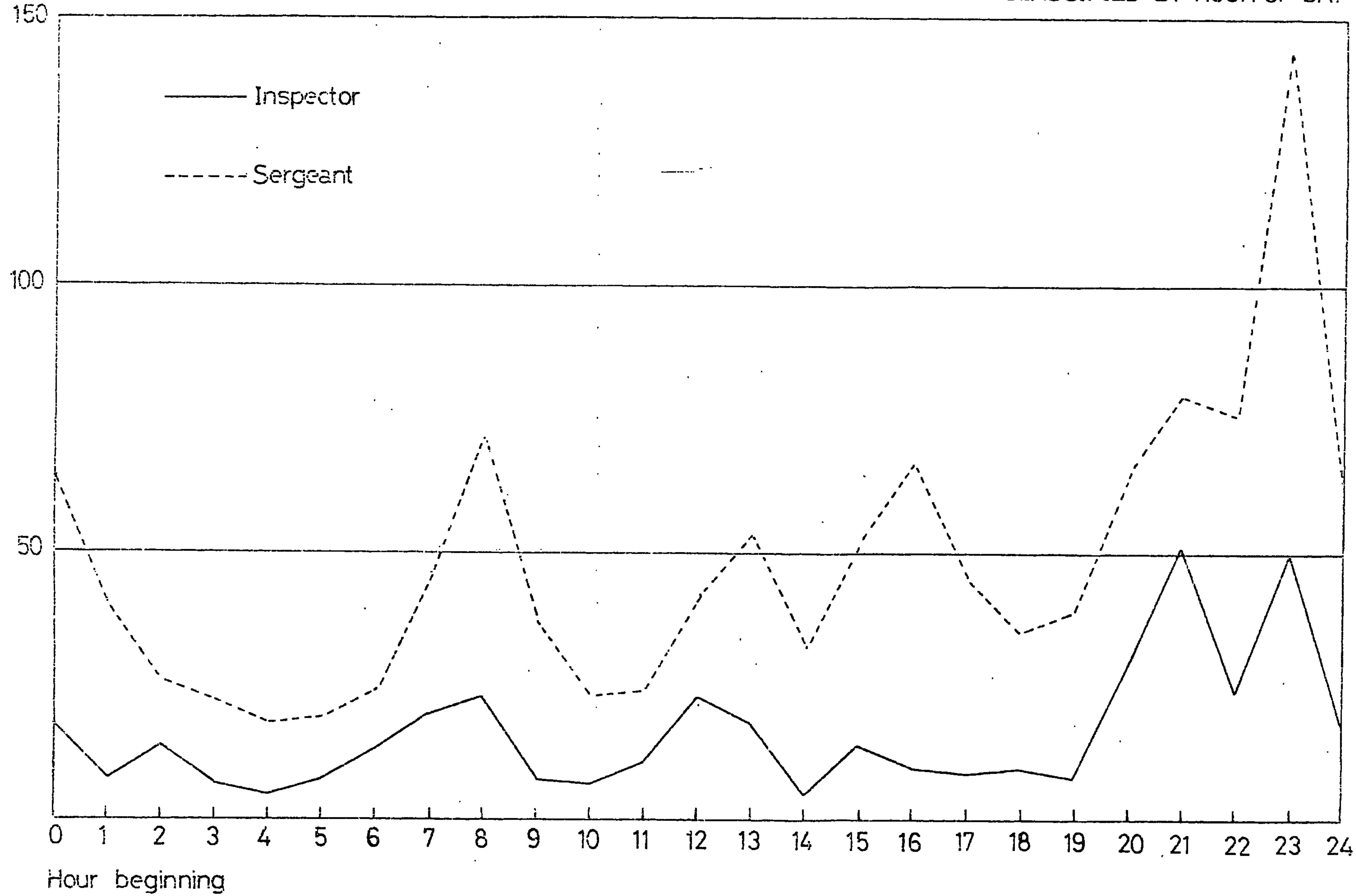


Table 3.11

Emergency Calls Handled by H.Q. Control Room Personnel:

Classified by Hour of Day

Hour beginning	H.Q. Control Room Personnel			Total
	Inspector	Sergeant	Others	
00.01	18	64	478	560
01.00	8	40	210	258
02.00	14	26	149	189
03.00	7	22	107	136
04.00	5	18	61	84
05.00	8	19	81	108
06.00	13	24	112	149
07.00	20	46	224	290
08.00	23	71	381	475
09.00	8	37	343	388
10.00	7	23	272	302
11.00	11	24	249	284
12.00	23	42	210	275
13.00	18	53	241	312
14.00	5	32	294	331
15.00	14	51	321	386
16.00	10	66	345	421
17.00	9	45	450	504
18.00	10	35	449	494
19.00	8	39	445	492
20.00	29	65	404	498
21.00	51	79	487	617
22.00	24	75	718	817
23.00	50	144	1005	1199
Totals	393	1140	8036	9569

followed up by four H.Q. patrol cars, another E division patrol car, an A division patrol car, two dog section vehicles, and a special incident squad vehicle.

Of the 1536 incidents initially attended by vhf vehicles, 308 (20%) were attended by between one and nine additional vhf vehicles. The breakdown of these multiple vhf vehicle attendances by type of incident is included in Table 3.12.

Table 3.12

Multiple Vhf Vehicle Attendance:
Classified by Type of Incident

Type of Incident	Attended by Vhf Vehicle		% with Multiple Attendance
	Single Attendance	Multiple Attendance	
1	429	94	21.9
3	277	55	19.9
6	563	108	19.2
7	13	6	46.2
8	254	45	17.7
Overall	1536	308	20.1

This shows that 46% of the serious incidents (Type 7) initially attended by vhf vehicles received attention from more than one vhf vehicle, and that 22% of traffic incidents (Type 1) were subsequently attended by additional vhf vehicles. For this latter category of incidents a large number of mobile units and associated police officers were sometimes required to deal with traffic congestion arising from a traffic accident blocking all or part of a carriageway.

Emergency Incident Sequel

Although all the incidents notifed to the Durham County Constabulary by a 999 call were treated as emergencies as a matter of policy, it was observed that some calls were not so urgent as others. An initial investigation suggested that 'not suitable' calls were running at a level of 5% of all emergency calls. Such calls were, for example, passing on information or reporting incidents requiring no immediate police attention.

This non-urgent aspect of incoming emergency calls was investigated by classifying all emergency calls according to their sequel. The following coding was used.

1. Crime, arrest.
2. Crime, no arrest.
3. Traffic incident, action required.
4. Other action required.
5. No action required.

Sequel 4 implied that another authority, for example, gas, electricity or water board, had been contacted to provide the required service, and sequel 5 included incidents where although police presence may have been instrumental in maintaining law and order, for example, in controlling domestic or public disturbances, no police action was actually required.

A breakdown of all incidents by type and sequel is included in Table 3.13.

Table 3.13

Emergency Incidents: Classified by Sequel

Sequel	Type 1	3	6	7	8	Total
1	32	18	134	8	84	276
2	1	3	1724	33	5	1766
3	707	-	-	-	-	707
4	58	911	1599	14	101	2683
5	112	2233	212	2	1578	4137
Totals	910	3165	3669	57	1768	9569

Of the 8659 non-traffic incidents, 2009 (23%) involved crimes (sequels 1 and 2). 740 (81%) of the 910 traffic incidents required some form of police attention. No police attention was required (sequel 5) for 3811 (77%) of the 4933 type 3 and 8 incidents. In the event of congestion in the emergency service, screening of incoming calls of type 3 and 8 would offer the greatest potential benefit in cutting down the number of calls receiving urgent priority attention.

CHAPTER IV

MOTOR PATROL REORGANISATION

4.1 Internal Police Planning Department Study

In the light of the experience gained during the 1969 study various conclusions were reached and several recommendations were made to the Durham County Police Force concerning the operations of their motor patrol force, and some minor aspects of H.Q. and divisional control room procedures.

Partly prompted by the university study the internal police planning department undertook later in 1969 a study of divisional motor patrols, Headquarters traffic patrols and Control Room. This study took into account

(i) divisional and H.Q. returns of process, cautions and incidents for June, 1969,

(ii) the accident rate for January through June 1969,

(iii) the crime rate for January through June 1969,

(iv) a workload survey for all drivers and supervision for a period of one week,

(v) a vehicle utilisation survey for all patrol vehicles for a period of one week,

and the views of motor patrol officers.

The subsequent report concluded that the use of divisional motor patrols was inefficient owing to lack of flexibility, some evidence in support of this view was provided by the university study which found that the level of interdivisional despatching was very low, see Table 3.4. It was recommended that all patrols be placed under H.Q.

control with an equalised workload allocation based on the measures (ii) and (iii) and the number of '999' calls, and that smaller patrol areas be specified to allow more precise location of patrols.

After consideration of the recommendations from both the university and the internal study there was a major reorganisation of the motor patrols in Durham Constabulary involving the creation of M division which became operational on the 8th December, 1969.

4.2 M Division

M division was designed to bring under one control

(a) Administration

(b) Accident Prevention

(c) Motor Patrols

(d) Motor Cycle Patrols

(e) Workshops

(f) Transport

(g) Control Room .

As a consequence of its creation the distinction between the former Headquarters traffic patrols, and divisional motor patrols was abolished. The term 'traffic patrols' was also discontinued and the terms of reference for M motor patrols were that their duties were to include traffic, crime and general duties without particular emphasis on any single aspect.

For purposes of organisation the county was divided into two motor patrol subdivisions and each subdivision was divided into two sections as follows.

North Subdivision

Section 1	G and D divisions
Section 2	C and H divisions.

South Subdivision

Section 3 A and F divisions

Section 4 B and E divisions.

These are shown in Figure 4.1

The A1(M) motorway was to be separately patrolled, and was divided into two routes to coincide with the sub-divisions of M division. Route 1 was in the north sub-division, and Route 2 in the south sub-division. The County was divided into patrol areas which were small geographical units in each division, for example, A division previously with four sub-divisions, A1 - A4, was divided into seven patrol areas, A1 - A7.

The only vehicles allocated to divisions were personnel carriers, transport vans, dog section vans, C.I.D. vehicles, and unit beat policing (panda) vehicles.

Radio communication procedure was slightly revised so that all patrol cars attached to M division had their existing call sign altered in such a manner that odd numbers were allocated to patrol cars in the north sub-division and even numbers to those in the south sub-division, giving H.Q. Control Room personnel a simple means for identifying any particular patrol vehicle.

After the creation of M division the distribution of motor patrols was as shown in Table 4.1.

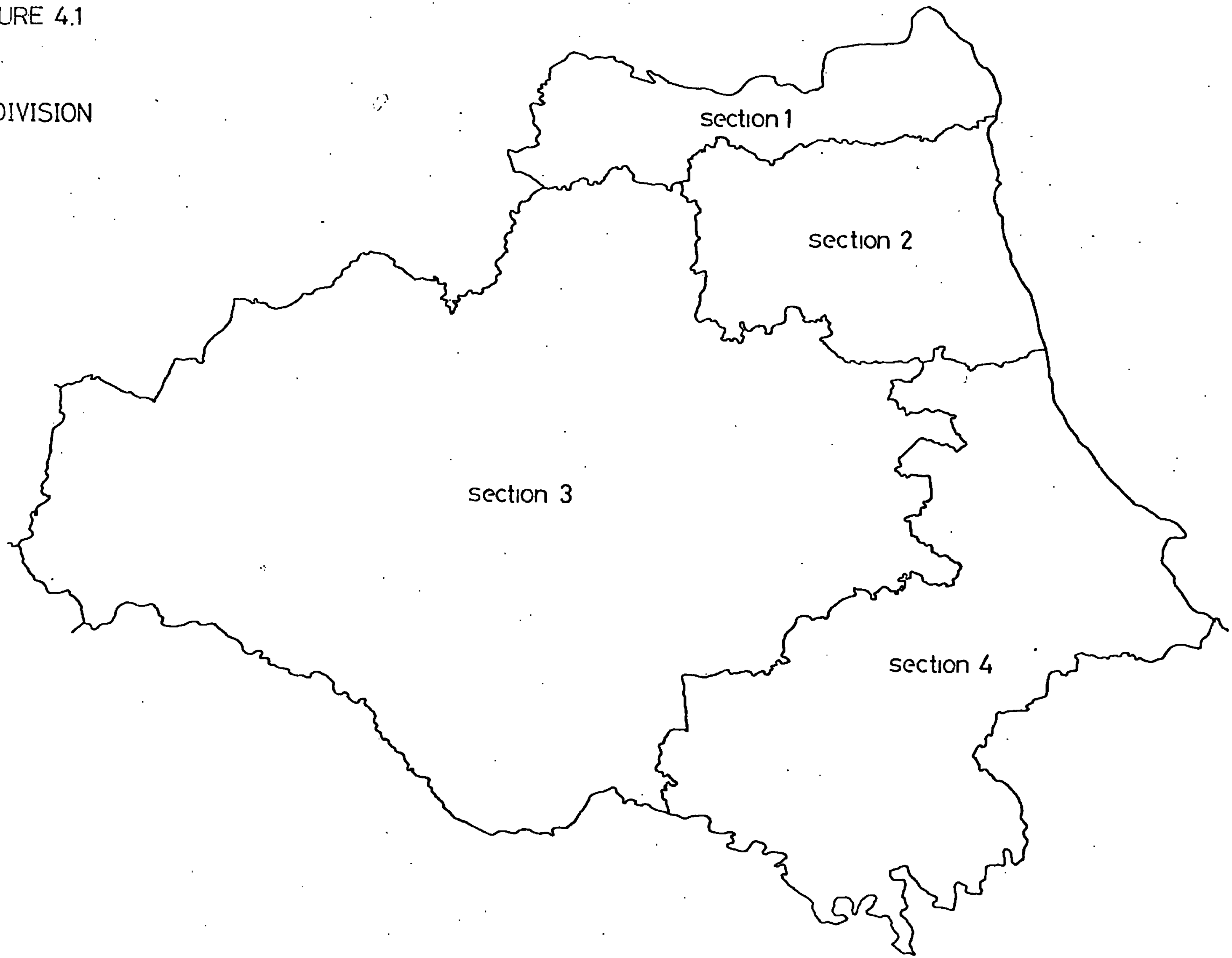
Table 4.1

Distribution of Motor Patrols. December 1969.

Section	Divisions	Motor Patrols
1	G,D	17
2	C,H	17
3	A,F	16
4	B,E	17
Supervision		4
Total		71

FIGURE 4.1

M DIVISION



4.3 Other Modifications

Consequent upon the results reported from the 1969 University study (Chapter III) other modifications concerned with operations in both Headquarters and divisional control rooms were made.

It had been observed in 1969 that an average delay of 2.6 minutes occured when a panda rather than a vhf vehicle was used. This was attributed to delay in answering the telephone in divisional or sub-divisional control rooms which meant that the message from H.Q. control room requesting the attendance of a panda vehicle was delayed.

The telephone used for these emergency incident messages was that used for all telephone purposes and to which no priority was attached. In an attempt to eliminate this source of delay a red telephone was installed in each divisional control room for the sole purpose of '999 call' messages from H.Q. control room requesting the attendance of a panda vehicle at an emergency incident. This telephone was to be given priority.

A redesigned message form to be used in both Headquarters and divisional control rooms was introduced incorporating provision for arrival time, and thus full response time information, to be recorded, which had been a feature missing from the previously used communications form, and which had to be specially collected for the 1969 study.

The other changes concerned the information that was available on vhf and panda vehicles. The first of these concerned the manner of data input to the H.Q. control room memory unit, the sole source of updated information on vhf vehicle location and status. This change is described in the Appendix. Its effect was that the information provided by the memory unit on the available vhf vehicle strength was no longer misleading.

The other change concerned the manner in which divisional control rooms recorded the activities of panda vehicles. A location and availability state record was introduced, which had to completed every hour. The information was to be obtained by the officer in charge in divisional control room radioing each of the panda vehicles and requesting location and state.

This information had been specially requested for a fortnight during the 1969 study, but the subsequent returns were found to be incomplete (see section 3.2.2.2). The introduction of the hourly location and state record for panda vehicles meant that this information was readily available.

4.4 Design of 1970 Study

In order to assess the effect of the reorganisation of the mobile patrols, a second study was designed to take place during the first three months of 1970. This allowed for a month between the implementation of the M division reorganisation and the first measurements of the 1970 study.

The following data was requested for the 1970 study.

From Headquarters Control Room

1. A coded copy of all message forms referring to 999 calls, for the period 4th January until 31st March, containing in addition to the information recorded in 1969, the time of arrival of vhf vehicles at the scene of an incident.

2. An hourly return, obtained by interrogation of the memory unit, showing the number of Class 1, 2, 4, and 5 vehicles (motor patrol cars, M division motor-cycles, serious incident squad vehicles, and dog

section vehicles, respectively) that were on patrol in each of the ten locations, A, B, C, D, E, F, G, and H divisions and motorway routes R1, R2, for the period 1st February until 14th February.

From Divisional and Sub-divisional Control Rooms.

3. A copy of all message forms (Exp. Form 82) relating to 999 calls, for the period 4th January until 31st March, containing in addition to the details recorded in 1969, the time of arrival of panda vehicles at the scene of an emergency incident.

4. A copy of all message forms relating to non-999 activities for the same period.

5. A copy of all Unit Beat - Hourly Location Forms (Form DU/DC 6), containing details of the location and availability state of all panda vehicles on duty at hourly intervals, for the period 1st February until 14th February.

In addition to the information requested from H.Q. Control Room memory unit in (2) it was also hoped to obtain at specified times, returns of the total number of vhf vehicles in the four classes, for checking purposes, and of total vehicles in all availability states (that is, states 1 to 7). This proved impossible as the memory was operated so that off duty vehicles (in state 8) were not recorded, and the vehicles in all states in any given location could not be totalled. The alternative of recording the numbers in each state in each location was not feasible because of the interrogation time involved, since all vehicle types were now recorded separately.

EXP. FORM 82 DURHAM CONSTABULARY MESSAGE NO.

MESSAGE FORM

~~909~~
Telephone
~~Radio~~
Verbal

Time received/dispatched :- 01.10 hrs. Date:- 21. 12. 69.

From :- INSP. TATE - CONTROL ROOM.

By/To :- P.C. MARSHALL. - COMMUNICATIONS.

TEXT OF MESSAGE:

AUTO ALARM SOUNDING -

DURHAM CITY RUGBY FOOTBALL CLUB,
GREEN LANE.
DURHAM CITY.

ACTION TAKEN

Vehicle dispatched - (Call Sign)	FB 12.	FB 15.	FB 3.	P. 10				
At (Time) -	01. 11	01. 11	01.12	01.13				

Circulated To -	INSP. ALDERSON							
At (Time) -	01.14.							

Copy of Message Passed To -	D/SUPT	SUB DIV SUPT.	C.I.D.	CH/PRO				
At (Time) -		02	20					

Arrival at Incident -	Call Sign	FB 12	FB 15	FB 3.	P. 10				
	Time	01.14	01.14.	01.17	01.20				

~~SITUATION~~/SEQUEL REPORT - At 01.45 hrs. From:- P. 10.

BURGLARY - 2 MEN ARRESTED.
(FOUND IN PREMISES).

Control Room Informed of Sequel At 01.50 hrs By PC. MARSHALL.

See * ~~Complaint Book.~~
~~Process Report.~~
~~Accident Report.~~
Crime Complaint.
~~Occurrence Book~~

Sgt Clarke.
Officer in charge.

DURHAM CONSTABULARY

FORM DU/DC 6

UNIT BEAT — HOURLY LOCATION FORM.

Date:- 15/12/69

Sub Division:- DURHAM

UNIT:- FB1.			UNIT:- FB 2.			UNIT:- FB 3.			UNIT:- FB.4.		
P.C. GADD CALL SIGN:- FB 12.			P.C. CUTHBERTSON CALL SIGN:- FB 15.			P.C. HALL. CALL SIGN:- FB 3.			P.C. FOSTER CALL SIGN:- FB 3,		
Hours	Location	State	Hours	Location	State	Hours	Location	State	Hours	Location	State
06.00.			06.00	ON DUTY	1				06.00	ON DUTY	1
			07.00	NEWTON HALL	1				07.00	MANSFORTH	2
			08.00	SALUTATION	2				08.00	SHINCLIFFE	1
			09.00	REFRESHMENT	4				09.00	COXHOE	2
			09.45	RESUMED - SUNDERLAND RD	1				10.00	COXHOE	2
10.00	ON DUTY	1	10.30	DURHAM COURT	7				10.15	REFRESHMENTS	4
11.00	GILESGATE.	5	11.00	RESUMED	1				11.00	RESUMED	1
12.00	HARE & HOUNDS	1	12.00	DURHAM	3				12.00	CHILTON	2
13.00	REFRESHMENTS	4	13.00	BELMONT.	1				13.00	FERRYHILL	1
13.45	RESUMED	1		PC. SANDERSON	(FB8)					PC. GREENFIELD	- FB3
14.00	MARKET PL.	1	14.00	ON DUTY	1				14.00	ON DUTY	1
15.00	LANGLEY MOOR	1	15.00	SHERBURN RD.	2				15.00	BP. AUCKLAND	7
16.00	SALUTATION	2	16.00	SUNDERLAND RD	2				16.00	CITY OFFICE	3
17.00	CITY OFFICE	3	17.00	SHERBURN RD.	1				17.00	BOWBURN	2
18.00	OFF DUTY	8	18.00	OFF DUTY	8				18.00	OFF DUTY	8
				PC DOXFORD -	FB8.					PC. HALL -	FB 4.
			1800	ON DUTY	1				18.00	ON DUTY	1
			19.00	CITY OFFICE	3				19.00	NEV. CROSS	1
			2000	CITY OFFICE	3				2000	FERRYHILL	2
			21.00	REFRESHMENTS	4				21.30	FERRYHILL.	5
	PC. DOXFORD -	FB8		PC DALTON -	FB12					PC. LAWSON	(FB14)
22.00	ELVET.	1	22.00	GILESGATE	1	22.00	FERRYHILL	1	22.00	DEAN BANK	1
23.00	MKT. PLACE	2	23.00	GILESGATE	2	23.00	COXHOE.	2	23.00	FERRYHILL	2
24.00	NORTH ROAD	1	24.00	SHERB. RD	1	24.00	BOWBURN	1	24.00	DEAN BANK	1
01.00	FRAM MOOR	1	01.00	DURHAM.	4	01.00	COXHOE	2.	01.00	DURHAM	4.
02.00	OFF DUTY	8	02.00	ELVET.	1	02.00	DURHAM.	8	02.00	COXHOE.	1
			03.00	GILESGATE.	1				03.00	FERRYHILL	2
			04.00	NORTH ROAD	5				04.00	COXHOE	1
			05.00	SUNDLD RD	1.				05.00	F'HILL STAT.	1
			06.00	GILESGATE	8				06.00	DEAN BANK	8

CHAPTER V

1970 STUDY

The 1970 study extended over the period from 4th January until 31st March. The following sources of information were used for all or part of this period (see section 4.4).

1. H.Q. Control Room message forms for details relating to incoming 999 calls.

2. The corresponding divisional control room message forms for these incidents.

3. H.Q. Control Room memory unit for the number and locations of available vhf vehicles.

4. Divisional and sub-divisional control room unit beat-hourly location forms for information on location and state of all panda vehicles.

5. Divisional and sub-divisional control room message forms for details relating to divisional activities other than those included in (2).

The results of the 1970 study are presented in section 5.1. The significance of changes between 1969 and 1970 are considered in section 5.2.

5.1 Results

5.1.1 Emergency Incident Demand

During the 87 days of the study a total of 10,219 emergency calls were made in the Durham Constabulary Area, an average daily rate of 117 emergency incidents, a 6% increase on the 1969 figure of 111.

The hourly variation in emergency incidents is shown in Figure 5.1. Comparison of this figure with the corresponding figure for 1969, Figure 3.1, shows that the diurnal distribution of emergency incidents remained the same. The proportion of incidents in each division remained the same (see Tables 3.1 and 5.1) and the day of week variation followed a similar pattern between Saturday with an average of 141 incidents and Wednesday with an average of 98 incidents. Again the busiest quarter was the last one on Saturday with an average of 63 incidents compared with the slackest which was the first quarter on Wednesday with 9 incidents, with a ratio between the two of 7 to 1, a slight decrease on the ratio between the busiest quarter (65 incidents) and the slackest quarter (9 incidents) in 1969.

A breakdown of the incidents by type (see Table 5.2) shows that the proportion of the incident types 1, 7, and 8 remained the same (compare Table 3.3) but that the proportions of incident types 3 and 6 changed substantially although the combined proportion of these types remained the same. A possible explanation for these changes is that many incidents of these two types showed a high degree of similarity and could have been classified as either type 3 or type 6.

5.1.2 Response

5.1.2.1 Type of Vehicle Used

The breakdown of emergency incidents by type and by type of vehicle used to provide initial attention is included in Table 5.2. The corresponding breakdown for 1969 is shown in Table 3.3.

Overall the proportion of incidents dealt with by the two types of

Figure 5.1

EMERGENCY INCIDENTS : CLASSIFIED BY HOUR OF DAY

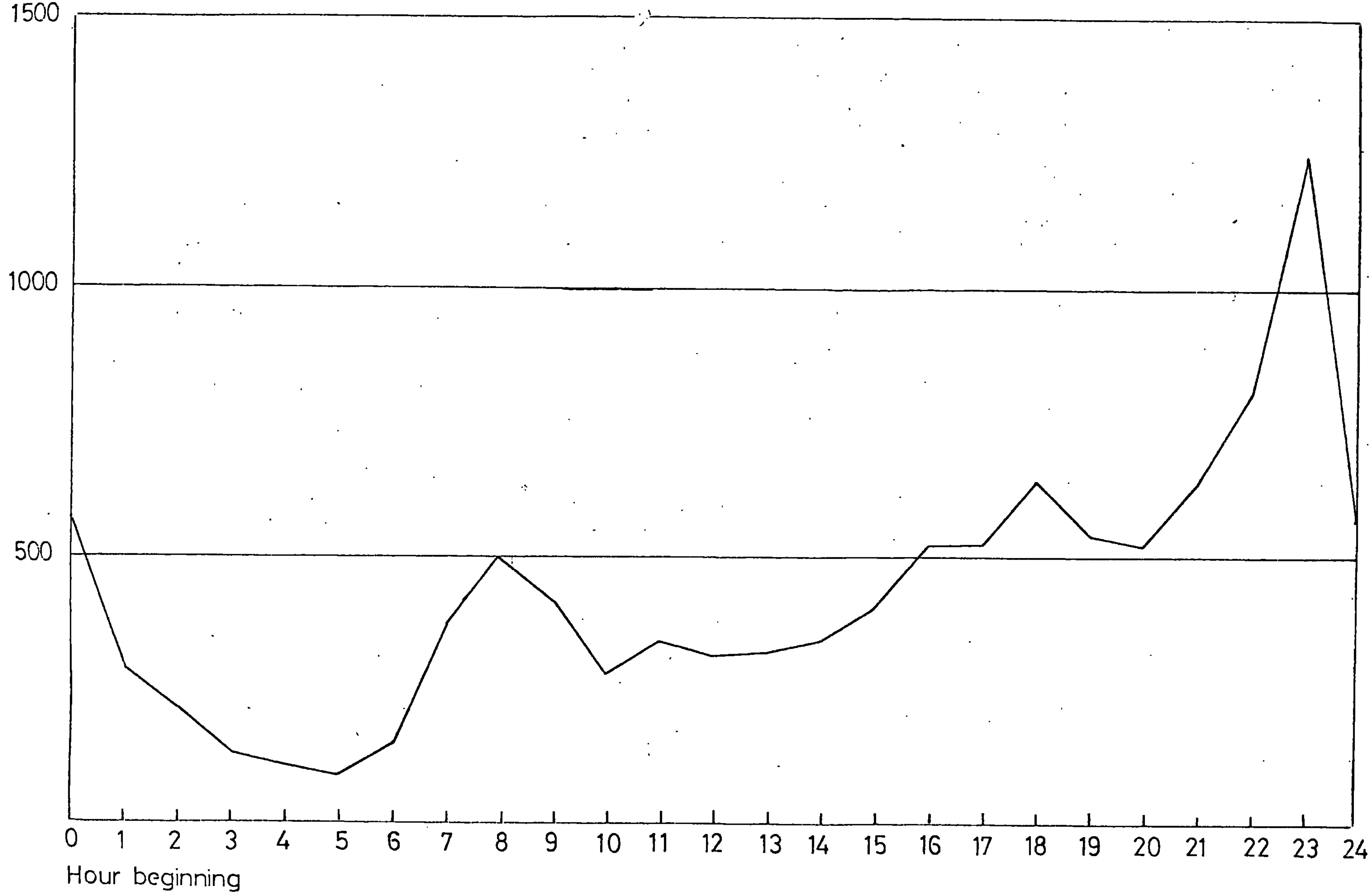


Table 5.1

Emergency Incidents: Classified by Hour of Day

Hour beginning	Division A	B	C	D	E	F	G	H	Total
00.01	30	96	49	76	55	52	91	116	565
01.00	10	45	18	52	19	29	57	58	288
02.00	8	26	32	33	11	21	36	41	208
03.00	9	20	13	24	9	10	15	26	126
04.00	5	13	15	18	15	9	16	15	106
05.00	3	13	9	14	4	6	18	23	90
06.00	8	21	11	23	16	15	19	34	147
07.00	17	72	49	42	19	41	70	60	370
08.00	26	81	54	64	29	53	98	95	500
09.00	20	51	49	64	35	52	61	78	410
10.00	18	40	31	38	26	24	51	55	283
11.00	20	46	36	54	31	28	63	61	339
12.00	12	34	21	64	26	26	70	57	310
13.00	15	40	16	64	36	21	59	70	321
14.00	24	50	32	39	30	35	58	70	338
15.00	21	42	28	76	43	33	73	87	403
16.00	23	70	45	70	67	47	75	121	518
17.00	23	74	42	84	54	44	96	103	520
18.00	27	103	53	103	55	51	104	147	643
19.00	24	75	38	101	57	43	92	111	541
20.00	30	58	54	71	61	30	79	136	519
21.00	42	93	54	104	60	35	98	142	628
22.00	32	106	90	111	71	69	148	176	803
23.00	58	185	133	167	137	118	192	253	1243
Totals	505	1454	972	1556	966	892	1739	2135	10219

Table 5.2

Emergency Incidents: Classified by Type of Vehicle Used

Type of Vehicle	Type of Incident											
	1	% of Total	3	% of Total	6	% of Total	7	% of Total	8	% of Total	Total	% of Total
Vhf	514	54.0	190	7.0	681	15.4	22	42.3	281	13.5	1688	16.5
Panda	437	46.0	2537	93.0	3732	84.6	30	57.7	1795	86.5	8531	83.5
Totals	951	100.0	2727	100.0	4413	100.0	52	100.0	2076	100.0	10219	100.0
% of Total	9.3		26.7		43.2		0.5		20.3		100.0	

Type.

1. Traffic.
3. Civil Assistance to Public .
6. Break-in, burglary, alarm, vehicle theft.
7. Severe assault, rape, serious crime.
8. Domestic.

vehicle remained at the same level as in 1969, with vhf vehicles providing initial attention for 1688 (17%) of the 10,219 incidents and panda vehicles attending to the remaining 83% .

The proportion of each type of incident dealt with by vhf and panda vehicles also remained the same with the exception of the type 7 incidents for which there was a 20% increase in those initially dealt with by panda vehicles. However these incidents only accounted for 0.5% of all emergency incidents.

A detailed breakdown of the vhf vehicles used, included in Table 5.3, shows that special incident squad and dog section vehicles were initially despatched to only 20 incidents, a significant reduction when compared with the figure of 91 recorded in 1969. M division patrol cars were despatched to 1665 of the other 1668 incidents, and M division motor cycles attended the remaining 3 incidents.

5.1.2.2 Vehicle Availability

Vhf Vehicles

The original intention for the study of vhf vehicles was to collect information for the fortnight 1st February until 14th February. A malfunction in the H.Q. Control Room memory unit necessitated a change in the original plans. Finally a fortnight's consecutive data was obtained for the period 12th February until 25th February. No cross-checking on the data was possible (see section 4.4).

The diurnal variations in the average number of available patrol cars, and of available patrol cars, motor cycles, serious incident squad and dog section vehicles are shown in Figure 5.2. The number of patrol cars available varied between 7 at 03.00 and 31 at 23.00 with an average of 15. The total number of available vhf vehicles in the above classes varied between 9 at 03.00 and 41 at 23.00 with an average of 20.

Table 5.3

Vhf Vehicles Used: Classified by Division of Incident

Division of Incident	M Division Motor Patrol Cars	M Division Motor Cycle Patrols	Special Incident Squad Vehicles	Dog Section Vehicles	Total
A	69	-	-	-	69
B	284	-	-	1	285
C	173	1	-	5	179
D	173	-	-	3	176
E	212	1	1	2	216
F	148	1	-	2	151
G	267	-	-	5	272
H	339	-	-	1	340
Totals	1665	3	1	19	1688

Figure 5.2.

AVAILABLE VHF VEHICLES : CLASSIFIED BY HOUR OF DAY

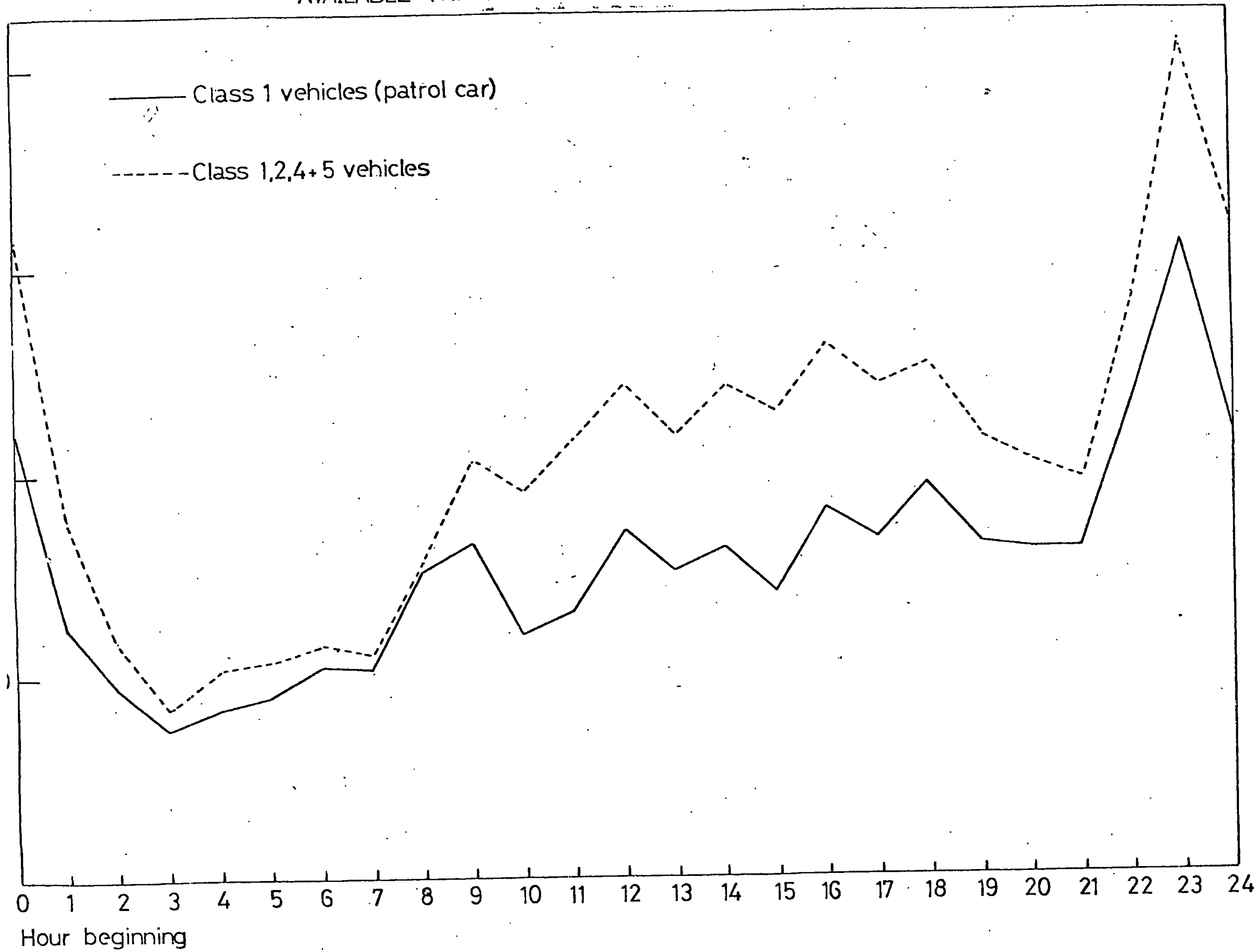


Table 5.4

Vhf Vehicles on Patrol: Classified by Hour of Day

Hour beginning	Class				Total
	Motor Patrol Cars	Motor Cycles	Serious Incident Squad	Dog Section	
00.01	22.0	-	3.1	6.3	31.4
01.00	12.6	-	1.9	3.3	17.8
02.00	9.5	-	0.7	1.5	11.7
03.00	7.4	-	0.6	0.6	8.6
04.00	8.4	-	1.1	0.8	10.3
05.00	8.9	-	1.1	0.8	10.8
06.00	10.4	-	0.5	0.7	11.6
07.00	10.3	-	0.4	0.3	11.0
08.00	15.1	-	0.3	0.3	15.7
09.00	16.4	2.1	1.5	0.5	20.5
10.00	12.0	2.3	3.2	1.5	19.0
11.00	13.3	1.9	3.1	3.3	21.6
12.00	16.9	1.4	2.9	3.1	24.3
13.00	14.9	2.4	3.0	1.5	21.8
14.00	16.2	2.4	3.4	2.3	24.3
15.00	13.9	2.3	4.0	2.6	22.8
16.00	17.9	2.4	3.6	2.4	26.3
17.00	16.5	2.4	4.0	1.4	24.3
18.00	19.2	1.2	3.2	1.6	25.2
19.00	16.2	0.5	2.4	2.6	21.7
20.00	16.1	0.1	1.6	2.6	20.4
21.00	16.0	-	1.9	1.6	19.5
22.00	23.1	-	2.2	3.1	28.4
23.00	30.9	-	3.1	6.9	40.9
Overall	15.2	0.9	2.2	2.1	20.4

All figures averaged over fortnight.

A divisional breakdown of the total patrol time by patrol cars is included in Table 5.5. This shows that the patrol time was fairly uniformly distributed over the divisions.

Table 5.5

Available Patrol Car Time: Classified by Division

Division	Patrol Hours	% of Total
A	518	11.5
B	588	13.0
C	628	13.9
D	496	11.0
E	676	15.0
F	553	12.2
G	594	13.1
H	466	10.3
Totals	4519	100.0

Panda Vehicles

The study of panda vehicles was carried out as planned during the first fortnight in February. When it had been completed it was found that the returns were not complete and further information was collected during the immediately following period 15th to 25th February for the sub-divisions whose original returns had been incomplete.

It had been thought that the introduction of a regular procedure for recording panda vehicle location and state (see section 4.3) would lead to an improved return rate and this belief was supported by a return rate of 83% during the original fortnight.

The hourly variation in the average number of panda vehicles on patrol is shown in Figure 5.3. The number of available panda vehicles varied between 27 at 02.00 and 74 at 22.00 with an average of 53. Low availability figures at 02.00, 10.00, and 18.00 were found to correspond with high figures for refreshments.

For beat policing purposes the original 22 sub-divisions of 1969 were still recognised, and each sub-division was split up into a number of unit or rural beats. Table 5.7 details the 126 unit and rural beats that were used.

Table 5.7

Panda Vehicle Beats: Classified by Division

Division	Type of Beat		Total
	Unit	Rural	
A	10	9	19
B	15	-	15
C	16	-	16
D	14	-	14
E	10	6	16
F	14	-	14
G	16	2	18
H	14	-	14
Totals	109	17	126

Full coverage of these beats required at least one panda vehicle on duty in each. Because of such factors as illness and rest days leading to manpower shortages there were occasions when one panda vehicle was given

Figure 5.3

AVAILABLE PANDA CARS : CLASSIFIED BY HOUR OF DAY

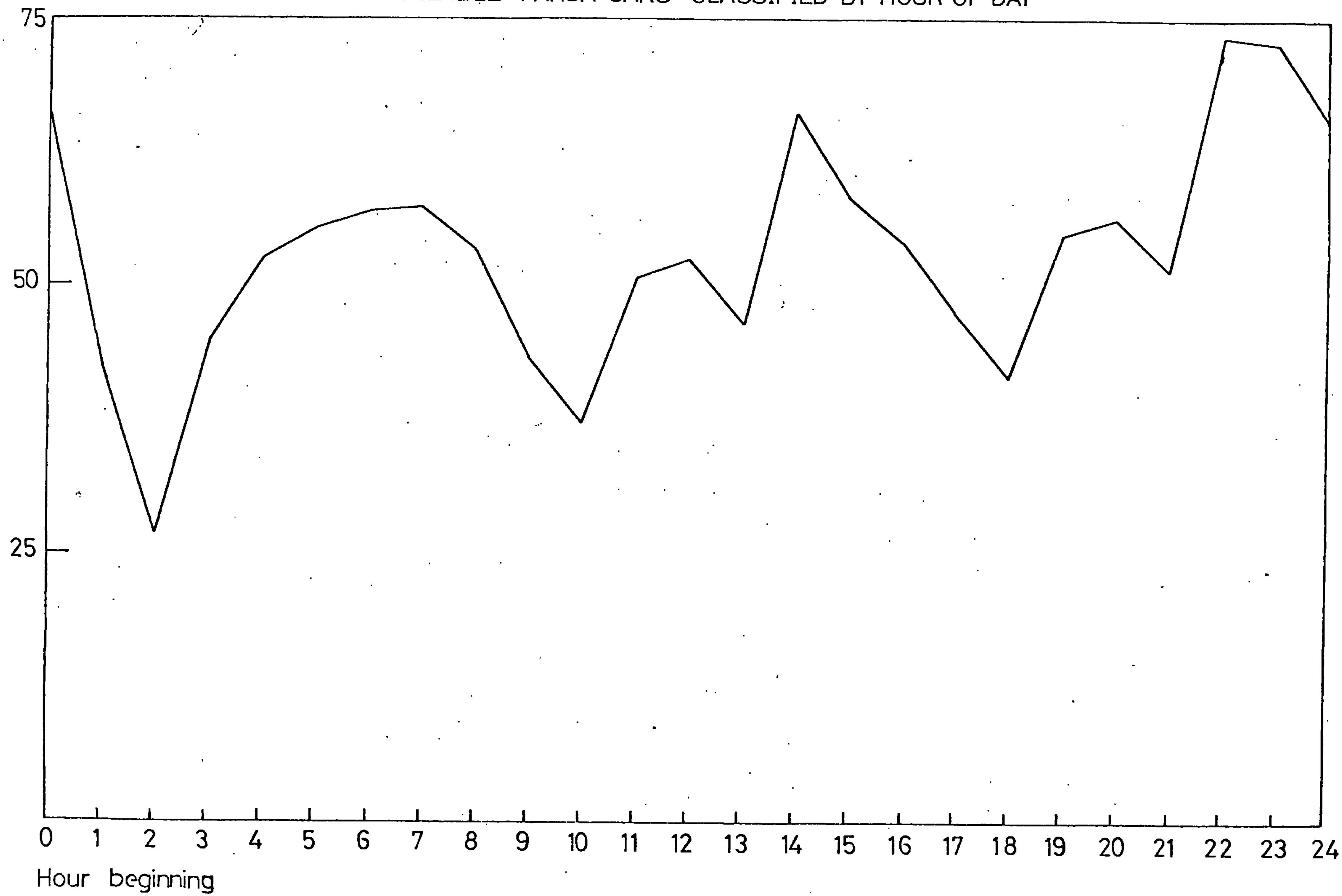


Table 5.6

Panda Vehicles on Patrol: Classified by Hour of Day

Hour beginning	Day of Week							Overall
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
00.01	59.2	64.7	66.3	73.4	63.7	57.4	75.0	65.7
01.00	40.3	39.0	46.3	44.3	45.4	41.9	39.3	42.3
02.00	25.7	26.0	31.6	29.3	23.9	26.0	26.3	26.9
03.00	38.8	42.0	48.6	49.4	50.5	42.0	43.2	44.9
04.00	47.0	54.0	52.0	56.5	53.4	51.5	53.7	52.6
05.00	54.8	56.0	50.8	55.9	62.6	59.0	49.2	55.4
06.00	55.7	54.8	55.0	56.3	56.6	62.0	58.5	57.0
07.00	55.7	54.8	54.5	53.3	62.0	66.5	54.5	57.3
08.00	50.5	49.5	50.7	54.0	58.0	61.5	51.5	53.7
09.00	46.0	40.5	39.8	41.0	41.0	45.0	50.5	43.4
10.00	44.0	35.0	37.0	32.5	39.0	33.5	40.0	37.3
11.00	52.0	45.8	52.0	50.3	51.0	51.0	53.5	50.8
12.00	47.2	51.2	52.0	55.0	43.5	62.0	56.5	52.5
13.00	40.2	47.0	45.3	48.8	44.5	52.5	47.0	46.5
14.00	62.5	70.1	73.3	71.4	57.5	66.2	64.0	66.4
15.00	53.7	62.0	63.3	62.7	53.5	57.8	56.0	58.5
16.00	49.2	61.1	56.7	52.3	53.5	48.6	61.0	54.6
17.00	46.3	49.1	47.3	47.0	43.5	50.5	51.5	47.9
18.00	36.3	40.5	42.7	45.1	42.0	42.3	42.5	41.7
19.00	56.8	51.3	55.1	58.5	51.0	56.2	56.0	55.0
20.00	52.0	55.2	55.0	59.2	54.5	52.0	67.0	56.4
21.00	50.7	49.3	52.1	53.5	46.5	55.1	53.5	51.6
22.00	66.3	74.2	71.4	77.1	75.1	76.4	74.0	73.5
23.00	71.2	74.4	74.0	81.7	67.2	72.3	70.0	73.0
Overall	48.8	52.0	53.0	54.5	51.6	53.7	53.9	52.7

All figures averaged over fortnight.

the task of patrolling more than one beat. Further not all beats were patrolled for 24 hours a day, particularly in rural areas, and in some urban areas one double crewed unit beat panda vehicle was used to patrol a combined beat rather than having two single crewed vehicles patrolling separate beats.

Panda vehicle coverage was defined as the percentage of panda vehicles that were on duty (in states 1 to 7) at any time. Coverage of 100% corresponded to 126 panda vehicles on duty. Figure 5.4 illustrates the hourly variation in average panda vehicle coverage, which was maintained at 75% except during the eight hour period 01.00 to 09.00 when it dropped to just under 60%, and averaged 70%.

The hourly variation in emergency incidents per panda vehicle on duty is shown in Figure 5.5. The emergency incident loading per panda vehicle varied between .014 at 05.00, or 71 vehicles for every incident, and .151 at 23.00, 7 vehicles per incident, with an average of .056. (Compare the loading in Lancaster, see section 1.1.3).

A breakdown of panda vehicle duty time classified by availability state and division is included in Table 5.10. This shows that the three main components of total duty time were patrolling at 60%, details at 13%, and refreshments at 10% . Attending to incidents, both emergency and background, accounted for 6% of the total. (A comparable breakdown of patrol car duty time is included in H.A. Taylor (21)). It also shows that the breakdown of panda vehicle duty time varied considerably between divisions. Thus in D division the proportion of time spent on patrol was 75% whereas in E division the proportion was 46%. The proportion of time spent dealing with incidents varied even more widely between 1.9% in E division and 12.3% in G division, a figure in excess of twice the average proportion of 6.1%. This was partly offset by the

Figure 5.4

PANDA VEHICLE COVERAGE: CLASSIFIED BY HOUR OF DAY

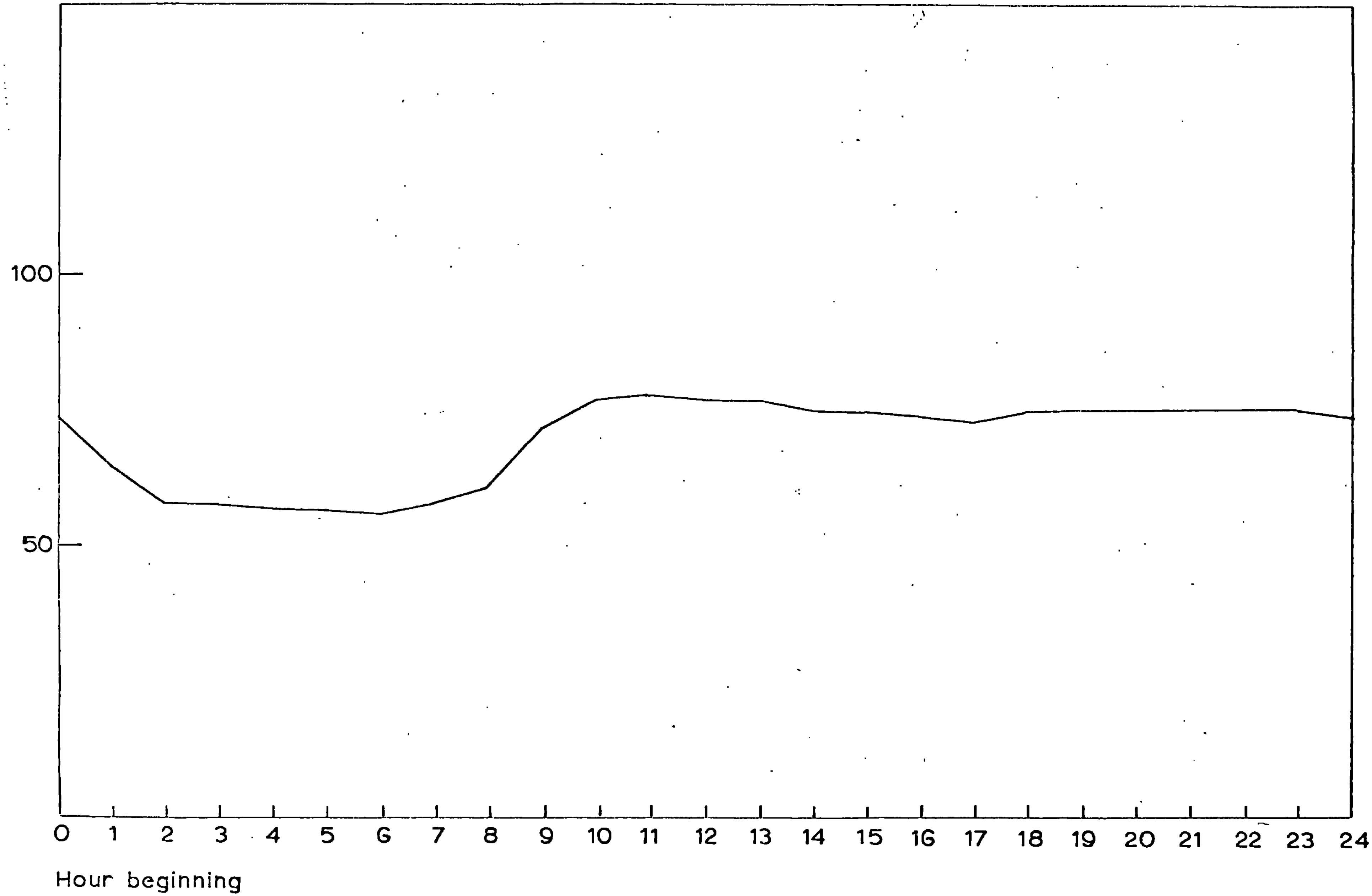


Table 5.8

Panda Vehicle Coverage: Classified by Hour of Day

Hour beginning	Panda Vehicles on Duty (Average)	% Coverage
00.01	92.7	73.6
01.00	82.0	65.1
02.00	73.1	58.0
03.00	73.0	57.9
04.00	72.1	57.2
05.00	71.8	57.0
06.00	70.1	55.6
07.00	73.3	58.2
08.00	76.2	60.5
09.00	91.1	72.3
10.00	97.2	77.1
11.00	97.6	77.5
12.00	97.2	77.1
13.00	96.6	76.7
14.00	93.9	74.5
15.00	95.0	75.4
16.00	93.4	74.1
17.00	92.3	73.3
18.00	94.1	74.7
19.00	94.5	75.0
20.00	94.5	75.0
21.00	93.9	74.5
22.00	94.2	74.8
23.00	94.5	75.0
Overall	2104.3	69.6

Figure 5.5

EMERGENCY INCIDENTS PER PANDA VEHICLE: CLASSIFIED BY HOUR OF DAY

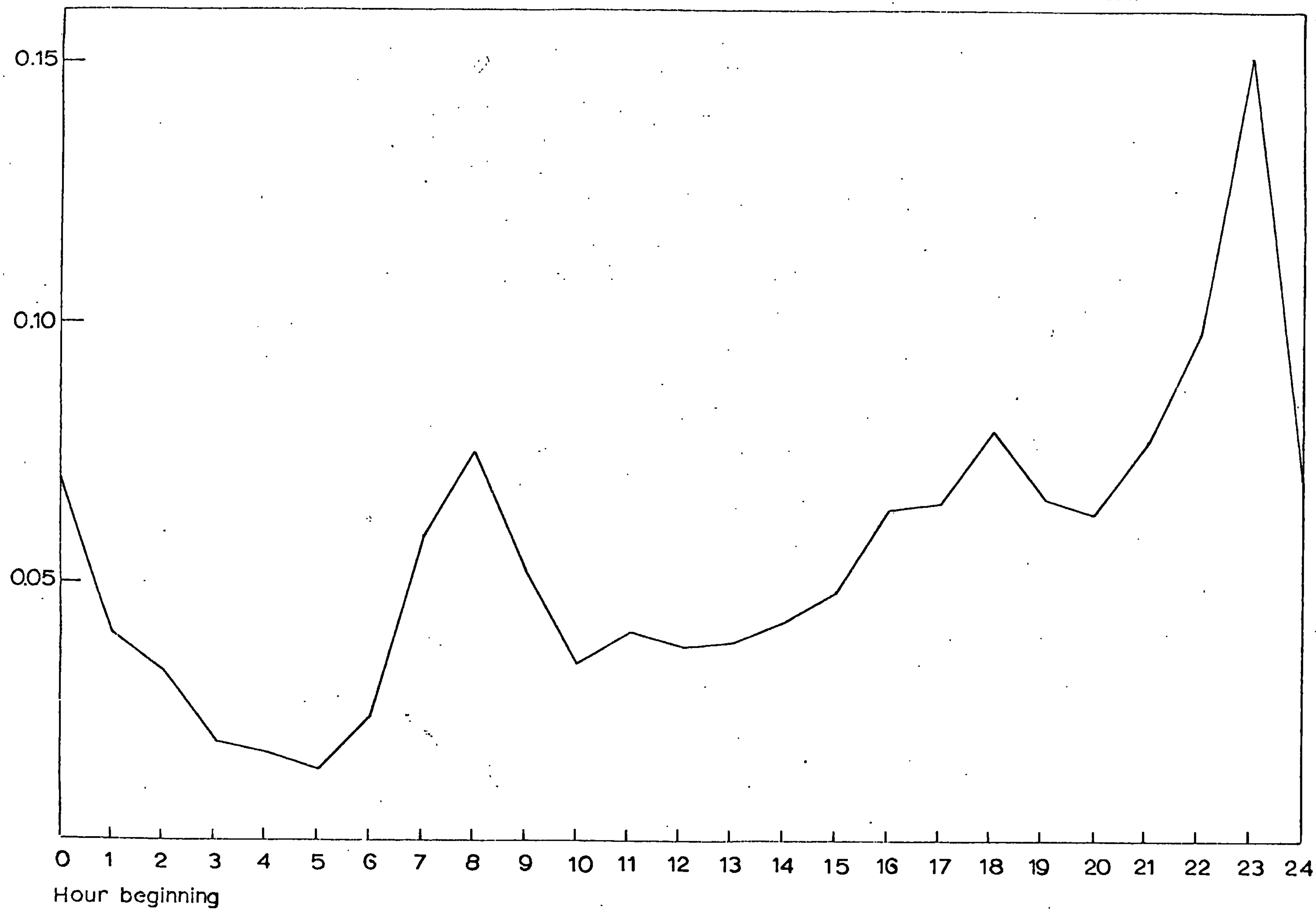


Table 5.9

Emergency Incidents per Panda Vehicle:

Classified by Hour of Day

Hour beginning	Emergency Incidents (Daily Average)	Panda Vehicles on Duty (Average)	Emergency Incidents per Panda Vehicle
00.01	6.5	92.7	.070
01.00	3.3	82.0	.040
02.00	2.4	73.1	.033
03.00	1.4	73.0	.019
04.00	1.2	72.1	.017
05.00	1.0	71.8	.014
06.00	1.7	70.1	.024
07.00	4.3	73.3	.059
08.00	5.7	76.2	.075
09.00	4.7	91.1	.052
10.00	3.3	97.2	.034
11.00	3.9	97.6	.040
12.00	3.6	97.2	.037
13.00	3.7	96.6	.038
14.00	3.9	93.9	.042
15.00	4.6	95.0	.048
16.00	6.0	93.4	.064
17.00	6.0	92.3	.065
18.00	7.4	94.1	.079
19.00	6.2	94.5	.066
20.00	6.0	94.5	.063
21.00	7.2	93.9	.077
22.00	9.2	94.2	.098
23.00	14.3	94.5	.151
Overall	117.5	2104.3	.056

Table 5.10

Panda Vehicle Duty Time: Classified by Division

Division	Availability State							Total
	1	2	3	4	5	6	7	
A	125.6	6.5	19.0	19.2	14.4	3.5	0.1	188.3
% of Total	66.7	3.5	10.1	10.2	7.6	1.9	-	100.0
B	131.0	12.0	21.5	22.7	45.1	19.8	1.2	253.3
% of Total	51.7	4.7	8.5	9.0	17.8	7.8	0.5	100.0
C	183.7	13.0	18.2	32.8	35.5	3.5	0.5	287.2
% of Total	64.0	4.5	6.3	11.4	12.4	1.2	0.2	100.0
D	237.7	9.2	4.4	35.9	26.4	3.9	1.1	318.6
% of Total	74.6	2.9	1.4	11.3	8.3	1.2	0.3	100.0
E	95.7	4.0	33.7	23.2	43.3	9.7	0.4	210.0
% of Total	45.6	1.9	16.0	11.0	20.6	4.6	0.2	100.0 *
F	170.5	12.9	17.2	25.0	19.0	2.2	0.6	247.4
% of Total	68.9	5.2	7.0	10.1	7.7	0.9	0.2	100.0
G	180.6	39.5	21.0	37.8	36.8	3.9	2.0	321.6
% of Total	56.2	12.3	6.5	11.8	11.4	1.2	0.6	100.0
H	140.1	31.5	12.6	27.4	54.2	11.6	0.5	277.9
% of Total	50.4	11.3	4.5	9.9	19.5	4.2	0.2	100.0
Totals	1264.9	128.6	147.6	224.0	274.7	58.1	6.4	2104.3
% of Total	60.1	6.1	7.0	10.6	13.1	2.8	0.3	100.0

All times in hours per day

* - state percentages for E division total to 99.9 because of round-off error.

State.

1. On Patrol
2. Incident
3. Standby
4. Refreshments
5. Detail
6. Not Available
7. Court.

proportion of time spent on details which varied between 21% for E division and 8% for A division. The combined proportion of time spent dealing with incidents and on details varied from 31% for H division to 11% for A division.

The divisional breakdown of emergency incidents per hour panda vehicle duty time is included in Table 5.11.

Table 5.11

Emergency Incidents per Panda Vehicle Duty Hour:

Classified by Division

Division	Emergency Incidents (Daily Average)	Panda Vehicle Duty Hours (Daily Average)	Emergency Incidents per Panda Vehicle Duty Hour
A	5.8	188.3	.031
B	16.7	253.3	.066
C	11.2	287.2	.039
D	17.9	318.6	.056
E	11.1	210.0	.053
F	10.3	247.4	.042
G	20.0	321.6	.062
H	24.5	277.9	.088
Overall	117.5	2104.3	.056

This shows that the emergency incident loading per panda vehicle duty hour varied between H division with a loading of .088, or an emergency incident every 11 hours of duty time, and A division with a loading of .031, an emergency incident every 32 hours of panda vehicle duty time, which is one incident in four shifts. Overall the loading was at a level of one emergency incident every 18 hours duty time.

Panda vehicle coverage, shown for the county as a whole in Figure 5.4, is broken down by division in Table 5.12. This shows that the coverage varied between 41% in A division with 9 rural beats and 10 unit beats, and 95% in D division with 14 unit beats and no rural beats. The overall figure, for 109 unit beats and 17 rural beats, was 70%.

Table 5.12

Panda Vehicle Coverage: Classified by Division

Division	Panda Vehicle Duty Hours (Daily Average)	Beats	Maximum Duty Hours (Daily)	% Coverage
A	188.3	19	456	41.3
B	253.3	15	360	70.4
C	287.2	16	384	74.8
D	318.6	14	336	94.8
E	210.0	16	384	54.7
F	247.4	14	336	73.6
G	321.6	18	432	74.4
H	277.9	14	336	82.7
Overall	2104.3	126	3024	69.6

No Car Available

'No car available' was recorded for 789 (8%) of the 10,219 emergency incidents, an average daily rate of 9.1 incidents, which was an increase of 38% on the 1969 level. The diurnal variation in the number of these incidents is illustrated in Figure 5.6.

Comparison with the corresponding figure for 1969, Figure 3.4, shows that high values of 'no car available' were recorded at 02.00, 07.00, and 23.00 for both years.

Figure 5.6

NO CAR AVAILABLE INCIDENTS: CLASSIFIED BY HOUR OF DAY

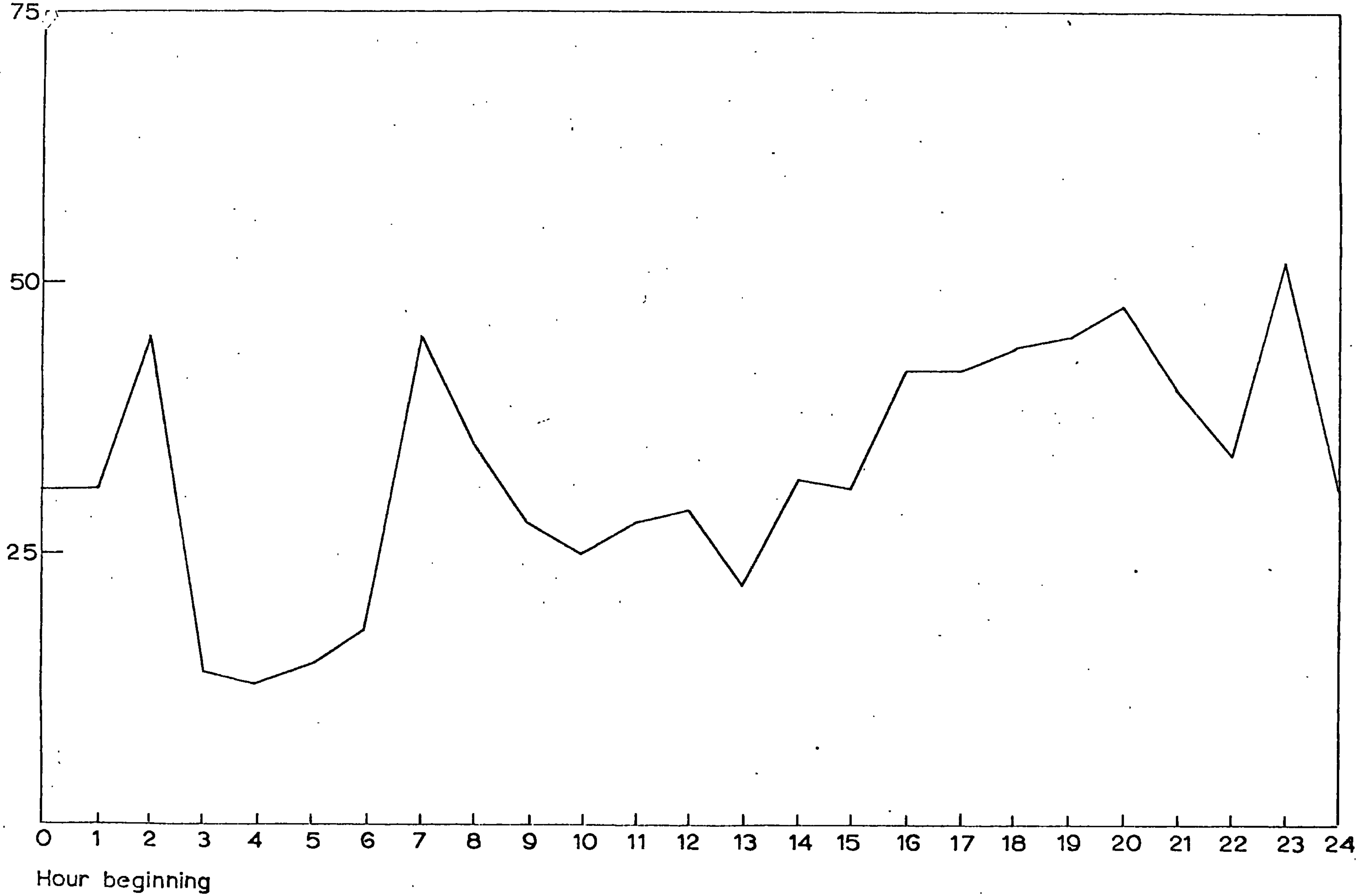


Table 5.13

No Car Available Incidents: Classified by Hour of Day

Hour beginning	Division								Total
	A	B	C	D	E	F	G	H	
00.01	1	2	5	6	4	5	2	6	31
01.00	2	11	3	4	2	2	4	3	31
02.00	3	1	10	9	2	9	7	4	45
03.00	1	3	-	2	2	1	2	3	14
04.00	1	3	1	1	1	2	3	1	13
05.00	-	4	1	4	-	-	5	1	15
06.00	-	5	-	3	1	-	2	7	18
07.00	2	11	4	3	3	7	6	9	45
08.00	3	7	5	4	2	6	7	1	35
09.00	2	4	5	5	3	4	3	2	28
10.00	1	5	2	-	7	2	7	1	25
11.00	2	3	5	5	4	1	6	2	28
12.00	-	2	6	6	2	3	9	1	29
13.00	1	2	2	3	2	2	3	7	22
14.00	1	6	3	5	2	4	9	2	32
15.00	1	6	4	3	3	3	6	5	31
16.00	-	5	3	4	7	8	11	4	42
17.00	2	6	4	7	5	5	6	7	42
18.00	3	11	3	9	4	4	3	7	44
19.00	4	11	6	3	4	6	5	6	45
20.00	-	8	7	7	5	2	8	11	48
21.00	3	6	7	9	7	1	3	4	40
22.00	1	6	4	3	5	7	5	3	34
23.00	3	4	14	5	3	6	9	8	52
Totals	37	132	104	110	80	90	131	105	789

5.1.2.3 Response Time

Arrival time for all incidents was recorded on the H.Q. Control Room message form. Despatch time for the vehicle attending an incident could be obtained from the H.Q. form if a vhf vehicle had been used or from the corresponding divisional form if a panda vehicle had been used. Complete response time information for any incident could be obtained either directly from the H.Q. form for incidents that had been dealt with by vhf vehicles, or indirectly by correlating the time of receipt and time of arrival from the H.Q. form with the time of despatch from the divisional form for incidents dealt with by panda vehicles.

The correlation of H.Q. and divisional forms was time consuming and a system of sampling was used for the analysis of complete response time information. Three ten-day sample periods, each involving approximately 1000 incidents, were used. These were the first, middle and last ten days of the three month study period.

For some incidents full response time information was not available, either because despatch time had not been recorded on the appropriate form, or because the call did not require attention, being informative or historic in nature and not suitable for the emergency service. The latter accounted for about 5% of all calls.

There were some incidents which the division or sub-division had been aware of before the relevant 999 call had been received at H.Q. Control Room, for which the time of despatch and sometimes the time of arrival were earlier than the time of receipt of the call. These incidents were eliminated from the response time sample.

The three sample periods were as follows, 4th to 13th January, 13th to 22nd February, and 22nd to 31st March. After statistical analysis of the characteristics of each period (see section 5.2, below) the three sample periods were combined to give a thirty day response time sample period. There were 3424 incidents in this period, of which 2742 (80%) had complete response time information (that is, time of despatch and time of arrival) and 3276 (96%) had response time information (arrival time only).

A breakdown of response characteristics by type of vehicle is contained in Table 5.14, and a breakdown of response time by division is included in Table 5.15.

Table 5.15

Response Time: Classified by Division

Division	Type of Vehicle				Overall	
	Vhf		Panda			
	Mean	Sample Size	Mean	Sample Size	Mean	Sample Size
A	7.5	21	9.7	136	9.4	157
B	7.2	94	10.6	372	9.9	466
C	8.5	64	9.1	243	9.0	307
D	7.2	56	7.5	458	7.5	514
E	7.0	84	12.0	246	10.7	330
F	7.9	51	11.0	232	10.4	283
G	7.2	101	9.4	453	9.0	554
H	7.3	119	9.2	546	8.9	665
Overall	7.4	590	9.6	2686	9.2	3276

All times in minutes

This shows that the vhf vehicle response time performance was uniform over the divisions while the panda vehicles showed a greater degree of variation between a mean of 7.5 minutes in D division and

Table 5.14

Response Characteristics: Classified by Type of Vehicle

Type of Vehicle	Handling Time				Travelling Time				Response Time			
	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size
Vhf	1.6	1.8	.076	585	5.7	5.0	0.21	585	7.4	5.6	0.23	590
Panda	4.1	4.5	.097	2157	4.9	3.9	.084	2157	9.6	8.4	0.16	2686
Overall	3.6	4.2	.080	2742	5.1	4.2	.080	2742	9.2	8.0	0.14	3276

All times in minutes

12.0 minutes in E division, in marked contrast to the situation observed in 1969 (see Table 3.8).

The significance of the changes in handling time, travelling time, and response time between 1969 and 1970 are considered in section 5.2 below.

There were 6795 incidents in the 57 non-sample days of the study. As despatch time information was not generally available for these incidents only response time could be obtained. The uncorrelated data required detailed study to eliminate errors. For example, when the data was first analysed it was found that for 18 incidents the arrival time preceded the time of receipt of the call.

The response time breakdown by type of vehicle for this period is included in Table 5.16. 54 (.08%) incidents had a response time in excess of one hour (compared with 15 (.04%) for the sample period) and 422 incidents (6%) had no arrival time.

Table 5.16

Non-Sample Response Time: Classified by Type of Vehicle

Type of Vehicle	Response Time			
	Mean	Standard Deviation	Standard Deviation of Mean	Sample Size
Vhf	7.6	6.4	0.19	1087
Panda	10.2	11.9	0.16	5286
Overall	9.8	11.2	0.14	6373

All times in minutes

Long Delays

Mean response time in itself does not indicate the incidence of long response times. Two aspects of long response times were considered. First the proportion of incidents with response times in excess of twenty minutes, and secondly the qualitative characteristics of very long response times which were taken to be those in excess of one hour. Table 5.17 contains a breakdown of responses in excess of twenty minutes for each of the sample periods.

Table 5.17

Proportion of Response Times in excess of Twenty Minutes: Classified by Sample Period

Sample Period	Proportion of Response Times in excess of 20 Minutes	% Improvement on 1969
1969	.084	-
First 1970	.076	10
Second 1970	.052	38
Third 1970	.052	38
Total 1970	.059	30
Non-Sample 1970	.071	15

A 30% improvement in this aspect of police emergency response is indicated by these figures. It may be noted that the non-sample period is seen to be appreciably different to the sample period and that the first sample period is considerably different to the other two.

There were 15 (.04%) incidents for which response time exceeded one hour during the thirty day sample period. For ten of these no divisional message form was available. The type/sequel records for these incidents showed that they were either of the assistance to public or domestic type with no police action required, or burglaries and break-ins which had already been executed and required C.I.D. rather than immediate attention.

Of the five incidents with divisional message forms available, two involved break-ins and did not require rapid attention, and a third involved a broken-down car and required enquiries to be made at taxation and regional crime offices before any action could be taken. A fourth involving a patrol car appeared to have a time error of one hour which could not be checked. The remaining call involved a domestic incident reported at 15.47 which did not receive attention until 17.49. A note on the divisional message form explained that all police personnel in the area were involved in an active search in an effort to apprehend the persons responsible for a jewellery theft earlier that afternoon.

5.1.2.4 Other Aspects of the Response Function

Handling of Incoming Calls in H.Q. Control Room

The hourly variations in the number of 999 calls handled by H.Q. Control Room inspector and sergeant are shown in Figure 5.7. Compared with the situation in 1969 (see Figure 3.8) the inspector handled slightly more calls, with a daily average of 7.8 calls, and a peak rate at 23.00 of 0.9 calls an hour. The sergeant handled slightly fewer calls with a daily average of 12.2 (compared with 13.3 in 1969) and the peak rate was reduced to 1.4 calls an hour (from 1.7) at 21.00.

Multiple Vhf Vehicle Response

Of the 1688 incidents at which vhf vehicles arrived first,

Figure 5.7

EMERGENCY CALLS HANDLED BY H.Q. CONTROL ROOM INSPECTOR+SERGEANT: CLASSIFIED BY HOUR OF DAY

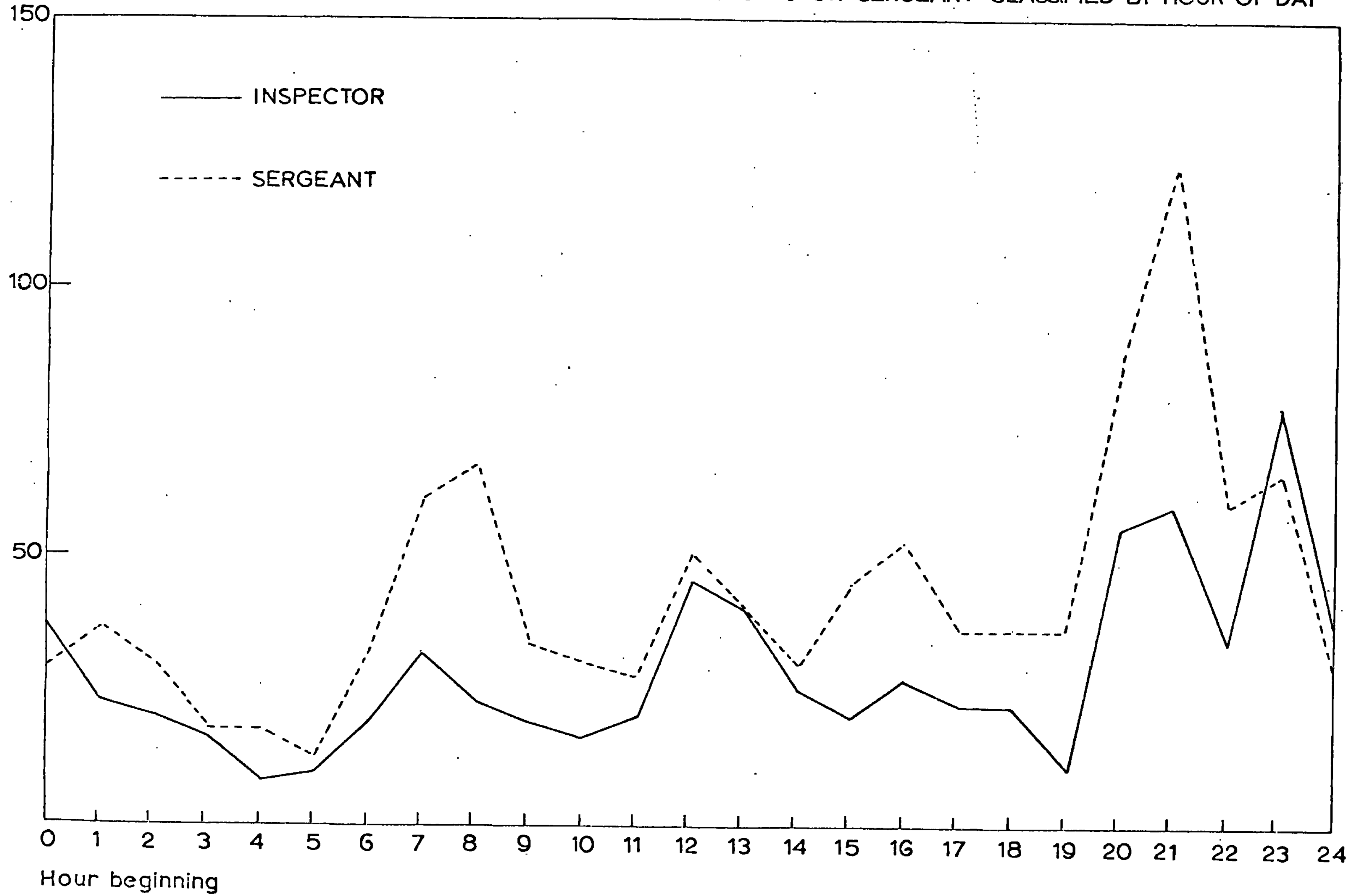


Table 5.18

Emergency Calls Handled by H.Q. Control Room Personnel:

Classified by Hour of Day

Hour beginning	H.Q. Control Room Personnel			Total
	Inspector	Sergeant	Others	
00.01	37	30	498	565
01.00	23	37	228	288
02.00	20	30	158	208
03.00	16	18	92	126
04.00	8	18	80	106
05.00	10	13	67	90
06.00	19	33	95	147
07.00	32	61	277	370
08.00	23	67	410	500
09.00	19	34	357	410
10.00	16	31	236	283
11.00	20	28	291	339
12.00	45	51	214	310
13.00	40	40	241	321
14.00	25	30	283	338
15.00	20	45	338	403
16.00	27	53	438	518
17.00	22	37	461	520
18.00	22	37	584	643
19.00	10	37	494	541
20.00	55	86	378	519
21.00	59	123	446	628
22.00	34	60	709	803
23.00	78	66	1099	1243
Totals	680	1065	8474	10219

140 (8%) were attended by more than one vhf vehicle compared with 20% in 1969. The breakdown, by type, of incidents for which more than one vhf vehicle was in attendance is included in Table 5.19.

Table 5.19

Multiple Vhf Vehicle Attendance: Classified by Type of Incident

Type of Incident	Attended by Vhf Vehicle		% with Multiple Attendance
	Single Attendance	Multiple Attendance	
1	514	55	10.7
3	190	8	4.2
6	681	41	6.0
7	22	5	22.7
8	281	31	11.0
Overall	1688	140	8.3

This shows that the type 7 incidents had the highest proportion of multiple vhf vehicle attendance (23%), although this represented a 50% reduction on the 1969 figure of 46% (see Table 3.12).

Multiple Despatch of Vehicles

For some emergency incidents more than one vhf vehicle was known to have attended the scene (see above). The number and types of vehicles that were despatched to an emergency incident depended upon the judgement of H.Q. Control Room personnel.

In order to investigate this aspect a detailed analysis was undertaken of the 713 emergency calls received by H.Q. Control Room in the week 5th to 11th January. Vehicle despatching information was available for 695 (97%) of these calls. For each call there was available a coded copy of the H.Q. Control Room message form and for most calls (79%) there was in addition a divisional form.

Incidents were classified into the same four main types, traffic accidents (type 1), offences against property (including auto alarms) (type 6), disturbances (type 8), and miscellaneous aids to public (type 3), but where divisional forms were available a rough classification was made into calls apparently requiring immediate attention (for example, intruders on premises, trouble outside pub) and those reporting past occurrences (for example, a break-in) or requiring aid (for example, sudden death).

Responses to calls were

(a) to despatch one or more vhf vehicles,

(b) to despatch one or more vhf vehicles and also one or more panda vehicles,

(c) to seek a vhf vehicle, and, not finding one, record 'no car available' and subsequently despatch one or more panda vehicles,

(d) to despatch one or more panda vehicles.

Table 5.20 contains a breakdown of the response to all calls. A more detailed breakdown by type of incident is included in Table 5.21. The overall figures for the full three month study show similar proportions of incident types (9.3%, 43.2%, 20.3%, and 26.7% respectively) and so these figures were taken to be representative.

Divisional Non-999 Workload

In addition to dealing with emergency incidents in their area, notified to divisions by the public via H.Q. Control Room, divisional panda vehicles are required to respond to additional non-generated incidents, which are notified directly to the divisional police. The

Table 5.20

H.Q. Control Room Vehicle Despatching Policy: Classified by Urgency of Call

Urgency of Call	Type of Vehicle Despatched				Total
	Vhf	Vhf and Panda	'No Car Available' Panda	Panda	
Immediate Attention	47 (10)	73 (19)	61 (10)	174 (29)	355 (68)
Reporting Offence or Aid Required	3	1	5	187 (10)	196 (10
No Details	32 (4)	-	11	101 (1)	144 (5)
Totals	82 (14)	74 (19)	77 (10)	462 (40)	695 (83)

Number in ( ) refers to calls to which more than one vhf or panda vehicle was despatched.

Table 5.21

H.Q. Control Room Vehicle Despatching Policy: Classified by Type of Incident

Type of Incident	Type of Vehicle Despatched				Total
	Vhf	Vhf and Panda	'No Car Available' Panda	Panda	
Traffic	26 (7)	27 (6)	16 (3)	11 (2)	80 (18)
Theft:					
Immediate Alarm	14 (2)	23 (3)	35 (6)	62 (9)	134 (20)
Immediate Other	1 (1)	9 (6)	3 (1)	12 (3)	25 (11)
Historic	2	1	4	90 (3)	97 (3)
No Details	23 (2)	-	10	48	81 (2)
Disturbance:					
Immediate	5	12 (4)	3	66 (11)	86 (15)
Historic	1	-	-	15 (2)	16 (2)
No Details	6 (2)	-	-	15	21 (2)
Miscellaneous:					
Immediate	1	2	4	23 (4)	30 (4)
Historic	-	-	1	82 (5)	83 (5)
No Details	3	-	1	38 (1)	42 (1)
Totals	82 (14)	74 (19)	77 (10)	462 (40)	695 (83)

Number in ( ) refers to calls to which more than one vhf or panda vehicle was despatched.

sources of these calls to divisional or sub-divisional control rooms are

(a) the public, either by telephone or in person,

(b) direct alarms from premises, and

(c) patrolling police personnel via personal radio, requesting assistance or information.

The work involved in dealing with these calls constitutes a demand on the panda vehicles which has to be satisfied, and which could affect the response provided when an emergency incident occurs in the division or sub-division.

In order to determine the level of activity represented by this non-999 workload the forms used for all messages (999, telephone, radio, or verbal) in divisional and sub-divisional control rooms were specially requested from all divisions for the week 11th to 17th January. It was found that this non-999 workload could be divided into

(i) administrative details, including dealing with stolen property, conveying hospital and other messages, making local enquiries, checking addresses, taking statements, and investigating beat complaints, none of which were of an urgent nature, and

(ii) urgent incidents, including calls which could quite possibly have been communicated by the emergency call service, and which required immediate attention.

The summary in Table 5.22 shows that during the week investigated there were a total of 1379 non-999 calls (telephone, radio, verbal) dealt with by the divisions directly. 263 (19%) of the calls were in the urgent category. Since there were 760 emergency calls during the same period the effective emergency workload on panda vehicles was increased by 35% when taking into account non-999 urgent incidents.

Table 5.22

Non-999 Incidents: Classified by Division

Division	Type of Incident		Total
	Administrative	Urgent	
A	52	9	16
B	175	29	204
C	128	35	163
D	99	40	139
E	218	31	249
F	118	29	147
G	151	36	187
H	175	54	229
Totals	1116	263	1379

The treatments given to the two types of non-999 incidents were compared using the available response time information. E division constituted the largest single divisional sample with 18% of the non-999 incidents and was used for this response comparison. Handling time was taken to be the most reliable measure of the treatment given to a non-999 incident as travelling time and response time would have been affected by subsequent diversion to other divisional activities.

The time information for type (i) incidents was found to be very patchy. Complete response time information was obtained for 122 (49%) of the 249 incidents in the sample. 27 (87%) of the 31 type (ii) incidents had complete information as opposed to only 95 (44%) of the 218 type (i) incidents. Handling time information was more fully available. 29 (94%) of the type (ii) incidents and 109 (50%) of the type (i) incidents had handling time information. A breakdown of the response characteristics by type of incident is included in Table 5.23.

Table 5.23

Handling Time and Response Time for Non-999 Incidents:

Classified by Type of Incident

Type of Incident	Handling Time		Response Time	
	Mean	Sample Size	Mean	Sample Size
Administrative	8.1	109	17.7	95
Urgent	1.9	29	6.2	27
Overall	6.8	138	15.2	122

All times in minutes

The corresponding response time mean for emergency incidents in E division was 12.0 minutes and the corresponding handling time mean for the whole county was 4.1 minutes. The figures included in Table 5.23 show that there was a considerable difference in the treatment that was given to the two types of non-999 incidents in terms of both handling time and response time performance.

Effect of 'No Car Available' on Response Characteristics

Response time information was available for 779 of the 789 incidents recorded as 'no car available'. 11 (1.4%) of these 779 incidents were subsequently attended by a vhf vehicle, the other 768 (98.6%) were attended by a panda vehicle. Table 5.24 includes the response characteristics for these 'no car available' incidents classified by type of vehicle. When compared with the overall response characteristics included in Table 5.14 it is seen that all panda vehicle characteristics were

Table 5.24

Response Characteristics for 'No Car Available' Incidents:

Classified by Type of Vehicle

Type of Vehicle	Handling Time			Travelling Time			Response Time		
	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size
Vhf	1.7	2.4	6	9.8	9.5	6	9.6	9.0	11
Panda	3.9	3.8	221	4.6	4.0	221	8.7	7.0	768
Overall	3.8	3.8	227	4.8	4.3	227	8.8	7.0	779

All times in minutes

improved for incidents with 'no car available'. The response time improvement (of 0.9 minutes from 9.6 to 8.7 minutes) was significant at the 5% level (t = 2.48). The vhf vehicle characteristics all exhibited a deterioration for incidents with 'no car available', handling time by 0.1 minutes, travelling time by 4.1 minutes and response time by 2.2 minutes. It is suggested that the travelling time change reflected the greater travelling distances involved for vhf vehicles despatched to an incident from another location.

Emergency Incident Sequel

A breakdown of emergency incidents by sequel is included in Table 5.25.

Table 5.25

Emergency Incidents: Classified by Sequel

Sequel	Type of Incident					Total
	1	3	6	7	8	
1	19	13	142	8	96	278
2	-	12	1749	34	20	1815
3	866	-	-	-	-	866
4	6	297	84	5	56	448
5	60	2405	2438	5	1904	6812
Totals	951	2727	4413	52	2076	10219

Of the 9268 non-traffic incidents, 2074 (22%) involved crimes, a similar situation to that observed in 1969 (see Table 3.13). The combined proportion of incidents with sequel 4 and 5 was 71% as in 1969, however the individual proportions had changed so that the proportion of sequel 4 incidents had fallen from 28% in 1969 to 4% in

1970, while correspondingly the proportion of sequel 5 incidents had risen from 43% to 67%. It is suggested that this change was probably caused by a change in coding, so that a sequel 4 incident, for example, a burst water main, was coded as sequel 5 (no police action required) although further action was necessary, rather than by a change in the nature of the incidents reported by emergemcy calls.

5.2 Comparisons of 1969 and 1970 Results

In this section the significance of the changes observed in various measurements between 1969 and 1970, and in some cases between sample periods in 1970, are considered. Specific measurements which were expected to be directly affected by the changes in operations subsequent to the 1969 findings (see sections 4.2 and 4.3) included

(1) the distribution of travelling time to emergency incidents for vhf vehicles,

(2) the distribution of handling time for emergency incidents attended by panda vehicles, and

(3) the number of incidents for which 'no car available' was recorded.

The distributions of vhf and panda vehicle response times were expected to be affected via the changes in (1) and (2) respectively.

5.2.1 Response Characteristics

For overall response time there were two comparisons to be made, the first between sample periods in 1970 and the second between a composite response time representative of 1970 and the corresponding quantity in 1969. Response characteristics for 1969 and 1970 are summarised in Tables 5.26 and 5.27 respectively.

Table 5.26

Response Characteristics. 1969

Handling Time			Travelling Time			Response Time		
Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size
5.1	6.2	783	6.0	7.1	783	11.1	10.0	783

All times in minutes

Table 5.27 shows that the response time variance of the combined sample periods was much smaller than the same quantity for the non-sample period. The data for the sample periods have been corrected by the correlation of H.Q. and divisional control room message forms and are free of the very large response times produced by errors in time entries, whereas these can still be present in the non-sample data. It is suggested that their removal has caused the slight reduction in mean (to 9.2 from 9.8) and the very large reduction in variance (to 64.1 from 125.2).

A consequence is that there is an unavoidable level of error incorporated in the non-sample data and for this reason the figures relating to the thirty day sample period alone are used in subsequent analysis.

The results of applying a t-test to the handling time, travelling time, and response time means for the three sample periods of 1970 are included in Table 5.28.

Table 5.27

Response Characteristics. 1970

Sample	Handling Time			Travelling Time			Response Time		
Period	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size
First	3.7	4.0	827	5.4	4.2	827	9.8	8.6	993
Second	3.6	4.2	916	5.0	4.4	916	8.9	7.3	1094
Third	3.5	4.4	999	4.9	4.0	999	8.9	7.8	1189
Total	3.6	4.2	2742	5.1	4.2	2742	9.2	8.0	3276
Non-Sample	-	-	-	-	-	-	9.8	11.2	6373

All times in minutes

Table 5.28

Calculated t-values for Comparison of 1970 Sample Period Response Characteristics

Samples Compared	Response Characteristic		
	Handling Time	Travelling Time	Response Time
First, Second	0.52	1.57	2.45*
Second, Third	0.31	0.68	0.28
First, Third	0.82	2.34*	2.69**

* - significant at 5% level
** - significant at 1% level .

A distinct trend of improvement in the three response characteristics through the sample periods is observed in Table 5.27. The t-values included in Table 5.28 show that the response time improvement between the first and second (from 9.8 to 8.9 minutes) and the first and third (from 9.8 to 8.9) sample periods, and the travelling time improvement between the first and third sample periods (from 5.4 to 4.9) were significant at the 5% level. The improvement in response time between the first and third samples was also significant at the 1% level.

Generally the properties of the first sample period were considerably different from those of the two later sample periods and it is possible that the working of the new organisation of motor patrols, which had only been operative for a month when the study (and the first sample period) began, improved during the course of the three months of the study.

For reasons explained above the sample periods were combined to provide response characteristic means for comparison with the corresponding quantities for 1969. The t-values obtained when the handling time, travelling time, and response time means for 1969 and 1970 were compared are included in Table 5.29.

Table 5.29

Calculated t-values for Comparison of 1969 and 1970 Response Characteristics

Samples Compared	Response Characteristic		
	Handling Time	Travelling Time	Response Time
1969, 1970	7.90***	4.70***	5.87***

*** --- significant at 0.1% level

All measures showed a highly significant (at 0.1% level) improvement in 1970 on the 1969 figures, handling time from 5.1 to 3.6, travelling time from 6.0 to 5.1, and response time from 11.1 to 9.2 minutes.

Response characteristics for 1969 and 1970 classified by type of vehicle are included in Table 5.30. The corresponding t-values obtained by comparing the two sets of means are included in Table 5.31.

Table 5.31

Calculated t-values for Comparison of 1969 and 1970 Response Characteristics: Classified by Type of Vehicle

Samples Compared	Response Characteristic		
	Handling Time	Travelling Time	Response Time
Vhf 1969, 1970	-0.79	3.11**	2.58**
Panda 1969, 1970	7.88***	3.83***	5.36***

Table 5.30

Response Characteristics for 1969 and 1970:

Classified by Type of Vehicle

Type of Vehicle	Response Characteristic		Year 1969	Year 1970
Vhf	Handling Time	Mean	1.5	1.6
		Standard Deviation	1.8	1.8
		Sample Size	143	585
	Travelling Time	Mean	7.5	5.7
		Standard Deviation	9.5	5.0
		Sample Size	143	585
	Response Time	Mean	9.0	7.4
		Standard Deviation	10.0	5.6
		Sample Size	143	590
Panda	Handling Time	Mean	5.9	4.1
		Standard Deviation	6.5	4.5
		Sample Size	640	2157
	Travelling Time	Mean	5.7	4.9
		Standard Deviation	6.4	3.9
		Sample Size	640	2157
	Response Time	Mean	11.6	9.6
		Standard Deviation	9.9	8.4
		Sample Size	640	2686

All times in minutes

These t-values show that the reduction in panda vehicle response time mean (from 11.6 to 9.6 minutes) was highly significant (at the 0.1% level) and was contributed to by a more highly significant improvement in handling time (from 5.9 to 4.1) and a slightly less highly significant improvement in travelling time (from 5.7 to 4.9 minutes).

The t-values also show that the improvement in vhf vehicle response time mean (from 9.0 to 7.4) was significant and could be attributed to a significant improvement in travelling time (from 7.5 to 5.7). Handling time showed a slight non-significant increase (from 1.5 to 1.6 minutes). This could possibly have been caused by the increased 'no car available' in 1970 and the need for extra interrogation of the H.Q. Control Room memory unit before a vhf vehicle could be despatched.

5.2.2 No Car Available

Between 1969 and 1970 the number of incidents for which 'no car available' was recorded increased both absolutely (daily average up from 6.6 to 9.1) and as a proportion of the total number of incidents (to 8% from 6%). In the same period the proportion of incidents for which a vhf vehicle was required increased (from 0.220 to 0.242). The diurnal variation of these incidents (see Figures 3.4 and 5.6) remained similar with the exception of large differences in the hours 03.00 to 04.00, 12.00 to 13.00, and 23.00 to 24.00.

The results of an analysis of variance on the 1969 and 1970 daily 'no car available' figures are included in Table 5.32.

Table 5.32

Analysis of Variance for Daily 'No Car Available'

in 1969 and 1970

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Variance Ratio
Between 1969 and 1970	1	257.71	257.71	15.34**
Among days of week within a year	12	201.60	16.80	1.11
Within Days of week	159	2410.08	15.16	
$F_{.05[12,159]} > F_{.05[12,\infty]} = 1.75$				

** - significant at 1% level.

The results of the analysis of variance included in Table 5.32 show that the variation among days of week within a year was not significant. For testing the variation between years the appropriate F-values were $F_{.05[1,11]} = 4.84$, $F_{.01[1,11]} = 9.65$, and $F_{.001[1,11]} = 19.69$. The increase in 'no car available' between 1969 and 1970 was significant at the 1% level.

CHAPTER VI

DISTRIBUTION OF POLICE MOBILE RESOURCES

Objectives and techniques of resource allocation in the police service were described in Chapter I. The purpose of this chapter is to review and extend previous work on allocation and scheduling of police resources in the light of the data from the 1969 and 1970 studies.

6.1 Objectives

Objectives can be specified for either of the two main approaches to optimal allocation of police resources, which are

1. allocation based on prevention, and
2. allocation based on response.

These approaches are related to a certain degree by the idea that any detections achieved as a result of pursuing objectives for the response function have a certain deterrent effect (of unknown magnitude), which is the basic objective of allocations based on the preventive function of police patrols.

The major example of work linking the two approaches is that of Lancaster (see section 1.2.2 and (4)) which seeks to combine results from both prevention and detection/response activities to provide a single measure of effectiveness to be optimised. Aspden and Chambers (27) subsequently performed this optimisation adopting a cost-effectiveness technique involving a mathematical programming model (see section 6.1.2 'Workload by Time').

6.1.1 Allocation based on Prevention

This approach is based on the idea that police patrols have a deterrent effect (see sections 1.1.1 and 1.1.2). The usual objective is to maximise the number of crimes prevented, with the assumption that certain combinations of patrols and circumstances (times, places) have the most beneficial deterrent effect. The constraints on the problem are the limitations on the amount of patrolling (for example, man-hours, cars) available.

Opportunities for prevention take into account local factors including

(a) population,

(b) area,

(c) population density,

(d) road mileage,

(e) traffic flow,

(f) rateable value, and

(g) retail trade statistics.

Allocations based on these factors can be considered to be desirable from the public's view as they lead to equal 'apparent police coverage' (for example, per person, per acre).

Assumptions are sometimes made that these factors contribute in a consistent manner to the number of incidents requiring police attention. The general problem of the prediction of crime occurrences from factors that have been observed to co-occur with criminal events is discussed in Stein, Crawshaw and Herron (20). See also the next section.

Other objectives for allocation based on the prevention function have been specified. Rosenshine (18) developed a patrol scheduling model to provide a random patrol pattern based on the hypothesis that the major purpose of police patrols is to reassure those who feel the need for protection and to discourage those who might, in the absence of patrol, commit crimes.

The measure of effectiveness used by the Lancaster investigators (see section 1.2.2 and (4)) took into account prevention and detection results. They also suggested the patrol preventive model,

number of crimes or accidents prevented during a given time period

$$= \frac{\sum_i K_i a_i n_i}{1 + \sum_i L_i a_i n_i} c$$

where the K_i and L_i's are positive constants and

n_i = number of patrols of i^{th} type on duty within section during period,

a_i = proportion of time for which patrols of i^{th} type are on patrol, and

c = number of crimes or accidents that would be commited during period if patrol densities were very low,

based on the results of the 'Best Patrol Experiment' (see section 1.1.2 and (3)).

The data collected by the present study does not enable models of the police preventive effect to be tested directly (but see Table 6.1 below).

6.1.2. Allocation based on Response

This approach is based on

(i) workload, as measured by non-generated police response activities including

(a) emergency incidents,

(b) other incidents, and

(c) recorded crime, or

(ii) specified measures of efficiency of various elements of the police response system including activities of

(a) communications centre, and

(b) mobile resources.

If the pattern of demand on the police response system as measured by (i) (a), (b), and (c) continues then a distribution of police mobile resources based on workload equalises the response workload on each police mobile unit allocated which is desirable from the police's view for internal morale purposes. If the factors used for preventive allocation (see section 6.1.1) make a pro rata contribution to response function workload (see section 6.1.1) then the allocations based on response function workload, and on prevention function workload (involving an equal amount of police patrolling activity per person, per acre, per mile of road) are identical.

Otherwise an allocation based on these preventive effect factors leads to disproportionate response function workloads so that in an area of mixed urban/rural characteristics, for example, a County Constabulary such as Durham, there will be under-utilisation of resources in the rural areas and over-utilisation in the urban areas. For example, Table 6.1, including a divisional breakdown for Durham Constabulary of population, area, and emergency incidents, shows that A division which is predominantly rural has 9% of the county's population, 41% of the area and 5% of the emergency incidents, whereas H division which is predominantly urban has 15% of the population, 2% of the area and 21% of the emergency incidents.

Table 6.1

Population, Area, and Emergency Incidents:

Classified by Division

Division	Population	% of Total	Area (Acres)	% of Total	Emergency** Incidents	% of Total
A	141,315	9.3	245,802	41.3	505	4.9
B	206,101	13.6	60,180	10.1	1454	14.2
C	179,390	11.8	48,649	8.2	972	9.5
D	185,100	12.2	16,025	2.7	1556	15.2
E	157,161	10.4	68,596	11.5	966	9.5
F	207,337	13.7	113,965	19.2	892	8.7
G	219,519	14.5	27,828	4.7	1739	17.0
H	219,270	14.5	13,400	2.3	2135	20.9
Totals	1,515,193	100.0	594,445	100.0	10219	100.0*

* - because of round-off error these percentages total to 99.9

** - these figures are from the 1970 study.

Examples of specific measures of police response efficiency include the response time of a police unit to an incident requiring urgent attention and the incidence of 'no car available'. The aim of minimising response time is desirable from the public's view and from the servicing aspect, including enhanced prospects for apprehending a criminal at or near the incident scene although it may conflict with the equalised workload objective (see below).

The incidence of 'no car available' is undesirable because it usually involves (for 98.6% of occasions) the despatch of a panda vehicle to an incident for which a vhf vehicle was considered more suitable, and in all cases involves an increased response time to the incident (see section 5.1.4 and below).

Models of Allocation based on Response

The use of the response function approach to allocation involves the specification of

(i) desired results, together with

(ii) the relevant constraints on the system, and

(iii) the formulation of a mathematical model to specify how the performance will vary with allocation.

Three specific models of the police response function will now be considered. They are

(a) workload model,

(b) response time model, and

(c) 'no car available' model.

Model (a) considers the spatial and temporal relationship between incidents requiring service and available police units, and attempts to schedule police response vehicles in terms of their individual (expected) workloads. Its specification involves an estimate of work and the techniques of resource allocation and scheduling, using the latter in the sense of allocating resources by time (shift).

The specification of model (b) involves consideration of expected travel distances, and the specification of model (c) involves the interaction between the arrival rate of incoming calls for service, the location and numbers of available mobile resources, and the despatching policies adopted in H.Q. Control Room.

Workload Models

Workload by Location

Let

n_{ij} = number of emergency incidents in location j during the time interval i,

a_{ij} = number of available patrol cars in location j during time interval i,

w_{ij} = emergency incident loading per available patrol car in location j during time interval i.

Then

$$w_{ij} = \frac{n_{ij}}{a_{ij}} .$$

A generalised emergency incident loading is defined as w_{ij}^{μ}, where the significance of the μ will be discussed below. During time interval i, the total generalised loading is

$$\sum_{j=1}^{n} w_{ij}^{\mu} , \quad i = 1,\ldots,m$$

where there are n locations j, and m time intervals i. During the same time interval there is a total of a_i available patrol cars in all locations

$$a_i = \sum_{j=1}^{n} a_{ij} , \quad i = 1,\ldots,m .$$

If these cars are to be allocated to locations at any one time so that the total generalised workload is minimised, then the allocation problem becomes

$$\text{minimise} \quad \sum_{j=1}^{n} \left\{ \frac{n_{ij}}{a_{ij}} \right\}^{\mu} , \quad i = 1, \ldots, m$$

subject to the constraint on the total number of available patrol cars at time i,

$$\sum_{j=1}^{n} a_{ij} = a_i , \quad i = 1,\ldots,m .$$

The Lagrangian function for this problem is

$$F(a_{ij}, \lambda) = \sum_{j=1}^{n} \left\{ \frac{n_{ij}}{a_{ij}} \right\}^{\mu} + \lambda \left(a_i - \sum_{j=1}^{n} a_{ij} \right).$$

The requirements for optimality are

$$\frac{\partial F}{\partial \lambda} = a_i - \sum_{j=1}^{n} a_{ij} = 0$$

which is just the constraint on the number of available cars, and

$$\frac{\partial F}{\partial a_{ij}} = \frac{\partial}{\partial a_{ij}} \left\{ \sum_{j=1}^{n} \left(\frac{n_{ij}}{a_{ij}} \right)^{\mu} \right\} - \lambda \frac{\partial}{\partial a_{ij}} \left\{ \sum_{j=1}^{n} a_{ij} \right\} = 0$$

or

$$\mu \left\{ \frac{n_{ij}}{a_{ij}} \right\}^{\mu-1} \frac{n_{ij}}{a_{ij}^2} + \lambda = 0$$

which leads to

$$a_{ij} = K \, n_{ij}^{\mu/\mu+1}$$

and using the constraint above

$$K \sum_{j=1}^{n} n_{ij}^{\mu/\mu+1} = a_i \, , \quad i = 1,\ldots,m$$

or

$$K = \frac{a_i}{\sum_{j=1}^{n} n_{ij}^{\mu/\mu+1}}$$

so that

$$a_{ij} = \frac{a_i n_{ij}^{\mu/\mu+1}}{\sum_{j=1}^{n} n_{ij}^{\mu/\mu+1}} \, , \quad \begin{array}{l} i = 1,\ldots,m \\ j = 1,\ldots,n \end{array}$$

gives the desired values for a_{ij}, given the values n_{ij}.

The workload, w_{ij}, in each location is given by

$$w_{ij} = \frac{n_{ij}}{a_{ij}}$$

$$= \frac{\sum_{j=1}^{n} n_{ij}^{\mu/\mu+1}}{a_i} \, n_{ij}^{1/\mu+1}$$

$$i = 1,\ldots,m, \quad j = 1,\ldots,n.$$

If $\mu \rightarrow 0$, then

$$w_{ij} \rightarrow n_{ij} ,$$

and if $\mu \rightarrow \infty$, then

$$w_{ij} \rightarrow \text{constant.}$$

Thus an allocation of available patrol cars between locations by this criterion (of minimum total generalised workload) satisfies the equalised workload objective if a high value is given to μ, so that each location, j, is allocated a number of cars in proportion to its number of emergency incidents during the corresponding time interval. Alternatively, if μ is given a small value, each location is allocated an equal number of cars, each of which has a workload proportional to the number of emergency incidents in its location. Thus the value of μ measures the importance attached to workload variations between locations.

The case $\mu = 1$, corresponding to minimising the total actual (linear) workload, leads to an allocation of cars to each location proportional to the square root of the number of emergency incidents in any specified time interval, and a disproportionate workload between locations.

Data for Model

To test how the actual distributions of patrol cars compared with this model the data collected during the 1970 study (Chapter V) on emergency incidents and available patrol cars was used.

The n locations, j, were taken to be the eight divisions A - H and the m time intervals, i, were taken to be the 24 hourly cells of the day. Daily average emergency incidents are included in Table 6.2, which is derived from Table 5.1 by dividing by 87, the number of days in the 1970 study. The numbers of available patrol cars are included in Table 6.3. These numbers only refer to the patrol cars in divisional locations and not to those in motorway locations. Hence the figures in Tables 5.4 and 6.3 show a discrepancy corresponding to the number of patrol cars available in motorway locations. The figures in Tables 6.2 and 6.3 give the required values for n_{ij}, a_{ij}. Using these values for n_{ij} and a_{ij} the required comparison of the model with actual experience was made by graphing $\log_{10} a_{ij}$ against $\log_{10} n_{ij}$ for various times of day (hours beginning 00.01, 06.00, 12.00, and 18.00).

The graph obtained, Figure 6.1, suggested that there was no strong correlation between a_{ij} and n_{ij} of this form, and the value indicated for μ was small (0.1). In other words, the present distribution of patrol cars is almost uniform by division and depends only to a small extent on workload.

Workload by Time

In the workload model above the aim was to find an allocation of the a_i available patrol cars at time i amongst the locations j in order to minimise the total generalised workload arising from (emergency) incidents. The aim of this model is to allocate patrol cars by time

Table 6.2

Emergency Incidents: Classified by Hour of Day

Daily Averages

Hour Beginning	Division A	B	C	D	E	F	G	H	Total
00.01	0.34	1.10	0.56	0.87	0.63	0.60	1.05	1.33	6.49
01.00	0.11	0.52	0.21	0.60	0.22	0.33	0.66	0.67	3.31
02.00	0.09	0.30	0.37	0.38	0.13	0.24	0.41	0.47	2.39
03.00	0.10	0.23	0.15	0.28	0.10	0.11	0.17	0.30	1.45
04.00	0.06	0.15	0.17	0.21	0.17	0.10	0.18	0.17	1.22
05.00	0.03	0.15	0.10	0.16	0.05	0.07	0.21	0.26	1.03
06.00	0.09	0.24	0.13	0.26	0.18	0.17	0.22	0.39	1.69
07.00	0.20	0.83	0.56	0.48	0.22	0.47	0.80	0.69	4.25
08.00	0.30	0.93	0.62	0.74	0.33	0.61	1.13	1.09	5.75
09.00	0.23	0.59	0.56	0.74	0.40	0.60	0.70	0.90	4.71
10.00	0.21	0.46	0.36	0.44	0.30	0.28	0.59	0.63	3.25
11.00	0.23	0.53	0.41	0.62	0.36	0.32	0.72	0.70	3.90
12.00	0.14	0.39	0.24	0.74	0.30	0.30	0.80	0.66	3.56
13.00	0.17	0.46	0.18	0.74	0.41	0.24	0.68	0.80	3.69
14.00	0.28	0.57	0.37	0.45	0.34	0.40	0.67	0.80	3.89
15.00	0.24	0.48	0.32	0.87	0.49	0.38	0.84	1.00	4.63
16.00	0.26	0.80	0.52	0.80	0.77	0.54	0.86	1.39	5.95
17.00	0.26	0.85	0.48	0.97	0.62	0.51	1.10	1.18	5.98
18.00	0.31	1.18	0.61	1.18	0.63	0.59	1.20	1.69	7.39
19.00	0.28	0.86	0.44	1.16	0.66	0.49	1.06	1.28	6.22
20.00	0.34	0.67	0.62	0.82	0.70	0.34	0.91	1.56	5.97
21.00	0.48	1.07	0.62	1.20	0.69	0.40	1.13	1.63	7.22
22.00	0.37	1.22	1.03	1.28	0.82	0.79	1.70	2.02	9.23
23.00	0.67	2.13	1.53	1.92	1.57	1.36	2.21	2.91	14.29
Totals	5.80*	16.71	11.17*	17.89*	11.10*	10.25*	19.99*	24.54*	117.46

All figures averaged over 87 days

* because of round-off error these columns do not total exactly.

Table 6.3

Available Patrol Cars:
Classified by Hour of Day

Hour Beginning	Division								Total
	A	B	C	D	E	F	G	H	
00.01	2.43	2.71	2.29	2.29	2.93	3.07	2.79	1.43	19.94
01.00	1.29	1.29	1.29	1.57	1.29	1.86	1.93	0.86	11.38
02.00	0.93	1.14	1.29	1.00	1.50	0.93	1.50	0.50	8.79
03.00	0.71	0.86	0.57	0.86	1.00	0.64	1.07	0.50	6.21
04.00	0.79	0.57	0.79	0.71	1.29	0.64	1.43	0.36	6.58
05.00	1.00	0.71	1.07	0.93	1.29	0.79	1.21	0.36	7.36
06.00	1.50	1.07	1.64	0.93	1.43	0.79	1.14	1.21	9.71
07.00	0.93	1.14	1.43	0.79	1.14	0.86	1.14	1.29	8.72
08.00	1.79	2.50	1.57	1.14	1.71	1.71	1.21	1.64	13.27
09.00	1.86	2.43	2.36	1.14	1.79	1.86	1.86	1.57	14.87
10.00	1.00	1.14	2.00	1.00	1.57	1.50	1.29	1.00	10.50
11.00	1.21	1.50	1.79	1.07	1.57	1.50	1.21	1.36	11.21
12.00	1.79	2.07	2.29	1.43	1.64	1.71	1.79	1.64	14.36
13.00	1.14	2.07	1.93	1.57	2.07	1.50	1.86	1.36	13.50
14.00	1.79	1.86	2.14	1.29	2.21	1.93	1.86	1.79	14.87
15.00	1.79	1.79	1.64	1.14	2.00	1.07	1.43	1.36	12.22
16.00	1.50	2.43	2.14	1.86	2.21	2.43	1.64	1.93	16.14
17.00	1.14	1.79	1.71	1.79	2.57	1.86	1.79	1.29	13.94
18.00	1.71	1.93	2.14	1.86	3.00	2.43	1.93	2.07	17.07
19.00	2.00	1.43	2.14	2.14	1.93	1.93	1.64	1.50	14.71
20.00	1.64	1.36	2.43	1.86	2.29	1.64	1.71	1.64	14.57
21.00	1.93	1.93	2.21	2.00	2.29	1.71	1.50	1.36	14.93
22.00	2.29	2.71	2.64	2.21	3.29	2.14	3.14	2.29	20.71
23.00	2.86	3.57	3.36	2.86	4.29	3.00	4.36	3.00	27.30
Overall	1.54	1.75	1.87	1.48	2.01	1.65	1.77	1.39	13.46

All figures averaged over fortnight

Figure G.1

GRAPH OF LOG(AVAILABLE PATROL CARS) v LOG(EMERGENCY INCIDENTS)

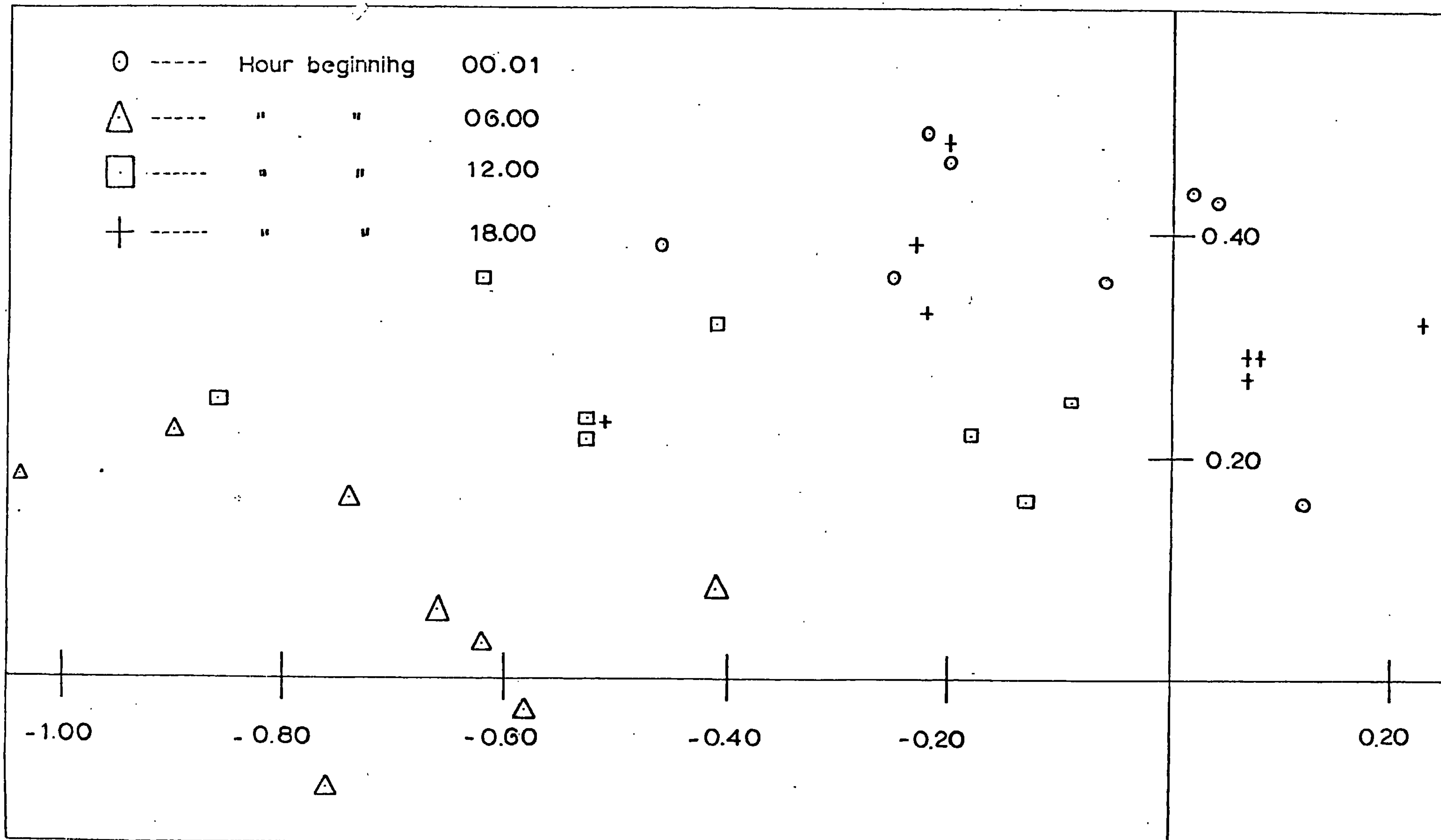


Table 6.4

Tabulated Values of $\log_{10}$ (available patrol cars) and $\log_{10}$ (emergency incidents):

Classified by Division

	Division	Available Patrol Cars	Emergency Incidents (Daily Av.)	$\log_{10}$ (Available Patrol Cars)	$\log_{10}$ (Emergency Incidents)
Hour Beginning 00.01	A	2.43	0.34	0.39	-0.46
	B	2.71	1.10	0.43	0.04
	C	2.29	0.56	0.36	-0.25
	D	2.29	0.87	0.36	-0.06
	E	2.93	0.63	0.47	-0.20
	F	3.07	0.60	0.49	-0.22
	G	2.79	1.05	0.44	0.02
	H	1.43	1.33	0.16	0.12
Overall		2.49	0.81	0.40	-0.90
Hour Beginning 06.00	A	1.50	0.09	0.18	-1.04
	B	1.07	0.24	0.03	-0.62
	C	1.64	0.13	0.22	-0.90
	D	0.93	0.26	-0.03	-0.58
	E	1.43	0.18	0.16	-0.74
	F	0.79	0.17	-0.10	-0.76
	G	1.14	0.22	0.06	-0.66
	H	1.21	0.39	0.08	-0.41
Overall		1.21	0.21	0.08	-0.68
Hour Beginning 12.00	A	1.79	0.14	0.25	-0.86
	B	2.07	0.39	0.32	-0.41
	C	2.29	0.24	0.36	-0.62
	D	1.43	0.74	0.16	-0.13
	E	1.64	0.30	0.22	-0.52
	F	1.71	0.30	0.23	-0.52
	G	1.79	0.80	0.25	-0.09
	H	1.64	0.66	0.22	-0.18
Overall		1.80	0.45	0.25	-0.35
Hour Beginning 18.00	A	1.71	0.31	0.23	-0.51
	B	1.93	1.18	0.29	0.07
	C	2.14	0.61	0.33	-0.22
	D	1.86	1.18	0.27	0.07
	E	3.00	0.63	0.48	-0.20
	F	2.43	0.59	0.39	-0.23
	G	1.93	1.20	0.29	0.08
	H	2.07	1.69	0.32	0.23
Overall		2.13	0.92	0.33	-0.03

interval (and hence shift) in order to minimise a specified measure of response service excesses and deficiencies. In effect the model aims to allocate patrol cars to shifts in order to match the demands on them as evenly as possible, assuming a constant workrate capability.

Let

a_{ij} = number of patrol cars available during time interval i in location j,

ℓ = length of shift, that is, number of time intervals, assuming all cars work ℓ consecutive time intervals,

a'_{ij} = number of patrol cars becoming available at beginning of time interval i in location j,

n_{ij} = number of emergency incidents in location j during the time interval i,

δ_{ij} = deficit of patrol cars during time interval i in location j,

ϵ_{ij} = excess of patrol cars during time interval i in location j.

Then the number of patrol cars available during time interval i,

$$a_{ij} = \sum_{k=i-\ell+1}^{i} a'_{kj}$$

that is, the number of patrol cars coming on duty at the beginning of time interval i together with those coming on duty at the beginning of the ℓ-1 previous time intervals which have not yet gone off duty.

Assuming that an incident loading of one incident per patrol car per hour is considered reasonable, then if

$$n_{ij} < \sum_{k=i-\ell+1}^{i} a'_{kj}$$

the excess

$$\epsilon_{ij} = \sum_{k=i-\ell+1}^{i} a'_{kj} - n_{ij} \qquad \text{(A)}$$

and deficit

$$\delta_{ij} = 0$$

whereas if

$$n_{ij} > \sum_{k=i-\ell+1}^{i} a'_{kj}$$

then deficit

$$\delta_{ij} = n_{ij} - \sum_{k=i-\ell+1}^{i} a'_{kj} \qquad \text{(B)}$$

and excess

$$\epsilon_{ij} = 0 .$$

Combining (A) and (B) we have

$$\sum_{k=i-\ell+1}^{i} a'_{kj} - \epsilon_{ij} + \delta_{ij} = n_{ij} \qquad \text{(C)}$$

with

$$\epsilon_{ij},\ \delta_{ij} \geq 0.$$

Penalties are assumed to be incurred if either a deficit or excess of patrol cars occurs. To be completely general these may vary according to the time interval, the location, and the nature of the discrepancy (that is, whether it is a shortage or surplus). For example, if there is a surplus the cars could be regarded as undertaking preventive work which may be regarded as having a lower 'value' in terms of police achievement than response work, in which case the level of the penalty becomes the difference between the two police achievement 'values'.

Alternatively the 'cost' of shortage may be measured in terms of a drop in police morale through overwork, or of loss of public goodwill if a patrol car has to rush one servicing job in order to attend another.

Let

$k_{ij}(\delta)$ = the penalty incurred in location j for unit shortage during time interval i,

$k_{ij}(\epsilon)$ = the penalty incurred in location j for unit overage during time interval i.

Then the total penalty incurred

$$= \sum_i \sum_j \{k_{ij}(\delta)\delta_{ij} + k_{ij}(\epsilon)\epsilon_{ij}\} \quad .$$

If the requirement is to schedule the patrol cars so that the total penalty incurred through discrepancies in meeting demand is minimised then the scheduling problem becomes

schedule patrol cars, that is, find values of a'_{kj}, so as to minimise the penalty function

$$\sum_i \sum_j \{k_{ij}(\delta)\delta_{ij} + k_{ij}(\epsilon)\epsilon_{ij}\}$$

where

$$\sum_{k=i-\ell+1}^{i} a'_{kj} - \epsilon_{ij} + \delta_{ij} = n_{ij}$$

and the total number of patrol cars available during time interval i in location j

$$a_{ij} = \sum_{k=i-\ell+1}^{i} a'_{kj} \quad .$$

If alternative incident loadings are considered so that, for example, a car could respond to (service) r incidents in one time interval then equations (A), (B) and (C) modify to

$$\epsilon_{ij} = r \sum_{k=i-\ell+1}^{i} a'_{kj} - n_{ij}, \qquad \delta_{ij} = 0$$

$$\delta_{ij} = n_{ij} - r \sum_{k=i-\ell+1}^{i} a'_{kj} \;, \quad \epsilon_{ij} = 0$$

and

$$r \sum_{k=i-\ell+1}^{i} a'_{kj} - \epsilon_{ij} + \delta_{ij} = n_{ij}$$

respectively.

Constraints on the scheduling problem which are desirable on administrative grounds include

(a) that the times at which shifts start should be as few as possible, that is, $a'_{ij} = 0$, for as many i as possible, and

(b) that cars (crews) should be grouped into as few modules as possible, the number of which should be greater than or equal to the number of times when shifts start,

in addition to the previously assumed constraint that all cars work ℓ consecutive time intervals.

If the penalty functions $k_{ij}(\delta)$, $k_{ij}(\epsilon)$ are specified to be linear as a first approximation to a solution of the scheduling problem, then in practice this model gives no information because the system is always in a state of excess, and so the sum of the penalty functions is fixed, being proportional simply to the excess of total police man-hours, however distributed, over total incidents.

In practice patrol cars are not restricted to patrolling a particular area so that the problem can be usefully restructured to that of specifying a_i for all locations

$$a_i = \sum_j a_{ij}$$

from a knowledge of n_i

$$n_i = \sum_j n_{ij} ,$$

in other words to determining the appropriate level of available patrol cars for the whole area concerned. This problem can be tackled by adopting the present workload of emergency incidents per available patrol car (0.4 per hour) and specifying the corresponding penalty function to be a function of the differences between the workload ratios

$$\frac{n_i}{a_i} , \qquad i = 1,\ldots,m$$

and the overall average workload of 0.4 emergency incidents per patrol car per hour (calculated on the assumption that patrol cars responded to every emergency incident, which is an exaggeration of the actual situation).

Recognising the administrative constraints specified above the scheduling problem becomes a combinatorial one of arranging modules (of cars, or their associated crews) to provide the desired police levels for n_i, $i = 1,\ldots,24$, incidents requiring attention taking into account required shift starting times, shift lengths, and shift rota systems.

To satisfy constraint (a) shift changes were taken to be those already in use, namely 00.01, 06.00, 08.00, 10.00, 14.00, 16.00, 18.00, and 22.00, with a shift length, ℓ , of eight hours. So the problem was to determine the modules a_k' coming on duty at these times, with n_i specified, $i = 1,\ldots,24$, to give the required level of available cars

$$a_i = \sum_{k=i-7}^{i} a_k'$$

where the relevant k for the summation on the right were only those specified above, so that, for example,

$$a_9 = a_7' + a_9'$$

$$a_{17} = a_{11}' + a_{15}' + a_{17}' .$$

Specifically the eight modules a'_1, a'_7, a'_9, a'_{11}, a'_{15}, a'_{17}, a'_{19} and a'_{23} were to be determined in order to match the demands on them as closely as possible. Formally if 0.4 emergency incidents per hour per patrol car was accepted to be a reasonable loading then the requirement was for

$$\frac{n_i}{a_i},$$

to be as close as possible to 0.4 for all i. As the penalties were to be cumulative over time intervals possible penalty functions for minimisation included

$$\sum_i \left| \frac{n_i}{a_i} - 0.4 \right|$$

and

$$\sum_i \left(\frac{n_i}{a_i} - 0.4 \right)^2 .$$

Ideally the problem solution is given by

$$a_i = \frac{n_i}{0.4}, \quad \text{for all i.}$$

This unconstrained optimum solution is included in Table 6.5, however the requirement of continuous eight hour shifts makes this solution to the scheduling problem infeasible (see below for fuller discussion).

With penalty function

$$\sum_i \left| \frac{n_i}{a_i} - 0.4 \right|$$

the average daily penalty incurred during the 1970 study was 2.32.

It will be shown below that an analytical solution of this problem in its present form is infeasible. However the problem can be solved by an enumeration technique. First of all the size of the enumeration for

Table 6.5

Unconstrained Optimum Number of Available Patrol Cars for Scheduling Problem:

Classified by Hour of Day

Hour Beginning	Patrol Cars Becoming Available	Total Available Patrol Cars	Emergency Incidents (Daily Average)	Optimum Number of Available Patrol Cars (Unconstrained) *
00.01	a'_1	$a'_{19} + a'_{23} + a'_1$	6.5	16
01.00	-	$a'_{19} + a'_{23} + a'_1$	3.3	8
02.00	-	$a'_{23} + a'_1$	2.4	6
03.00	-	$a'_{23} + a'_1$	1.4	4
04.00	-	$a'_{23} + a'_1$	1.2	3
05.00	-	$a'_{23} + a'_1$	1.0	3
06.00	a'_7	$a'_1 + a'_7$	1.7	4
07.00	-	$a'_1 + a'_7$	4.3	11
08.00	a'_9	$a'_7 + a'_9$	5.7	14
09.00	-	$a'_7 + a'_9$	4.7	12
10.00	a'_{11}	$a'_7 + a'_9 + a'_{11}$	3.3	8
11.00	-	$a'_7 + a'_9 + a'_{11}$	3.9	10
12.00	-	$a'_7 + a'_9 + a'_{11}$	3.6	9
13.00	-	$a'_7 + a'_9 + a'_{11}$	3.7	9
14.00	a'_{15}	$a'_9 + a'_{11} + a'_{15}$	3.9	10
15.00	-	$a'_9 + a'_{11} + a'_{15}$	4.6	12
16.00	a'_{17}	$a'_{11} + a'_{15} + a'_{17}$	6.0	15
17.00	-	$a'_{11} + a'_{15} + a'_{17}$	6.0	15
18.00	a'_{19}	$a'_{15} + a'_{17} + a'_{19}$	7.4	19
19.00	-	$a'_{15} + a'_{17} + a'_{19}$	6.2	16
20.00	-	$a'_{15} + a'_{17} + a'_{19}$	6.0	15
21.00	-	$a'_{15} + a'_{17} + a'_{19}$	7.2	18
22.00	a'_{23}	$a'_{17} + a'_{19} + a'_{23}$	9.2	23
23.00	-	$a'_{17} + a'_{19} + a'_{23}$	14.3	36

* - these figures are rounded off to the nearest integer

the present problem will be discussed and then by way of example the solution to a limited version of the problem will be given.

Consideration of requirements in the hour beginning 23.00 shows that the sum of three car modules should be as close as possible to 36 (see Table 6.5) so that each module on duty at that time may contain at least 12 cars. On the other hand a similar consideration of requirements in the hour beginning 05.00 shows that each module on duty at that time may contain only one car.

As the module a'_{23} is on duty during both the time intervals considered above and there are eight modules to be considered a complete enumeration of this problem could involve the evaluation of 12^8 alternative module configurations, $(a'_1,\ldots,a'_{23}) = (1,\ldots,1) \ldots,$ $(12,\ldots,12)$. That is 430×10^6 possibilities and although the number of enumerations necessary to cover the optimum allocation of cars to modules can be reduced by considering the feasible range of variation of each module size as has been done above for a'_{23} it is still a vast enumeration.

In order to make a solution by enumeration viable a heuristic-analytic procedure on the above lines is needed in order to reduce the number of alternatives requiring consideration.

The problem as described above involves one feature which leads to this vast enumeration requirement and that is overlapping modules, when modules starting at different times are on duty concurrently.

Without the overlapping shift feature a solution to the scheduling problem can be readily obtained.

For example, consider the scheduling problem for three modules a'_1, a'_9, and a'_{17} each working consecutive eight hour shifts. Then the minimisation of

$$\sum_{i=1}^{24} \left| \frac{n_i}{a_i} - 0.4 \right|$$

is equivalent to the minimisation of

$$\sum_{i=1}^{8} \left| \frac{n_i}{a'_1} - 0.4 \right| + \sum_{i=9}^{16} \left| \frac{n_i}{a'_9} - 0.4 \right| + \sum_{i=17}^{24} \left| \frac{n_i}{a'_{17}} - 0.4 \right| .$$

Table 6.5 shows that a'_1 should be between 3 and 16, a'_9 between 8 and 14, and a'_{17} between 15 and 36. The solution can be obtained by considering each module independently, as there is no interference between successive modules, so that $14 + 7 + 22 = 43$ enumerations are sufficient to determine the optimum instead of the $14 \times 7 \times 22 = 2156$ that would be necessary if interference between modules occurred.

The solution procedure is to calculate

$$z_1 = \sum_{i=1}^{8} \left| \frac{n_i}{a'_1} - 0.4 \right|$$

for $a'_1 = 3$ to 16 and select the value of a'_1, a'^*_1, giving the minimum of z_1, z^*_1, and then

$$z_9 = \sum_{i=9}^{16} \left| \frac{n_i}{a'_9} - 0.4 \right|$$

for $a'_9 = 8$ to 14 and select a'^*_9 to give z^*_9, and then

$$z_{17} = \sum_{i=17}^{24} \left| \frac{n_i}{a'_{17}} - 0.4 \right|$$

for $a'_{17} = 15$ to 36 to select a'^*_{17} giving the minimum z^*_{17}.

The overall solution to the problem is then obtained by combining the three values $a_1'^*$, $a_9'^*$, and $a_{17}'^*$, and the corresponding value, z^*, of the penalty function is given by

$$z^* = z_1^* + z_9^* + z_{17}^* \quad .$$

If the range of values that can be assumed by any a_i' is much larger than in this example, then the search for the unique minimum may be reduced by adopting a suitable starting point for the enumeration and stopping when the minimum has been positively identified. Examples of possible starting values include

(a) average value of $\frac{n_i}{0.4}$ for i in the range under consideration, for example $\frac{1}{8}\sum_{i=1}^{8} \frac{n_i}{0.4}$ for a_1' in the current example, and

(b) the midpoint in the range of possible values.

Whichever starting point is used the next step is to calculate z for starting point ± 1 and thus determine the direction of decreasing z.

The solution obtained for this example is included in Table 6.6 . The optimum schedule is seen to be $a_1'^* = 9$, $a_9'^* = 10$, $a_{17}'^* = 19$ with corresponding average daily penalty

$$z^* = 1.57 + 0.46 + 0.77 = 2.80$$

which it may be observed is in excess of the recorded value of 2.32. It can also be seen that the optimal solution is fairly insensitive to changes in a_1' but is increasingly sensitive to changes in a_{17}' and a_9' .

The hourly variation in workload that is obtained on the basis of 1970 emergency incidents and this scheduling of patrol car modules is illustrated in Figure 6.2. Comparison with the actual situation in 1970, illustrated in Figure 6.3, shows that this simple three module system is incapable of evening out the workload variations currently existing.

Table 6.6

Tabulated Values of Objective Function
For Three Module Scheduling Solution:

Classified by Number of Cars in Module

First Module		Second Module		Third Module	
Number of cars	Objective Function	Number of cars	Objective Function	Number of cars	Objective Function
3	4.20	8	0.98	15	0.94
4	2.87	9	0.56	16	0.85
5	2.24	10	0.46*	17	0.83
6	1.87	11	0.50	18	0.78
7	1.72	12	0.56	19	0.77*
8	1.59	13	0.72	20	0.84
9	1.57*	14	0.82	21	0.86
10	1.58			22	0.91
11	1.60			23	0.94
12	1.66			24	1.00
13	1.73			25	1.04
14	1.76			26	1.11
15	1.81			27	1.16
16	1.84			28	1.21
				29	1.22
				30	1.27
				31	1.32
				32	1.34
				33	1.38
				34	1.40
				35	1.44
				36	1.45

* - Optimal Value

Figure 6.2

EMERGENCY INCIDENTS PER AVAILABLE PATROL CAR : CLASSIFIED BY HOUR OF DAY

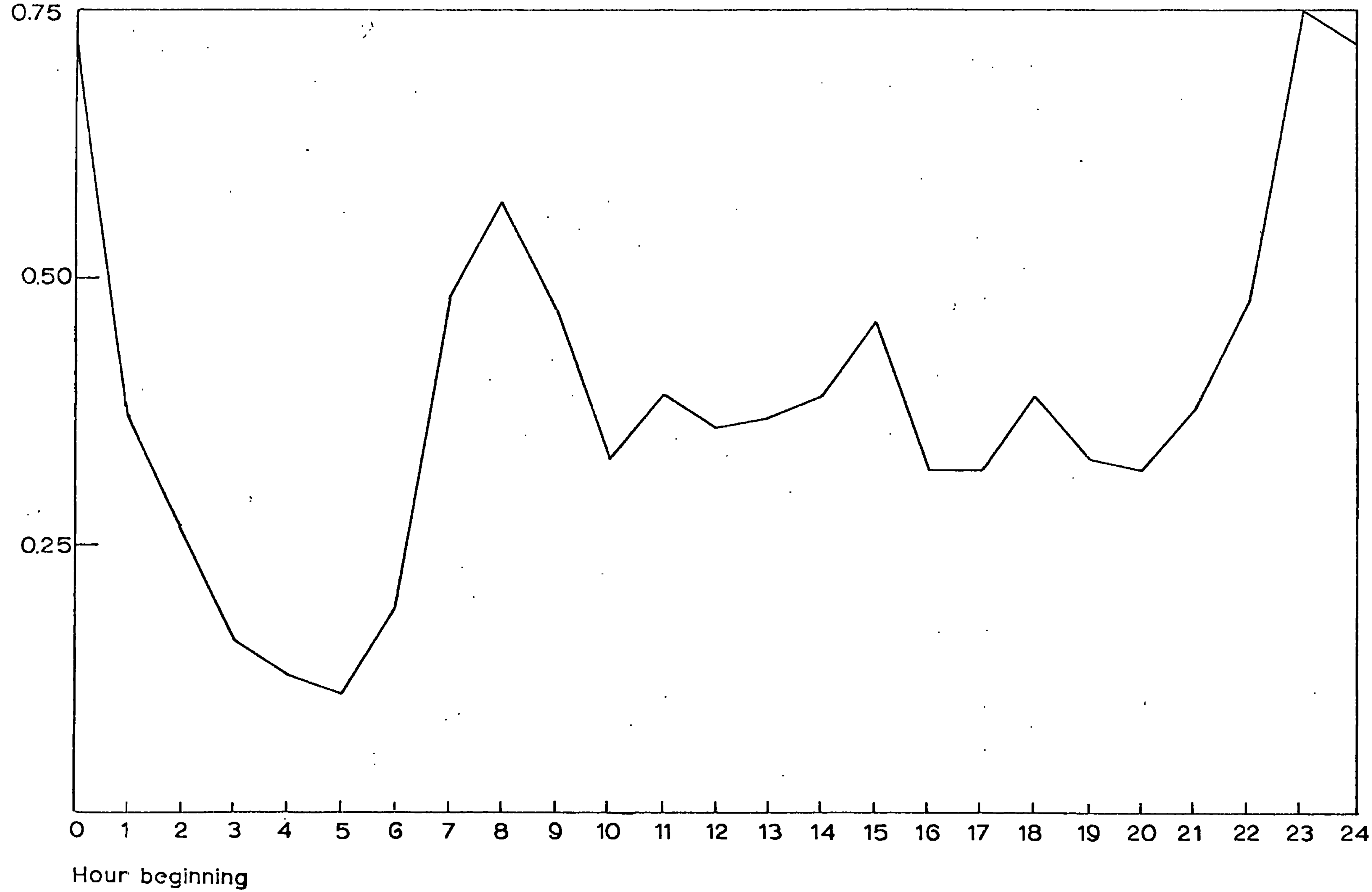


Table 6.7

Emergency Incidents per Available Patrol Car
(Scheduled for Three Modules):

Classified by Hour of Day

Hour Beginning	Emergency Incidents (Daily Average)	Available Patrol Cars Scheduled	Emergency Incidents per Available Patrol Car
00.01	6.5	9	0.72
01.00	3.3	9	0.37
02.00	2.4	9	0.27
03.00	1.4	9	0.16
04.00	1.2	9	0.13
05.00	1.0	9	0.11
06.00	1.7	9	0.19
07.00	4.3	9	0.48
08.00	5.7	10	0.57
09.00	4.7	10	0.47
10.00	3.3	10	0.33
11.00	3.9	10	0.39
12.00	3.6	10	0.36
13.00	3.7	10	0.37
14.00	3.9	10	0.39
15.00	4.6	10	0.46
16.00	6.0	19	0.32
17.00	6.0	19	0.32
18.00	7.4	19	0.39
19.00	6.2	19	0.33
20.00	6.0	19	0.32
21.00	7.2	19	0.38
22.00	9.2	19	0.48
23.00	14.3	19	0.75
Overall	4.9	13	0.39

Figure 6.3

EMERGENCY INCIDENTS PER AVAILABLE PATROL CAR: CLASSIFIED BY HOUR OF DAY

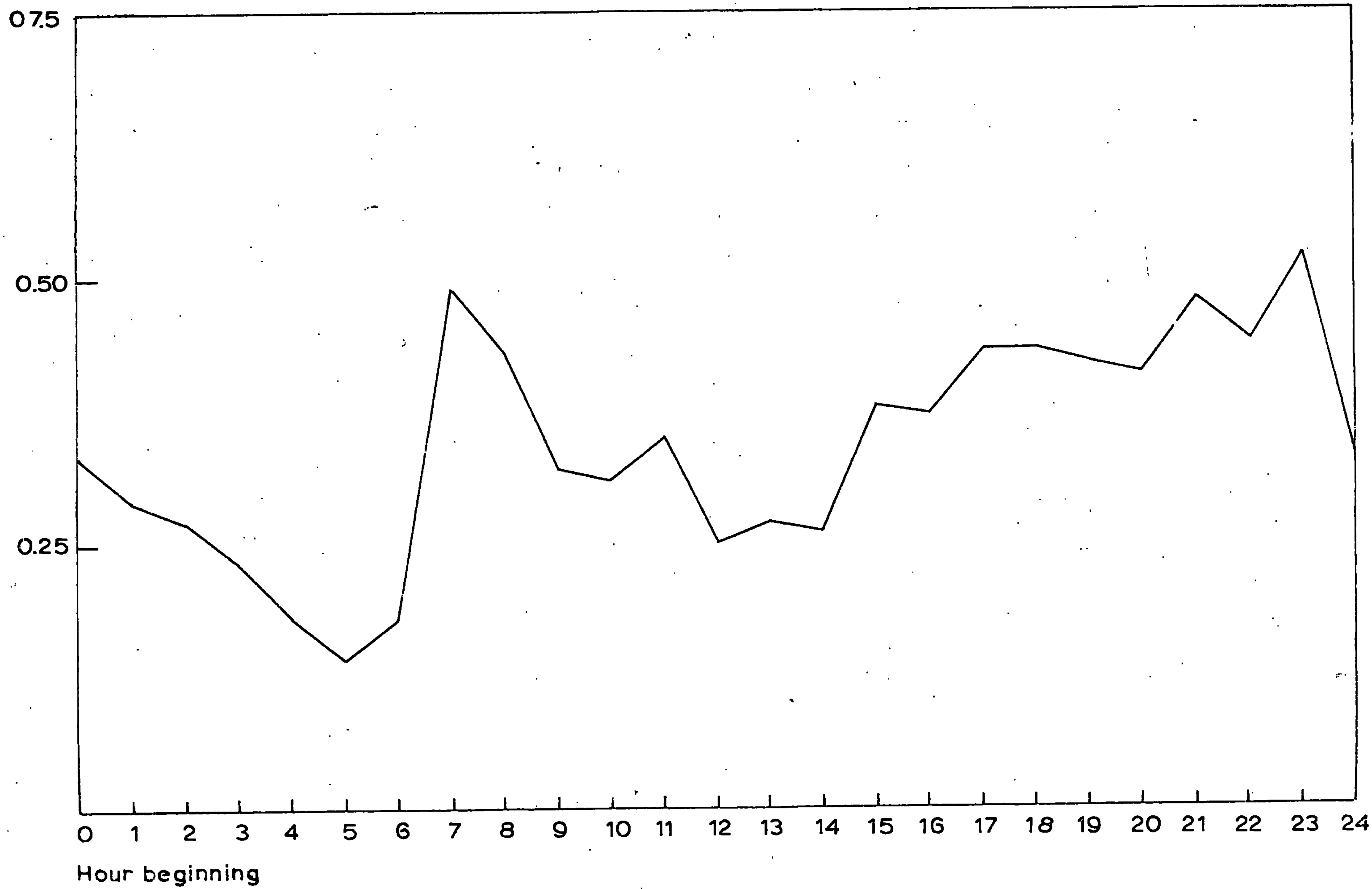


Table 6.8

Emergency Incidents per Available Patrol Car:

Classified by Hour of Day

Hour Beginning	Emergency Incidents (Daily Average)	Available Patrol Cars (Average)	Emergency Incidents per Available Patrol Car
00.01	6.5	19.9	0.33
01.00	3.3	11.4	0.29
02.00	2.4	8.8	0.27
03.00	1.4	6.2	0.23
04.00	1.2	6.6	0.18
05.00	1.0	7.4	0.14
06.00	1.7	9.7	0.18
07.00	4.3	8.7	0.49
08.00	5.7	13.3	0.43
09.00	4.7	14.9	0.32
10.00	3.3	10.5	0.31
11.00	3.9	11.2	0.35
12.00	3.6	14.4	0.25
13.00	3.7	13.5	0.27
14.00	3.9	14.9	0.26
15.00	4.6	12.2	0.38
16.00	6.0	16.1	0.37
17.00	6.0	13.9	0.43
18.00	7.4	17.1	0.43
19.00	6.2	14.7	0.42
20.00	6.0	14.6	0.41
21.00	7.2	14.9	0.48
22.00	9.2	20.7	0.44
23.00	14.3	27.3	0.52
Overall	4.9	13.4	0.37

The main difficulty is seen to be scheduling sufficient cars to service the peak of emergency incident demand beginning at 07.00 without having patrol cars underutilised (in terms of emergency incident work-load) during the hours 03.00 to 07.00. Moving the three shift start times, to 06.00, 14.00 and 22.00, for example, does not ease this situation materially as the high level of patrol cars then needed to service the 22.00 to 01.00 peak of emergency incidents will be equally underutilised during the period 03.00 to 06.00.

Because of these features in the emergency incident demand pattern the concept of overlapping certain shifts to deal with these incident peaks is a sound one.

Finally we consider more fully the scheduling problem for the present shift system, with the constraint of eight-hour unbroken shifts.

Interpreting the requirements of the problem as summarised in Table 6.5 leads to the identification of the following inequalities

$$8 \leqslant a'_{19} + a'_{23} + a'_{1} \leqslant 16 \qquad \text{(i)}$$

$$3 \leqslant a'_{23} + a'_{1} \leqslant 6 \qquad \text{(ii)}$$

$$4 \leqslant a'_{1} + a'_{7} \leqslant 11 \qquad \text{(iii)}$$

$$12 \leqslant a'_{7} + a'_{9} \leqslant 14 \qquad \text{(iv)}$$

$$8 \leqslant a'_{7} + a'_{9} + a'_{11} \leqslant 10 \qquad \text{(v)}$$

$$10 \leqslant a'_{9} + a'_{11} + a'_{15} \leqslant 12 \qquad \text{(vi)}$$

$$15 \leqslant a'_{11} + a'_{15} + a'_{17} \leqslant 15 \qquad \text{(vii)}$$

$$15 \leqslant a'_{15} + a'_{17} + a'_{19} \leqslant 19 \qquad \text{(viii)}$$

$$23 \leqslant a'_{17} + a'_{19} + a'_{23} \leqslant 36 \qquad \text{(ix)}$$

the first of which is obtained by considering minimum and maximum car requirements in the hours beginning 00.01 and 01.00, and the following eight inequalities are obtained in a similar manner.

Additionally the eight-hour unbroken shift constraint means that $a_i' \geq 0$, for all applicable i.

It can now be readily shown that there is no feasible solution to this system of linear inequalities, for from (iv) and (v) we have the requirement

$$-6 \leq a_{11}' \leq -2$$

which is contrary to the non-negative constraint imposed.

If the scheduling problem discussed above is slightly reformulated a solution can be obtained by the use of a standard linear programming algorithm as follows.

Specify the scheduling problem as schedule patrol cars, that is, find values of a_i' , so as to minimise the total amount of patrol car effort used throughout the day with the constraint that workload is never to exceed 0.4 incidents per available patrol car per hour, which is equivalent to attaching an infinite penalty to patrol car deficits in the general model developed above.

So the problem becomes, find values of a_i' so as to minimise the total patrol car effort (patrol car hours used)

$$z = \sum_i a_i'$$

subject to the constraints

$$
\begin{aligned}
a_1' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + a_{19}' + a_{23}' &\geq 16 \\
a_1' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + a_{23}' &\geq 6 \\
a_1' + a_7' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad &\geq 11 \\
a_7' + a_9' \qquad\qquad\qquad\qquad\qquad\qquad\qquad &\geq 14 \\
a_7' + a_9' + a_{11}' \qquad\qquad\qquad\qquad\qquad\qquad &\geq 10 \\
a_9' + a_{11}' + a_{15}' \qquad\qquad\qquad\qquad &\geq 12 \\
a_{11}' + a_{15}' + a_{17}' \qquad\qquad\qquad &\geq 15 \\
a_{15}' + a_{17}' + a_{19}' \qquad\qquad &\geq 19 \\
a_{17}' + a_{19}' + a_{23}' &\geq 36
\end{aligned}
$$

obtained by specifying that the number of available patrol cars at any time is greater than or equal to the number of incidents at that time divided by 0.4, the incident loading (see Table 6.5).

Introducing the slack vector $\underline{s} = (s_1,\dots,s_9)$ the problem becomes minimise

$$z = \sum_i a_i'$$

subject to

$$
\begin{aligned}
a_1' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + a_{19}' + a_{23}' - s_1 &= 16 \\
a_1' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad + a_{23}' - s_2 &= 6 \\
a_1' + a_7' \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad - s_3 &= 11 \\
a_7' + a_9' \qquad\qquad\qquad\qquad\qquad\qquad\qquad - s_4 &= 14 \\
a_7' + a_9' + a_{11}' \qquad\qquad\qquad\qquad\qquad\qquad - s_5 &= 10 \\
a_9' + a_{11}' + a_{15}' \qquad\qquad\qquad\qquad - s_6 &= 12 \\
a_{11}' + a_{15}' + a_{17}' \qquad\qquad\qquad - s_7 &= 15 \\
a_{15}' + a_{17}' + a_{19}' \qquad\qquad - s_8 &= 19 \\
a_{17}' + a_{19}' + a_{23}' - s_9 &= 36
\end{aligned}
$$

Selection of a basic feasible solution $a'_1 = 6$, $a'_7 = 5$, $a'_9 = 9$, $a'_{11} = 0$, $a'_{15} = 15$, $a'_{17} = 0$, $a'_{19} = 36$, $a'_{23} = 0$, $s_1 = 26$, $s_2 = 0$, $s_3 = 0$, $s_4 = 0$, $s_5 = 4$, $s_6 = 12$, $s_7 = 0$, $s_8 = 32$, $s_9 = 0$, with $z = 71$ by inspection, and one iteration leads to one of the optimum solutions $a'_1 = 6$, $a'_7 = 5$, $a'_9 = 9$, $a'_{11} = 0$, $a'_{15} = 3$, $a'_{17} = 12$, $a'_{19} = 24$, $a'_{23} = 0$, $s_1 = 14$, $s_5 = 4$, $s_8 = 20$, and all other slack variables zero with a minimum objective function value, z*, of 59.

This optimum solution incorporates slack of 14 available cars between 00.01 and 02.00, 4 available cars between 10.00 and 14.00, and 20 available cars between 18.00 and 22.00, and involves an available patrol car level between a minimum of 6 in the interval 02.00 to 06.00 and a maximum of 39 in the interval 18.00 to 22.00.

The associated average daily penalty incurred

$$\sum_i \left| \frac{n_i}{a_i} - 0.4 \right|$$

is 3.10 which is in excess of the penalty associated with the previous solution, a feature which could have been anticipated as this solution is not designed to maintain workload as close as possible to 0.4 but rather to ensure a sufficiency of available patrol cars throughout a shift in order to meet all service demands without exceeding a workloading of 0.4.

This sufficiency is achieved at the cost of under utilisation of patrol cars during some intervals, notably during the interval 18.00 to 22.00 when over 50% of available cars are 'slack'.

Illustration of the hourly variation in workload obtained on the basis of this scheduling solution shows a similar pattern to that observed in Figure 6.2 for the previous solution, with large fluctuations in workload up to the constrained maximum of 0 4. This solution also involves a 50% increase on the average daily patrol car effort currently (1970) used (from 323 hours to 472 hours).

This solution is not unique and there are five other solutions with $z = 59$. The chief difference between these alternative solutions concerns the distribution of the slack available cars over the intervals of the day. The actual numbers of available patrol cars at any time remain substantially the same and so there is no overall advantage in adopting one of the solutions in preference to the others.

It is interesting to note that when solving a similar problem Aspden and Chambers (27) experienced a similar effect of highly uneven manpower requirements and attempted to handle it by imposing the constraint of eight hour shifts but allowed unit beat patrols (neighbourhood constables on foot patrol) to continue to work split shifts (unlike our model). The subsequent optimal solution included unit beat patrols for the first time, the presence of which helped to even out the manpower requirements throughout the day for their more effective types of mobile resources.

Response Time Models

Heuristic and analytic models for predicting travel times have been developed by Burt and Dyer (5), and Larson (17). The former was developed with special reference to the urban road network of Los Angeles with a similar area (900 sq. miles) to County Durham but such different road characteristics and configuration as to make the model inapplicable to the Durham situation. The Larson model, although based on some fairly restrictive assumptions, has a more generally useful approach and will be discussed now.

Larson Model

The Larson model gives the following expression for expected travel time

$$E_{tt} = t_s + \frac{2}{3s}\left\{\frac{A}{K}\right\}^{\frac{1}{2}}(2 - \zeta)$$

where

K = number of police cars allocated to location,

ζ = availability of the police cars (proportion of duty time on patrol),

s = average speed of travel in the location,

A = area of the location,

t_s = starting time

E_{tt} = expected travel time in the location,

under certain rigorous assumptions (see Larson (17)).

Essentially with 'start-up' time, t_s, set to zero, the model says that expected travel time is equal to expected travel distance divided by speed of travel.

Expected travel distance depends upon the geometry of the area A (and, of course, on the configuration of the road network) and the assumed location of a police car when despatched. Incidents are assumed to occur uniformly over the area concerned.

As an illustration let area A constitute a circular region of radius a with a uniform incident density ρ and assume a police car is located at the centre of mass of the region, then mean (expected) travel distance to incidents, E_{td}, is given by

$$E_{td} = \frac{1}{\pi a^2 \rho} \int_0^a 2\pi r^2 \rho \, dr$$

(by considering an annulus, width dr, inner radius r, around the centre of mass).

So

$$E_{td} = \frac{1}{a^2}\left\{\frac{2}{3} r^3\right\}_0^a$$

$$= \frac{2}{3} a$$

or
$$\frac{2}{3}\left\{\frac{A}{\pi}\right\}^{\frac{1}{2}} \tag{A}$$

since
$$A = \pi a^2 .$$

If alternatively the area A constitutes a square region of side 2a then under the same conditions as for the circular region

$$E_{td} = \frac{2}{a^2\rho}\int_0^a \rho\, dx \int_0^x \{x^2 + y^2\}^{\frac{1}{2}}\, dy$$

$$= \frac{2}{a^2}\int_0^a x^2 dx \int_0^{\pi/4} \sec^3\theta\, d\theta$$

$$= \frac{2}{3a}\int_0^{\pi/4} \sec^3\theta\, d\theta$$

$$= \frac{2.296}{3a}$$

$$= 0.574\,\frac{2\{A\}^{\frac{1}{2}}}{3} . \tag{B}$$

Comparison of (A) and (B) shows that E_{td} for circular regions $\left(= 0.564\,\frac{2\{A\}^{\frac{1}{2}}}{3}\right)$ is slightly smaller than E_{td} for square regions (of the same area A).

In the Larson model the factor (expcted travel distance/speed of travel) is modified to take into account K police units on duty in the area A, with availability ζ, and the effect of availability on the expected travel distance. In particular the road configuration is assumed to form a rectangular grid, and ζ is assumed to exceed 0.3 so that one car is always available in one of five adjacent areas.

Interdistrict dispatching is assumed to take place and patrol discipline is assumed to be one car to each of K patrol areas, rather than random patrol by K cars of the whole area A. Note that this discipline more closely corresponds to the panda vehicle situation than to the vhf vehicle situation which has been seen above to correspond more closely with the second patrol discipline (see also below).

Data for Model

The response time data collected in 1970 (see section 5.1.2.3) was used to test the validity of the Larson model for Durham Constabulary conditions. Tests were made using the data for both panda vehicles and patrol cars. Table 6.9 contains a divisional breakdown of the panda vehicle travelling speeds obtained when the model was used with known values of A, K, ζ, and mean travelling times from the 1970 study, with $t_s = 0$.

Table 6.9

Panda Vehicle Travelling Speed Calculated using Larson Model: Classified by Division

Division	A (Square Miles)	K	ζ	Mean tt (Minutes)	Calculated Speed (M.P.H.)
A	384	8	0.67	5.9	62.5
B	94	11	0.52	5.4	32.0
C	76	12	0.64	5.2	26.3
D	25	13	0.75	3.9	17.8
E	107	9	0.46	5.4	39.3
F	178	10	0.69	6.1	36.2
G	43	13	0.56	4.4	23.8
H	21	12	0.50	4.8	16.5
Overall	928	88	0.60	4.9	37.1

Although no information was collected on travelling speeds on route to an emergency incident the values contained in Table 6.9 are generally of a reasonable order (with the exception of A division, see below). The actual travelling time means for panda vehicles in 1970 showed little variation between a large rural division such as A with a high {A/K} factor, and compact urban divisions such as D, G and H with low {A/K} factors.

The travelling speeds in Table 6.9 suggest that panda vehicles in A division were able to use much higher travelling speeds than those in D, G, and H divisions thus compensating for the unfavourable {A/K} factor. In fact the figure for A division in Table 6.9 is probably artificially inflated by the inclusion in A of a large amount of area which gives rise to very few incidents.

Patrol cars operated over the whole county in 1970 without regard to divisional boundaries. Table 6.10 shows the patrol car travelling speed calculated using the Larson model.

Table 6.10

Patrol Car Travelling Speed Calculated using Larson Model

Division	A (Square Miles)	K	ζ	Mean tt (Minutes)	Calculated Speed (M.P.H.)
All	928	22**	0.60*	5.7	63.8

* - this figure was taken from H.A.Taylor (21)

** - this figure was imputed on the basis of available cars × (availability)$^{-1}$.

The calculated travelling speed is too large to be reasonable and the Larson model does not give a reasonable fit for this set of patrol car data. A possible explanation for the poor fit for patrol cars as compared to that for panda vehicles is that the assumptions regarding road configuration made by Larson are approximately justified on a divisional basis but not on an overall county basis.

If the Larson model is taken to be a valid model for panda vehicles then it can be used to determine the number of panda vehicles required to achieve any specified expected travelling time performance.

For example, if the expected travelling time to any incident for a panda vehicle is not to exceed four minutes then we have

$$\frac{2}{3s}\left\{\frac{A}{K}\right\}^{\frac{1}{2}}(2-\zeta) \leq 4$$

where $t_s = 0$ in the model and A, s are in the appropriate units. Substituting known values for A, s, and ζ from Table 6.9 gives K = 132. This represents a 50% increase on the 1970 level of an average number of 88 panda vehicles on patrol in the whole county. If the specified expected travelling time value was to be halved from four to two minutes then the same procedure gives K = 528. In general

$$K \; \alpha \; \frac{1}{E_{tt}^2} \; .$$

If alternatively it is specified that existing panda vehicles are to be allocated to divisions in order to equalise expected travelling time performance then, with $t_s = 0$, we obtain

$$K \; \alpha \; \frac{A}{s^2}(2-\zeta)^2$$

and assuming that availability is uniform over all divisions

$$K \; \alpha \; \frac{A}{s^2} \; .$$

The divisional distribution of panda vehicles obtained using the equalised expected travelling time performance objective for panda vehicle allocation is shown in Table 6.11

Table 6.11

Panda Vehicle Allocation by Equalised
Expected Travelling Time Objective:
Classified by Division

Division	A (Square Miles)	s^2 (M.P.H.)^2	$\frac{A}{s^2}$	Panda Vehicles Allocated
A	384	3906.25	.098	12
B	94	1024.00	.092	11
C	76	691.69	.110	13
D	25	316.84	.079	9
E	107	1544.49	.069	8
F	178	1310.44	.136	16
G	43	566.44	.076	9
H	21	272.25	.077	9
Overall	928	1376.41	.067	88

The present (1970) divisional distribution of available panda vehicles is included in Table 6.9. Comparison of the two allocations shows that the more compact divisions D, G and H would lose cars to the larger divisions A and F (which would exaggerate the disproportionate workload between these divisions, see below).

If an allocation of police vehicles is made using the equalised workload objective then, using the previously established notation,

$$a_{ij} = \frac{n_{ij}}{w_{ij}}$$

$$= \frac{n_{ij}}{w}$$

where w is the equalised workload.

Let

t_{ij} = expected travel time in location j during time interval i,

A_j = area of location j,

then using the Larson travel time model with $t_s = 0$,

$$t_{ij} = \frac{2}{3s}\left\{\frac{A_j}{a_{ij}}\right\}^{\frac{1}{2}}$$

since $\zeta = 1$, with $k = a_{ij}$

$$= \frac{2}{3s}\left\{\frac{A_j w}{n_{ij}}\right\}^{\frac{1}{2}}, \text{ since } a_{ij} = \frac{n_{ij}}{w} .$$

If the probability density function of incidents requiring service, ρ, is constant over the area under consideration then

$$t_{ij} = \frac{2}{3s}\left\{\frac{w}{\rho}\right\}^{\frac{1}{2}}$$

since $n_{ij} = \rho A_j$

which is independent of the location j (s assumed constant). This observation will be commented on below.

<u>No Car Available Model</u>

Let

x_{ij} = number of incidents for which 'no car available' is recorded in location j during time interval i,

x = total daily number of 'no car available' incidents,

v = proportion of the total number of incidents for which a patrol car is required,

p_{ij} = $P(a_{ij} = 0)$,

with a_{ij}, n_{ij} defined as above. Then an expression for x_{ij} can be derived as follows,

'no car available' will be recorded for an incident if a patrol car is required for the incident and the relevant location has no available patrol cars.

Now the number of incidents for which a patrol car is required in location j during time interval i

$$= vn_{ij} .$$

Patrol cars perform their patrolling duties in a fairly independent manner and it will be assumed that the number of patrol cars in any particular location follows the Poisson distribution so that

$$P(a_{ij} = n) = \frac{\bar{a}_{ij}^{\,n} \, e^{-\bar{a}_{ij}}}{n!}$$

and

$$p_{ij} = P(a_{ij} = 0)$$

$$= e^{-\bar{a}_{ij}} \quad .$$

Equivalently for a proportion $e^{-\bar{a}_{ij}}$ of the time interval i there will be no available patrol cars in location j, so

x_{ij} = (proportion of incidents in location j during time interval i for which a patrol car is required) × (proportion of time interval i for which no patrol car is available in location j)

$$= vn_{ij} e^{-\bar{a}_{ij}} \qquad \text{(A)}$$

and

$$x = \sum_i \sum_j x_{ij}$$

$$= \sum_i \sum_j vn_{ij} \, e^{-\bar{a}_{ij}} \quad .$$

This basic model can be extended to take into account two possibilities for choice of locations j. The above expression (A) gives a prediction of 'no car available' in location j during time interval i under the implicit assumption that the whole of location j is searched for an available patrol car. It could also happen that because of various physical factors the search is only made over certain sub-locations of the location j.

In this case the expression (A) for x_{ij} is modified as follows.

Let

s_j = number of sublocations in location j,

b_{ij} = number of available patrol cars in a sublocation of location j during time interval i,

$q_{ij} = P(b_{ij} = 0)$.

The expression for p_{ij} above is modified under the same assumption of Poisson distribution of available patrol cars to give

$$\begin{aligned} q_{ij} &= P(b_{ij} = 0) \\ &= \left\{ \frac{\bar{b}_{ij}^{\,n}\, e^{-\bar{b}_{ij}}}{n!} \right\}_{n=0} \\ &= e^{-\bar{b}_{ij}} \\ &= e^{-\bar{a}_{ij}/s_j} \end{aligned}$$

since $\bar{a}_{ij} = s_j \bar{b}_{ij}$.

Then if x'_{ij} represents the number of 'no car available' incidents in the location j during time interval i with sublocation search for available patrol cars

$$x'_{ij} = \sum v \frac{n_{ij}}{s_j} e^{-\bar{a}_{ij}/s_j}$$

where the summation is over all sublocations of the location j.

So

$$x'_{ij} = v n_{ij} e^{-\bar{a}_{ij}/s_j} \tag{B}$$

assuming that incidents, n_{ij}, are uniformly distributed over all sublocations of location j.

Comparison of the 'no car available' predictors (A) and (B), based on location and sublocation search, shows that

$$x'_{ij} \geq x_{ij}$$

since, $s_j > 1$, so that 'no car available' figures recorded for sub-location search will exceed those recorded for location search by a factor

$$x'_{ij} : x_{ij}$$

$$= e^{-\bar{a}_{ij}/s_j} : e^{-\bar{a}_{ij}}$$

$$= e^{(1-s_j^{-1})\bar{a}_{ij}} : 1 .$$

<u>Data for Model</u>

Using figures from the 1970 study we have

v = proportion of incidents for which a patrol car was required

$$= \frac{\text{number of times patrol car required}}{\text{number of incidents}}$$

= {(number of times patrol car used) + (number of incidents for which 'no car available' recorded)} / {number of incidents}

$$= \frac{1688 + 789}{10219}$$

$$= 0.242 .$$

Hence (A) and (B) become

$$x_{ij} = 0.242 n_{ij} e^{-\bar{a}_{ij}}$$

$$x'_{ij} = 0.242 n_{ij} e^{-\bar{a}_{ij}/s_j} .$$

To check these models the data in Tables 6.2 and 6.3 was used to provide suitable values for n_{ij} and $\bar{a}_{ij}$ with the m time intervals, i, taken to be the 24 hourly cells of the day and the n locations, j, taken to be the eight divisions A - H. The s_j sublocations were taken to be the subdivisions (patrol areas) of the j-th division.

The two predictions of 'no car available' for divisional and sub-divisional car search for each hour of the day, that is

$$\sum_j x_{ij} , \quad \text{and} \quad \sum_j x'_{ij}$$

are compared in Figure 6.4 with the corresponding actual 'no car available' figures recorded in 1970 from Table 5.13.

This figure shows that the two predictions provide an upper and lower bound for the actual figures recorded. A relation of the approximate form

actual 'no car available'

$$= \frac{6}{5} x_{ij} + \frac{1}{6} x'_{ij}$$

is indicated, giving greater weight to the predicted 'no car available' figures based on divisional search for available patrol cars.

Link of Response Time and 'No Car Available' Models

It has been observed above that actual 'no car available' figures are bounded above by predicted 'no car available' figures for subdivisional patrol car search and below by predicted 'no car available' figures for divisional patrol car search.

The number of incidents for which 'no car available' is recorded depends to a certain extent on the policies of individual H.Q. Control Room officers concerning the search procedure for available cars to despatch to an incident. A consistent measure of 'no car available' could be obtained by defining an envelope about each incident location such that the expected travel time to the incident for any patrol car within the envelope is less than an acceptable operational limit.

In this case 'no car available' corresponds to expected travel time greater than acceptable limit, (that is, no patrol car available within envelope) and expected travel time then covers both these measures of

Figure 6.4

ACTUAL AND PREDICTED NO CAR AVAILABLE INCIDENTS : CLASSIFIED BY HOUR OF DAY

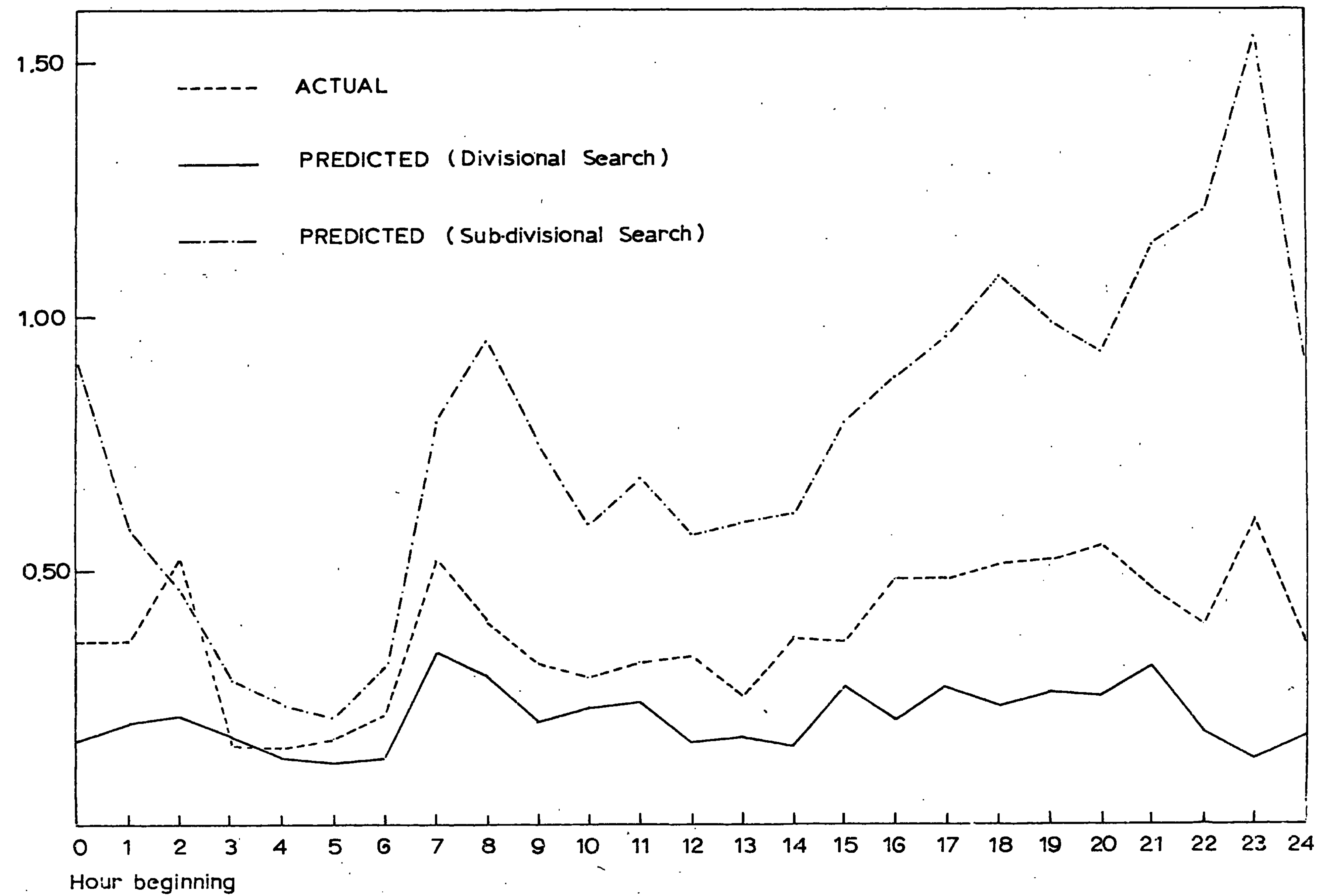


Table 6.12

Actual and Predicted No Car Available Incidents for 1970:

Classified by Hour of Day

Hour Beginning	Actual (Daily Average)	Predicted with Division as Location (Daily Average)	Predicted with Subdivision as Location (Daily Average)
00.01	0.36	0.17	0.91
01.00	0.36	0.20	0.58
02.00	0.52	0.21	0.46
03.00	0.16	0.17	0.29
04.00	0.15	0.13	0.24
05.00	0.17	0.12	0.21
06.00	0.21	0.13	0.31
07.00	0.52	0.34	0.79
08.00	0.40	0.29	0.95
09.00	0.32	0.20	0.75
10.00	0.29	0.23	0.59
11.00	0.32	0.24	0.68
12.00	0.33	0.16	0.57
13.00	0.25	0.17	0.59
14.00	0.37	0.15	0.61
15.00	0.36	0.27	0.79
16.00	0.48	0.20	0.88
17.00	0.48	0.27	0.96
18.00	0.51	0.23	1.08
19.00	0.52	0.26	0.99
20.00	0.55	0.25	0.93
21.00	0.46	0.31	1.14
22.00	0.39	0.18	1.21
23.00	0.60	0.13	1.55
Totals	9.08	5.01	18.06

police emergency response. This point is discussed further in the section below dealing with patrol discipline.

In effect this consistent definition of 'no car available' means that in compact divisions such as D, G, and H the envelope would closely correspond with the divisional boundary (and x_{ij} would be the appropriate predictor of 'no car available') whereas in larger rural divisions such as A and E the incident envelope would correspond more closely to the subdivisional boundary (and x'_{ij} would be the appropriate predictor of 'no car available').

Use of Model to explain 'No Car Available' Differences between 1969 and 1970

Let

$x_{ij}(69)$ = predicted 'no car available' for 1969 assuming divisional search in location j during time interval i,

$x'_{ij}(69)$ = predicted 'no car available' for 1969 assuming subdivisional search in location j during time interval i,

and let $x_{ij}(70)$, $x'_{ij}(70)$ be the corresponding quantities for 1970.

In 1969 the proportion of incidents for which a patrol car was required was

$$\frac{570 + 1536}{9569} = 0.220$$

so that

$$x_{ij}(69) = 0.220 n_{ij} \, e^{-\bar{a}_{ij}}$$

$$x'_{ij}(69) = 0.220 n_{ij} \, e^{-\bar{a}_{ij}/s_j}$$

$$x_{ij}(70) = 0.242 n_{ij} \, e^{-\bar{a}_{ij}}$$

$$x'_{ij}(70) = 0.242 n_{ij} \, e^{-\bar{a}_{ij}/s_j}$$

with the appropriate values for n_{ij}, $\bar{a}_{ij}$, and s_j for each year.

The $\bar{a}_{ij}$ values for 1970 are contained in Table 6.3. The corresponding values for 1969 were known to be unreliable (see section 3.2.2.2 above). These values were imputed as follows. In 1970 with a mobile strength of 67 patrol cars the average value for $\sum_j a_{ij}$ was 13.4 representing 20% turnout of total patrol cars on patrol. Assuming that the same turnout was also achieved in 1969 then with a fleet size of 66 the average value for $\sum_j a_{ij}$ was 13.20.

Hence the 1970, 1969 ratio of predicted average daily 'no car available' based on subdivisional search is

$$x'(70) \;:\; x'(69)$$

$$= 0.242 \times 117.46 \times e^{-13.4/38} : 0.220 \times 111.27 \times e^{-13.2/22}$$

$$= 20.03 \;:\; 13.43$$

$$= 1.49 \;:\; 1.$$

The ratio of predicted average daily 'no car available' based on divisional search is

$$x(70) \;:\; x(69)$$

$$= 0.242 \times 117.46 \times e^{-13.4/8} : 0.220 \times 111.27 \times e^{-13.2/8}$$

$$= 5.30 \;:\; 4.70$$

$$= 1.13 \;:\; 1\,.$$

The actual ratio of average daily 'no car available' incidents was

$$\frac{789}{87} \;:\; \frac{570}{86}$$

$$= 9.07 \;:\; 6.63$$

$$= 1.37 \;:\; 1$$

which lies between the two ratios calculated above.

Use of Model for Patrol Car Allocation

The 'no car available' model can be used to predict the number of available patrol cars required in order to reduce 'no car available' to a specified proportion of all incidents. In 1969 the proportion was 6.0% and in 1970 the figure was 7.7% .

If a proportion of 1% is specified then using the divisional search model we have

$$x_{ij} \doteq 0.242\, n_{ij}\, e^{-\bar{a}_{ij}}$$

and also

$$x_{ij} = 0.01\, n_{ij}$$

so that the number of available patrol cars required to effect this reduction in the proportion of 'no car available' incidents is given by

$$e^{-\bar{a}_{ij}} = \frac{0.01}{0.242}$$

$$e^{\bar{a}_{ij}} = 24.2$$

$$\bar{a}_{ij} = 3.19$$

which requires

$$\sum_j \bar{a}_{ij} = 8 \times 3.19$$

$$= 26$$

patrol cars available on average at any time, an increase of 100% on the 1970 figure of 13.

In general, using the divisional search model,

$$\bar{a}_{ij} = \log_e \{0.242\, n_{ij}\, x_{ij}^{-1}\} .$$

The 'no car available' model can be used in a similar manner to which the response time model was used above to obtain an allocation of patrol cars over the county.

Let

$$a_j = \sum_i \bar{a}_{ij}$$

$$n_j = \sum_i n_{ij}$$

and consider 'no car available' by location so that

$$a_j = \log_e \{0.242\, n_j\, x_j^{-1}\} .$$

If an equalised 'no car available' objective is specified for patrol car allocation then

$$a_j = K + \log_e n_j$$

where

$$K = \log_e 0.242 - \log_e x_j .$$

With $\sum_j a_j = 13$, and the values for n_j from the 1970 study included in Table 6.13 below, the constant $x_j = 0.6440$ and $K = -0.9760$, so that the divisional allocation of patrol cars is given by

$$a_j = \log_e n_j - 0.9760 .$$

The divisional allocation of available patrol cars calculated using the equalised 'no car available' objective is contained in Table 6.13.

Table 6.13

Available Patrol Car Allocation by Equalised 'No Car Available' Objective:

Classified by Division

Division	Emergency Incidents (Daily Average)	Patrol Cars Allocated
A	5.8	0.78
B	16.7	1.84
C	11.2	1.44
D	17.9	1.91
E	11.1	1.43
F	10.3	1.36
G	20.0	2.12
H	24.5	2.22
Totals	117.5	13.10

The figures in the patrol cars allocated column should be interpreted as average available patrol car levels to be achieved. Comparison with the actual distribution recorded in 1970 (see Table 6.3 above) shows that divisions B, D, G, and H would be allocated more patrol cars which would be transferred from divisions A,C,E and F. In particular the patrol car presence in A division would be halved and that in H division increased by over 50%. With this allocation the daily average 'no car available' figure could be expected to be reduced to 5.15 incidents (compared with a recorded figure of 9.1 incidents in 1970).

The workload by division that would be obtained using this allocation is illustrated in Table 6.14 together with the workload by division that was experienced in 1970.

Table 6.14

Emergency Incident Workload for Patrol Cars Allocated by Equalised 'No Car Available' Objective and Actual Patrol Cars:

Classified by Division

Division	Emergency Incidents (Daily Average)	Allocated Patrol Cars	Workload (Hourly)	Actual Patrol Cars	Workload (Hourly)
A	5.8	0.78	0.31	1.54	0.16
B	16.7	1.84	0.38	1.75	0.40
C	11.2	1.44	0.32	1.87	0.25
D	17.9	1.91	0.39	1.48	0.50
E	11.1	1.43	0.32	2.01	0.23
F	10.3	1.36	0.32	1.65	0.26
G	20.0	2.12	0.39	1.77	0.47
H	24.5	2.22	0.46	1.39	0.73
Overall	117.5	13.10	0.37	13.46	0.36

This shows that the equalised 'no car available' allocation of patrol cars also leads to a substantially more even distribution of workload amongst divisions (compared with the situation measured in 1970). However this allocation also implies an adverse effect on expected travel/response times in divisions that would be losing cars, through the increased divisional $\{\text{area/available cars}\}^{\frac{1}{2}}$ factors. In particular the expected travel time in A division would increase in the ratio

$$\left\{\frac{1.54}{0.78}\right\}^{\frac{1}{2}} : 1$$

$$= 1.4 : 1$$

although the expected travel times in B, D, G, and H divisions would be reduced.

<u>Effect of 'No Car Available' on Response</u>

In section 5.1.2.4 the response time performance for 'no car available' incidents was considered. It was noted there that 768 (98.6%) of the 779 'no car available' incidents for which information was available were attended by panda vehicles with an average response time of 8.7 minutes, compared with the average patrol car response time of 7.4 minutes, so that if 'no car available' was recorded for an incident, then for 98.6% of these incidents

(i) the delay in responding was increased, on average from 7.4 to 8.7 minutes, and

(ii) a panda vehicle was despatched to an incident for which a patrol car was required, possibly resulting in a non-quantifiable effect on the response efficiency.

For the other 1.4% of incidents which a patrol car still attended the average response time was found to be 9.6 minutes compared with the usual average of 7.4 minutes, so that an extra response delay of 2.2 minutes was incurred. On average response time was 9.2 minutes so the effect of 'no car available' on an individual incident represents an expected extra response delay of

$$.014 \times (9.6 - 7.4) + .986 \times (8.7 - 7.4)$$

$$= 1.3 \text{ minutes}$$

or 14% of the normally expected delay of 9.2 minutes.

Overall, since 'no car available' incidents constituted 7.7% of all incidents, the proportion increase in delay attributable to 'no car available' was

$$\frac{.077 \times 1.3}{9.2}$$

or 1% .

Relation of Models

It is interesting to note the interrelationship of the models described in the above section.

From the individual police officers point of view an allocation based on an equalised workload objective has the advantage that it avoids disproportionate loading in some areas or during some shifts. If incidents making up the workload considered in this allocation are distributed uniformly over the area under consideration then this allocation also satisfies the equalised response time objective as established above.

However the data collected during the 1969 and 1970 studies described in Chapters III and V showed that in Durham Constabulary, with mixed urban/rural characteristics, incidents were not uniformly distributed over the area under consideration. Hence in the more rural areas where the incident density per unit area was lower the number of police cars allocated on an equalised workload basis were incapable of providing an equal expected response time performance because of large $\{A\}^{\frac{1}{2}}$ factors, and hence under these circumstances expected travel time considerations need to be taken into account.

As expected travel time is proportional to $\{\text{area}\}^{\frac{1}{2}}$, restrictions upon what is considered an acceptable response delay are encountered as area increases, and lead to the idea outlined above of 'no car available' when there is no patrol car available within an area, the incident 'envelope', allowing acceptable expected travel time performance, and local panda vehicles are alternatively despatched to an incident with a possible loss of efficiency.

The interrelationship of factors affecting police response 'efficiency' are considered below in conjunction with police policy for allocation objectives.

6.1.3 Other Approaches to Allocation

Various other approaches to resource allocation were discussed in Chapter I. The applicability of these approaches to the present problem will now be discussed.

Queueing Theory

Patrol Cars

Emergency calls are assumed to form an input with Poisson distribution to the police response service assumed to be composed of c available patrol cars, with an ~~constant~~ exponential service time distribution, forming a pool of servers. The appropriate queueing model is $M/\cancel{D}^{M}/C$ (see Cox and Smith (8)).

Let

n = total number of calls in system,

p_n = probability that there are n calls in system,

λ_n = arrival rate of calls when there are n calls in system,

μ_n = service rate of incidents when there are n calls in system,

λ = arrival rate of calls for service independent of n,

μ = service rate per server (patrol car).

Then

$$\lambda_n = \lambda , \qquad \text{for all } n$$

$$\mu_n = \begin{cases} n\mu , & n < c \\ c\mu , & n \geq c \end{cases}$$

and

$$p_n = \begin{cases} \dfrac{(c\rho)^n}{n!} p_o , & n < c \\[2ex] \dfrac{c^c}{c!} \rho^n p_o , & n \geq c \end{cases}$$

where

$$p_o = \left\{ 1 + c\rho + \frac{(c\rho)^2}{2!} + \ldots + \frac{(c\rho)^{c-1}}{(c-1)!} + \frac{(c\rho)^c}{c!(1-\rho)} \right\}^{-1}$$

provided

$$\rho = \frac{\lambda}{c\mu} < 1 .$$

Data for Model

Assuming that patrol cars serviced all emergency incidents then from the 1970 study the average rate of arrival, λ,

$$= \frac{10219}{87 \times 24}$$

$$= 4.89 \qquad \text{calls/hour.}$$

Mean ~~Constant~~ service time was assumed to be 40 minutes (2/3 hour), (see section 3.2.2.3). The average number of available patrol cars, c, was 15 (including those patrolling motorway). Thus

$$\mu = 1.5$$

and the traffic intensity

$$\rho = \frac{\lambda}{c\mu}$$

$$= 0.22 \quad (< 1)$$

so that there is a stable solution to the queueing model.

Evaluation of the state probabilities, p_n, with the above values for λ, μ, c, and ρ gave the values in Table 6.15.

Table 6.15

State Probabilities for M/~~D~~M/C Queue Model of Emergency Response System for Patrol Cars

Number of Calls in System (n)	Probability (p_n)
0	0.038
1	0.125
2	0.204
3	0.222
4	0.181
5	0.118
6	0.064
7	0.030
8	0.012
9	0.004
10	0.001
> 10	0.001

The low state probabilities, p_n, obtained reflect a lack of congestion in the emergency response system formed by patrol cars as modelled by the M/~~D~~M/C queue. In fact patrol cars dealt with 16% of emergency incidents so that there is no evidence on this basis of any congestion in the patrol car field response to emergency calls.

Panda Vehicles

For panda vehicles each division operates as a separate system. Every division is assumed to use all of its available panda vehicles to service incoming emergency calls irrespective of nominal beat areas. With ~~an~~ the assumed ~~constant~~ exponential service time distribution the appropriate queueing model is M/~~D~~M/C for each division.

Data for Model

Using the data from the 1970 study together with the value for c from section 5.1.2.2 the state probabilities for each divisional queueing model were as shown in Table 6.16. These figures show that in H division with the highest arrival rate of calls for service ($\lambda = 1.02$ calls/hour) and highest traffic intensity ($\rho = 0.113$) the probability of more than half the available vehicles being engaged in service was .006 indicating a low level of congestion.

The calculated state probabilities for both patrol cars and panda vehicles indicate that there was no congestion in the emergency response service as modelled by the $M/\overset{M}{\cancel{D}}/C$ queue. The probability of a wait before a vehicle (either patrol or panda) was available for despatch was very small (of the order of .001).
From the server's point of view the beginning of service was usually immediate. From the customer's (public's) point of view the service commenced after a delay corresponding to the response time of the first police unit.

A complete specification of the stages of service and the corresponding delays encountered follows.

(a) For patrol cars

(i) handling time in H.Q. Control Room,

(ii) waiting time for available patrol car,

(iii) travelling time on route to incident, and

(iv) time spent at incident scene,

or

(b) For panda vehicles

(i) handling time in H.Q. Control Room,

(ii) handling time in divisional and/or subdivisional control room,

(iii) waiting time for available panda vehicle,

(iv) travelling time on route to incident, and

(v) time spent at incident scene.

Table 6.16

State Probabilities for M/$\overset{M}{\cancel{D}}$/C Queue Model of Emergency Response System for Panda Vehicles:

Classified by Division

Division	n	p_n	λ	c	μ	ρ
A	0	0.852	0.24	5	1.5	.032
	1	0.136				
	2	0.011				
	3	0.001				
B	0	0.627	0.70	5	1.5	.093
	1	0.293				
	2	0.068				
	3	0.011				
	4	0.001				
C	0	0.731	0.47	8	1.5	.039
	1	0.229				
	2	0.036				
	3	0.004				
D	0	0.607	0.75	10	1.5	.05
	1	0.303				
	2	0.076				
	3	0.013				
	4	0.002				
E	0	0.736	0.46	4	1.5	.077
	1	0.226				
	2	0.035				
	3	0.004				
F	0	0.751	0.43	7	1.5	.041
	1	0.215				
	2	0.031				
	3	0.003				
G	0	0.575	0.83	8	1.5	.069
	1	0.318				
	2	0.088				
	3	0.016				
	4	0.002				
H	0	0.507	1.02	6	1.5	.113
	1	0.344				
	2	0.117				
	3	0.027				
	4	0.005				
	5	0.001				

The figures in Tables 6.15 and 6.16 above have shown that delay stages a(ii) and b(iii) are practically zero, so that the response delay is in practice made up of the handling and travelling time components only.

Mathematical Programming

The usual applications of mathematical programming techniques (some of which were described in Chapter I) to resource allocation involve the consideration of a number of competing activities requiring constrained resources, where not all of the activities can be operated at their highest individual levels.

In the police system investigated all service activities were operated at the highest level demanded without meeting resource constraints, for example, for both panda and vhf vehicles 60% of duty time was spent on patrol. Thus the activities were not 'competing' in the mathematical programming sense and this technique is not directly applicable.

However if the Lancaster measure of effectiveness (see section 1.2.2 and (4)) is adopted and the optimising objective is to maximise 'potential' good results of police activity including those accruing from patrol discoveries, to a certain extent irrespective of actual crime levels experienced and the possible feedback effect of results on crimes; then mathematical programming becomes applicable and such a model for the police deployment problem (in Lancaster) has been developed and solved (see Aspden and Chambers (27) and Aspden (28)).

6.2 Mobile Patrol Policy

After main allocation objectives have been specified further police policy decisions can include considerations of such factors as

(1) patrol discipline, and

(2) beat description.

Patrol Discipline

Patrol discipline involves the allocation of K cars to patrol areas so that either

(a) one car is allocated to each of K patrol areas in the overall area A to be patrolled, in which case additionally the procedure for covering patrol areas when one or more cars are not available must be specified, or

(b) the same number of cars, K, are allocated to patrol, in a random fashion, the whole of area A.

In the first case there will be either one or no car in each of the K patrol areas. As 60% of total car duty time is spent on patrol (see section 5.1.2.2 and Table 5.10) on average 2 out of every 5 patrol areas will have no available patrol car at any one time. In the event of an incident arising in one of the patrol areas with its beat car already engaged either

(i) the incident will have to wait for service until the beat car becomes available, which is undesirable, or

(ii) a car will be despatched to the incident from one of the adjoining beats.

The procedure for despatching a beat car from an adjoining patrol area as required by (ii) could be specified so as to take into account any relevant local conditions (for example, one-way streets, traffic congestion, unbridged rivers). These procedures might involve a certain amount of additional information flow over the appropriate radio network in order to keep all cars informed of their up to date patrolling obligations.

In the second case the problem of engaged cars is automatically taken account of by the remaining available cars. The probability of a car in any particular location at any specified instant will however be reduced by a factor depending upon the reduction of available cars on total on-duty cars. With this patrol discipline the number of cars in any location is assumed to follow the Poisson distribution.

Beat Description

If patrol discipline (a) is chosen then the corresponding K patrol areas must be structured. Initial requirements could include contiguity of a beat, and/or 'convenient' road network. The beats could further be structured to allow for equalised workload (see section 1.2.2 and Gass (12)), involving patrol areas of differing size, and hence differing expected response time characteristics, or for equalised expected response time performance involving patrol areas of the same size but possibly differing workloads.

The effect of each policy, that is, choice of patrol discipline together with beat description, can be measured in terms of

(1) workload,

(2) expected travel time, and

(3) 'no car available',

using the models described in section 6.1.2 above, and in terms of its effect on other features of response such as multiple despatch of vhf vehicles to incidents, if these can be determined quantitatively.

Expected Travel Distance

The Larson travel time model was developed under the assumption that each police patrol vehicle was allocated to an individual beat. The formula for expected travel distance for a circular region developed in section 6.1.2 above depended upon the assumption that one vehicle was in the area. For the case where K vehicles are patrolling the whole area a modified expression for expected travel distance is needed in order to compare the travel time expectations under different patrol disciplines.

Let

A = area of circular region,

a = radius of circular region,

K = number of cars allocated to patrol the area A, assuming that these cars randomly patrol the whole of area A uniformly, and

E_{td} = the expected travel distance for the nearest of the K vehicles to an incident at the centre of the region.

The distribution function of the distance for one car

$$F(r) = P(\text{distance} \leq r)$$

$$= \frac{\text{area inside circle of radius } r}{\text{area of region}}$$

$$= \frac{r^2}{a^2},$$

under the uniform random distribution assumed above, and the probability density function $f(r)$ for one car

$$= \frac{dF}{dr}$$

$$= \frac{2r}{a^2}$$

For K cars

$$F_K(r) = \{F(r)\}^K$$

$$= \left\{\frac{r^2}{a^2}\right\}^K$$

Hence the probability that one car is at a distance between r and $r+dr$ from the incident and the other $K-1$ cars are at a distance $> r+dr$ from the incident,

$$= K\{1 - F(r)\}^{K-1}\, dF(r)$$

$$= K\{1 - F(r)\}^{K-1}\, f(r)dr$$

$$= K\left\{\frac{a^2 - r^2}{a^2}\right\}^{K-1} \frac{2r}{a^2}\, dr$$

$$= \frac{2Kr}{a^2}\left\{\frac{a^2 - r^2}{a^2}\right\}^{K-1} dr$$

Thus

$$E_{td} = \int_0^a \frac{2Kr^2}{a^2}\left\{\frac{a^2 - r^2}{a^2}\right\}^{K-1} dr$$

and making the substitution

$$r = a \sin \theta, \quad dr = a \cos \theta\, d\theta$$

$$E_{td} = 2aK \int_0^{\pi/2} \sin^2 \theta \cos^{2K-1} \theta\, d\theta$$

$$= \frac{(2^K\, K!)^2}{(2K+1)!}\, a$$

or

$$\frac{(2^K\, K!)^2}{(2K+1)!}\left\{\frac{A}{\pi}\right\}^2 .$$

For $K = 1$, this reduces to

$$E_{td} = \frac{2}{3}\left\{\frac{A}{\pi}\right\}^{\frac{1}{2}}$$

as derived in section 6.1.2 above.

An approximation for E_{td} for increasing K can be developed using Stirling's approximation for n!

$$n! \sim \{2\pi n\}^{\frac{1}{2}} \left\{ \frac{n}{e} \right\}^{n} ,$$

as follows,

$$E_{td} = \frac{(2^K\ K!)^2}{(2K+1)!}\ a$$

$$\sim \frac{2^{2K} \cdot 2\pi K \cdot \left(\frac{K}{e}\right)^{2K}}{\{2\pi(2K+1)\}^{\frac{1}{2}} \cdot \left(\frac{2K+1}{e}\right)^{2K+1}} \cdot a$$

$$= \frac{2^{2K}\sqrt{2\pi} \cdot K^{2K+1} \cdot e}{(2K+1)^{2K+3/2}}\ a$$

$$= \frac{2^{2K}\ \sqrt{2\pi} \cdot K^{2K+1} \cdot e}{(2K+1)^{\frac{1}{2}}\left(1 + \frac{1}{2K}\right)^{2K+1}(2K)^{2K+1}}\ a$$

$$= \frac{e\sqrt{2\pi}}{2(2K+1)^{\frac{1}{2}}\left(1 + \frac{1}{2K}\right)^{2K+1}}\ a$$

and as

$$\left(1 + \frac{1}{2K}\right)^{2K} \to e, \quad \text{as} \quad K \to \infty$$

$$E_{td} \approx \frac{(2\pi)^{\frac{1}{2}}}{2(2K+1)^{\frac{1}{2}}\left(1 + \frac{1}{2K}\right)}\ a$$

also

$$(2K+1)^{\frac{1}{2}} \to (2K)^{\frac{1}{2}}, \quad \text{and} \quad \frac{2K+1}{2K} \to 1$$

$$\text{as} \qquad K \to \infty$$

and so

$$E_{td} \approx \left\{\frac{\pi}{K}\right\}^{\frac{1}{2}} \frac{a}{2},$$

as K increases.

Expected Travel Distance for Second Car

It was suggested in section 6.1.2 above that 'no car available' could be consistently interpreted as no available car within acceptable expected travel time envelope of an incident, or equivalently the expected travel distance for the nearest available car is larger than some acceptable value. It was observed in section 5.1.2.4 that multiple patrol cars were despatched to emergency incidents for 8% of incidents initially attended by patrol cars in 1970 (see Tables 5.19, 5.20 and 5.21). Accordingly the partially redundant 'no car available' measure of response may be replaced by the E_{td} measure for the second nearest patrol car to an incident in order to take into account the multiple patrol car despatch feature of the police emergency response when comparing various combinations of patrol disciplines and beat descriptions.

Using the same notation as above

$$F(r) = \frac{r^2}{a^2}$$

and

$$f(r) = \frac{2r}{a^2}$$

For K cars

$$F_K(r) = \{F(r)\}^K$$

$$= \left\{\frac{r^2}{a^2}\right\}^K .$$

Hence the probability that the second nearest car is a distance between r and r + dr from the incident, the nearest car is at a distance < r from the incident and the remaining K-2 cars are at a distance > r + dr from the incident

$$= {}^KC_{K-2}\, F(r)\{1 - F(r)\}^{K-2}\, dF(r)$$

$$= K(K-1)\, F(r)\{1 - F(r)\}^{K-2}\, dF(r)$$

$$= K(K-1)\, \frac{r^2}{a^2}\left(1 - \frac{r^2}{a^2}\right)^{K-2} \frac{2r}{a^2}\, dr$$

Thus E_{td} (for second car)

$$= \int_0^a 2K(K-1)\left\{1 - \frac{r^2}{a^2}\right\}^{K-2} \frac{r^4}{a^4}\, dr$$

and with the substitution

$$r = a \sin\theta, \quad dr = a\cos\theta\, d\theta$$

$$E_{td} = \int_0^{\pi/2} 2aK(K-1)\cos^{2K-4}\theta\, \sin^4\theta\, \cos\theta\, d\theta$$

$$= 2aK(K-1)\int_0^{\pi/2} \cos^{2K-3}\theta\, \sin^4\theta\, d\theta$$

$$= \frac{3(2^K\, K!)^2}{2(2K+1)!}\, a$$

Comparison with the expression obtained above for E_{td} for the nearest car shows that the ratio of E_{td} for second car to E_{td} for nearest car

$$= 1.5 : 1 .$$

The approximate formula for E_{td} as K increases is obtained in a similar manner to above and is

$$E_{td} \approx \left\{\frac{\pi}{K}\right\}^{\frac{1}{2}} \frac{3a}{4} ,$$

as K increases.

Expected Travel Distances under Different Policies

When comparing expected travel distances under certain combinations of patrol disciplines and beat descriptions it is important to consider not the overall expected travel distance under a policy but rather the expected travel distance to be encountered under the most unfavourable set of circumstances that could arise with a particular policy, that is, policy selection should be based on minimax principles.

Thus with K cars patrolling area A, radius a

$$E_{td} = \frac{(2^K K!)^2}{(2K+1)!} a .$$

However if the one car per beat patrol discipline is used with equal area beats each of area $\frac{A}{n}$, with n cars on-duty, then if all on-duty cars were available

$$\max E_{td} = \frac{2}{3}\left\{\frac{A}{n\pi}\right\}^{\frac{1}{2}} .$$

However on average K, the number of available cars, $= \frac{3}{5}n$ (see Table 5.10) so that using a discipline involving one car patrolling two areas (see below)

$$\max E_{td} = \frac{2}{3}\left\{\frac{2A}{n\pi}\right\}^{\frac{1}{2}}$$

approximately, since the area to be patrolled will be doubled for some of the cars. Thus a valid comparison between the two policies mentioned (all cars patrol whole area; and individual patrol areas with equal area beats) is obtained by comparing

$$\frac{(2^K K!)^2}{(2K+1)!} a, \quad \text{and} \quad \frac{2}{3}\left\{\frac{2A}{n\pi}\right\}^{\frac{1}{2}}$$

where $K = \frac{3}{5}n$, rather than

$$\frac{(2^K K!)^2}{(2K+1)!} a, \quad \text{and} \quad \frac{2}{3}\left\{\frac{A}{n\pi}\right\}^{\frac{1}{2}} .$$

Using the approximation for

$$\frac{(2^K K!)^2}{(2K+1)!}$$

the comparison is between

$$\left\{\frac{\pi}{K}\right\}^{\frac{1}{2}} \frac{a}{2}, \quad \text{and} \quad \frac{2}{3}\left\{\frac{2A}{n\pi}\right\}^{\frac{1}{2}}$$

or

$$\frac{1}{2K^{\frac{1}{2}}} \{A\}^{\frac{1}{2}}, \quad \text{and} \quad \frac{2\sqrt{2}}{3n^{\frac{1}{2}}\ \pi^{\frac{1}{2}}} \{A\}^{\frac{1}{2}}$$

which with A = 928 square miles, K = 13, n = 22 (imputed from K = 13, and availability of 60%) gives a comparison between 4.22, and 3.45 miles, an expected travel distance advantage in favour of the second patrol discipline.

It is interesting to note that if the expected travel distance interpretation of 'no car available' is used, then with maximum expected travel distance of five miles specified (so that if no patrol car is available within a five-mile radius of an incident, for which it is required, it is recorded as 'no car available') each car could cover 79 (25π) square miles from the response viewpoint, and if patrol cars were organised over Durham County so that there was no overlapping of patrol areas, then $\frac{928}{79}$ or 12 available cars would be sufficient to satisfy this response specification. This figure shows good agreement with the recorded figure of 13 for 1970 excluding the cars permanently patrolling the motorway (see Table 6.3).

Information Flow

The additional procedures necessary to deal with occasions when a car allocated to a beat is engaged were briefly mentioned above. One possible arrangement for the second patrol discipline when these procedures become necessary is to have cars (and beats) paired off in a predetermined fashion. In the event of one car being engaged the other car in the pair then becomes responsible for both beats.

This procedure involves informing (by vhf radio) the paired car of its temporarily extended patrolling responsibility but need not necessarily involve any additional radio messages as the original radio message from H.Q. Control Room despatching the first car to the incident could also be broadcast for the attention of the paired car.

As the proportion of time spent attending to incidents is less than 10% of total duty time (See H.A.Taylor (21)) the probability of both members of a pair being simultaneously involved with an incident in their own beat is of the order of 1%. Additionally this pairing implies staggering of generated duties including details and refreshments.

Expected Travel Distances for Second Car under Different Policies

For K available cars patrolling area A

$$E_{td} \text{ (second car)}$$

$$\simeq \frac{3}{2} E_{td} \text{ (first car)}$$

$$\simeq \frac{3}{2} \frac{(2^K K!)^2}{(2K+1)!} \left\{ \frac{A}{\pi} \right\}^{\frac{1}{2}}$$

For individual beat areas of equal area the worst set of circumstances is one of each of two neighbouring sets of pairs engaged so that

$$E_{td} \text{ (first car)}$$

$$\approx \frac{2}{3} \left\{ \frac{2A}{n\pi} \right\}^{\frac{1}{2}}, \qquad \text{see above}$$

and $\qquad E_{td}$ (second car)

$$\approx \frac{2}{3} \left\{ \frac{4A}{n\pi} \right\}^{\frac{1}{2}}$$

which is 1.4 E_{td} (first car) as compared to the factor 1.5 : 1 observed above for the other patrol discipline.

Using the above values for A, K, and n, the expected travel distances for the second car under the two patrol disciplines are calculated to be

6.33, and 4.88 miles

so that from the multiple attendance aspect of the response function the second patrol discipline has a large advantage.

It should be noted that incidents requiring multiple patrol car attendance accounted for 140 (8%) of the 1688 incidents attended by vhf vehicles during the 1970 study (see Table 5.19) or 1% of the total number of incidents. Thus the expected travel distance for the second nearest car is not an important feature of a patrol discipline.

Workload by Location under Different Policies

For the first patrol discipline the workload by location will on average be equalised over all cars. The same is true for the second discipline with the equalised workload beat description. For the second discipline with equalised area beat description the individual workloads will, in general, differ, being proportional to the number of incidents in the beat (see section 6.1.2 above).

The workload by time will in all cases depend on the scheduling schemes used.

Summary of Differences between Patrol Policies

The above comparisons of the various patrol disciplines and their corresponding beat descriptions are summarised in Table 6.17 in terms of the response function characteristics considered, using the same values for K, A, and n as above.

Table 6.17

Patrol Discipline Properties:

Classified by Response Function Characteristic

Response Function Characteristic	Patrol Discipline		
	All Patrol Cars patrol whole county	Individual Patrol Car Beats	
		Equalised Areas	Equalised Workload
Workload by Location	Equal	Proportional to number of incidents	Equal
Expected travel distance for nearest car	4.22	3.45	Between * 1.28 and 7.93
Expected travel distance for second nearest car	6.33	4.88	Between ** 2.78 and 8.68

All distances in miles

* - considering two highest and two lowest incident density beats

** - considering four highest and four lowest incident density beats.

6.3 Optimal Distribution Policy

It has been seen in this chapter that it is difficult to find a common measure for police performance. For example, police workload (by location and by time) and response time are both features of the police response service which may be taken into consideration when allocating police resources but which, as has been seen above (see Table 6.11) are not easily related in terms of a common quantifiable effect on the effectiveness of the police response.

Police workload is easily measured in terms of generated or non-generated incidents per unit of police resource (man or vehicle) and has been widely used as the basis of a 'hazard formula' for the allocation of these resources (see, for example, Baltimore (1), Gass (12), and Wilson (26)). Although large discrepancies in workload by location and by time as measured by emergency incidents per available police vehicle have been noted in Durham Constabulary during the present studies (see section 5.1.2.2, Figure 5.5 and Table 5.11) and redistribution of vehicles amongst divisions and/or shifts might be considered desirable the overall workload level is not high by police standards elsewhere (see section 1.1.3 'Chicago' and (7)) and there is no evidence to suggest any adverse effect on police response efficiency (see, for example, section 6.1.3 'Queueing Theory' Tables 6.15 and 6.16).

The workload by location model developed suggested that the allocation of patrol cars by location was in practice only slightly dependent upon workload (see section 6.1.2. Figure 6.1). The workload by time considerations showed that scheduling schemes pose considerable solution problems arising from highly uneven demands on police resources, and administrative requirements (see section 6.1.2).

The response time model by Larson (17) was tested and found to be valid for the panda vehicle situation but not for the patrol car situation, possibly because the latter did not satisfy the somewhat idealised road network configuration requirements of the model as well as the former.

Using this model an allocation of panda vehicles to divisions under an equalised travel time expectation was calculated (see Table 6.11). This allocation of panda vehicles was found to lead to increased allocation of vehicles to divisions with low workload and hence an exaggeration of already existing workload differences.

No patrol car available considerations led to a model which was capable of providing upper and lower bounds for observed behaviour in 1970 (see Figure 6.4) and an explanation for the 1969, 1970 increase in recorded 'no car available' incidents in terms of revised boundaries and search procedures.

An allocation of patrol cars by division with an equalised 'no car available' objective was calculated (see Table 6.13) and shown to lead to more patrol cars being allocated to divisions with higher incident loadings and a corresponding benefit of a calculated decrease of nearly 50% on existing (1970) 'no car available' levels, a more even distribution of emergency incident workload amongst divisions, but up to a 40% increase in expected travel/response times for those divisions which would receive a smaller allocation of patrol cars.

A suggestion for a consistent definition of 'no car available' is made which introduces the idea of an acceptable response/travel time envelope about an incident, so that an incident with no available patrol cars within its 'envelope' is defined as 'no car available'.

Allocation has also been discussed in terms of patrol policy, which may be defined as a patrol discipline together with a corresponding beat description. Some of the possible policies are compared in terms of expected effect on incident workload, expected travel/response times, and multiple attendance characteristics (see Table 6.17). Sample figures calculated suggested that, for example, the 'individual patrol areas with equal area beats' policy has an expected travel time advantage over the 'all cars patrol whole area' policy.

CHAPTER VII

CONCLUSIONS

The operations of the mobile resources of Durham County Constabulary have been studied with particular reference to their function of responding to calls for service, both emergency and otherwise. Data collected during two three-month survey periods a year apart has been analysed.

1. The main quantitative aspects of the performance of the mobile police system were found to be incident workload, response time to incidents, and recordings of 'no car available'. The nature of the work undertaken, the numbers and types of vehicles available, the proportion of duty time spent on various activities, and the characteristics of the response to a call for service were also evaluated (see Chapters III and V).

2. The effects of organisational changes (see sections 4.2 and 4.3) made between the two survey periods have been assessed in terms of these measures of performance. The main effects were found to be

(i) a significant improvement in patrol car travelling time,

(ii) a significant improvement in panda vehicle handling time, and

(iii) a significant increase in the number of no car available incidents recorded.

These and other effects of the changes are fully reported in section 5.2.

3. Mathematical models of travel/response time and of the other measures of police performance have been tested and found to be generally

applicable to the Durham Constabulary situation. They have been used to explain some of the observed changes and to form a basis for the evaluation of various policies for allocating mobile resources to optimise performance (see section 6.1.2).

4. Possible objectives for mobile police resource allocation have been considered; these include equalising incident workload, minimising expected travel/response time, and minimising the number of no car available incidents recorded. The consequences of these objectives on allocation and on patrol car organisation have been evaluated and it was found that there was a conflict under Durham Constabulary conditions between workload and response time requirements (see section 6.3).

5. Tentative recommendations have been formulated for mobile resource allocation in an area of mixed urban/rural characteristics. It has been concluded that the best allocation will provide adequate mobile police presence in all locations without experiencing either exceptionally high incident workloads or response times, and that this can be best attained by standardising the predicted incidence of 'no car available' over all locations (see section 6.1.2). It has been shown that this allocation also helps to even out the variations in incident workload between divisions and does not give rise to unreasonably high expected travel/response times.

Appendix

Vehicle Availability System

The focus for all vhf radio communications in Durham Constabulary is H.Q. Control Room. The radio procedure adopted requires all vhf vehicles to report to H.Q. Control Room with details of their call-sign, location (division/sub-division or special, see below), availability state (1 - 8, see below), class of vehicle (1 - 8, see below), and radio channel.

This information is manually input to the H.Q. Control Room memory unit, which can summarise it on a display console. The memory can give total numbers, and also list call-signs, of vhf vehicles subdivided by location, state, and class, and also total these over sub-divisional locations to give divisional totals, and over class, but not over state, and can output the location, availability state and radio channel code for a particular vehicle when given its call-sign.

A.1. 1969 Operation

In 1969 the codings used were

Location

Entered by divisional letter, A - H, and sub-divisional number to give one of the 22 sub-divisions (see Figure 2.1) as follows

Division		Sub-division
A	1	Bishop Auckland
	2	Spennymoor
	3	Wolsingham
	4	Barnard Castle
B	1	Hartlepool
	2	Peterlee

Division		Sub-division
C	1	Houghton-le-Spring
	2	Chester-le-Street
	3	Washington
	4	Seaham
D	1	South Shields
	2	Jarrow
E	1	Darlington
	2	Newton Aycliffe
F	1	Durham City
	2	Meadowfield
	3	Stanley
	4	Consett
G	1	Gateshead
	2	Whickham
H	1	Central
	2	Roker

Availability State

1. On Patrol
2. Incident
3. Standby
4. Refreshments
5. Detail
6. Not Available
7. Court
8. Off Duty

Class of Vehicle

1. Headquarters Traffic Patrol (Cars)
2. Headquarters Traffic Patrol (Motor Cycle)
3. Divisional Patrols.

4. Serious Incident Squad
5. Dog Section
6. Headquarters Supervision
7. Divisional Supervision
8. Headquarters Senior Officers.

Special Locations

In addition to the 22 sub-divisional locations specified above there were the following special locations.

Traffic Bases

T1	Aycliffe
T2	Seaham Harbour

Serious Incident Squad Bases

01	Houghton-le-Spring
02	Meadowfield
03	Jarrow
04	Shildon
05	Hartlepool

Dog Bases

P1	Aycliffe
P2	Sherburn Village
P3	Chester Moor
P4	Peterlee

Others

M1	Motorway
N1	Workshops (Aycliffe)
R1	Ramp
Q1	Headquarters

The memory was operated so that it contained details of all vhf vehicles (both operational and non-operational, see below), in all states, including state 8 (off duty), and in all locations.

When the 1969 vhf vehicle availability study was planned the existence of the special locations was not taken into account and so when a cross-check was performed on the data subsequently collected, by totalling vhf vehicles over location, and availability state, the hourly totals did not agree because vehicles in the special locations had not been accounted for.

Also because all vhf vehicles (including, for example, workshops breakdown vehicle and prison vans) were recorded in the memory unit, and hence included in the study data, the total number of vehicles in state 1 was not representative of the real total of operational vehicles, that is, those in classes 1, 2, 3, 4, and 5. Because of these discrepancies the planned cross-checking of the availability study data could not be performed satisfactorily (see section 3.2.2.2).

A.2. 1970 Operation

The codings used were

Location

By divisional letter, A - H, and sub-divisional (patrol area) number as in 1969, except that the number of locations had been expanded so that there were 38 sub-divisions (patrol areas) available in 1970 as follows.

Division	Sub-divisions
A	1 - 7
B	1 - 4
C	1 - 5
D	1 - 4
E	1 - 4
F	1 - 6
G	1 - 5
H	1 - 3

Availability State

The same eight codings were used as in 1969 with the essential difference that whereas in 1969 vehicles going off duty were recorded in the memory as state 8, in 1970 these off-duty vehicles were deleted from the memory.

Class of Vehicle

1. Motor Patrol Cars
2. M Division Motor Cycles
3. Divisional Vehicles
4. Serious Incident Squad
5. Dog Section Vehicles
6. Motor Patrol Supervision
7. Headquarters Senior Officers.

Only vhf vehicles in classes 1, 2, 4, and 5 (that is, the operational vehicles) were recorded in the memory, and these were recorded separately for the 1970 vhf vehicle availability study (see section 4.4).

Special Locations

In addition to the 38 sub-divisional locations specified above there were the following special locations.

Motor Patrol Bases

M1	Section 1 (Jarrow)
M2	Section 2 (Houghton)
M3	Section 3 (Meadowfield)
M4	Section 4 (Aycliffe)

Special Incident Squad Bases

01	Houghton-le-Spring
02	Meadowfield
03	Jarrow
04	Shildon
05	Hartlepool.

Dog Bases

P1	Aycliffe
P2	Sherburn Village
P3	Chester Moor
P4	Peterlee

Others

M5	Workshops (Aycliffe)
M6	South Shields Garage
M7	Gateshead Garage
Q1	Headquarters
R1	Motorway North
R2	Motorway South
R3	Durham Ramp
R4	Marley Hill Wireless Depot.

The changes in operation in 1970, with only vehicles in classes 1, 2, 4, and 5 recorded and vehicles in availability state 8 deleted from the memory meant that again no cross-checking on the collected data on the number of vehicles in sub-divisional and motorway locations was possible. Further the inability of the memory to total vehicles over state meant that the number of vehicles in state 1 (on patrol) could not be cross-checked.

The changes had the positive effect that only on-duty operational vhf vehicles were displayed on the console when the memory was interrogated and that the totals recorded were of vehicles genuinely available for attending to incidents.

A.3. Organisation of Vhf Vehicle Information

Information from vhf vehicles is communicated via vhf radio to radio operators (one per radio channel) in H.Q. Control Room, who are responsible for updating the contents of the memory unit.

Vhf vehicles should communicate with H.Q. Control Room when

(i) they come on duty,

(ii) they change their status, that is, change location, availability state, or radio channel, and

(iii) they go off duty.

In the first case the vehicle will sign-on by radioing the operator in H.Q. Control Room with details of call-sign, availability state, class of vehicle, and radio channel. This information will then be keyed into the memory by the operator concerned. In the second case the change in status is reported and the appropriate updated information is keyed into the memory. In the third case, when the vehicle signs-off, the availability state was altered to 8 (1969), or the details of the vehicle were deleted from the memory (1970).

In sections A.1, and A.2 above differences in the general operating procedures and status codings that existed in 1969 and 1970 were specified.

As H.Q. Control Room memory unit was the sole source of updated information on vhf vehicles, the reliability of the information was investigated.

Observation of the radio operations in H.Q. Control Room identified congestion of air-space as a possible source of errors in the information available. As the same shifts were worked by a number of vehicles it was possible that up to 20 vehicles could be simultaneously trying to log-on or off. This caused congestion of 'air-space' so that some of these vehicles were not able to contact H.Q. Control Room, and also overloaded the radio operator who could, even though receiving a logging-on or off message, forget to key-in the appropriate information to the memory.

At other times this congestion should not have been a problem as the subsequent figures for the number of messages relating to changes of status show.

A.4. Study of Vhf Radio Communications

A detailed analysis of the Control Room log recording all vhf radio messages was carried out in 1969 to check the number of messages transmitted by vehicles, the air-time used on the two regular radio channels, and the validity of some of the memory unit contents.

An early conclusion reached was that the output provided by the memory unit when interrogated was frequently based on fairly inadequate information. This followed the finding that for H.Q. and divisional patrol cars the average number of calls made to the H.Q. Control Room radio operator giving information was 0.9 per hour of patrol time. Table A.1. includes a breakdown of radio messages per hour patrol time classified by type of patrol car.

Table A.1

Radio Messages per Patrol Hour:
Classified by Type of Patrol Car.

Type of Patrol Car	Radio Messages	Patrol Hours	Radio Messages per Patrol Hour
H.Q.	162	150	1.1
A	47	64	0.7
E	53	64	0.8
H	66	76	0.9
Overall	328	354	0.9

In periods in July and September of 1969 the amount of air-time used on the two vhf radio channels was logged to investigate the occurrence of congestion. It was found that in any half-hour channel 2 was occupied for between $5\frac{1}{2}$ and just over 20 minutes. The corresponding figures for channel 3 were 5 and $13\frac{1}{2}$ minutes. The average call made was about 0.5 minutes.

Assuming that these calls from vehicles satisfy the requirements for randomness (which seems reasonable except at times of shift changes) then the incoming calls constitute a Poisson input to the available radio operator, and assuming further that the length of a call follows the negative exponential distribution, then each radio channel has the structure of a M/M/1 queue (see Cox and Smith (8)).

Analysis of the queue situation shows that with a utilisation of 20 minutes in the half-hour, on average there is always one vehicle waiting to call, and one vehicle calling, and that a vehicle, on average, has to wait 0.5 minutes before being answered.

Panda vehicles in 'A' division necessarily on vhf (see section 2.3) were found to create inaccuracies in the memory unit contents. On one occasion investigated it was found that although the memory unit recorded as available three panda vehicles, no calls had been made by them, and they were not listed on the duty sheet as having been on duty that day.

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