NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF APPLIED MATHEMATICS

NOVEMBER 2001 EXAMINATION

SMA 5192 APPLICATIONS OF QUANTITATIVE ANALYSIS

November 2001 | 4 Hours

This examination contains **ONE** question only.
Statistical tables have been provided, and silent calculators may be used.

INSTRUCTIONS

The following document about rural policing is in three parts.

a) A review of the effects of population sparsity on the policing of rural areas in Bushland.
b) A set of appendices giving some statistical analyses that have already been performed.
c) An application of a hexagon model to the current situation of the Lionden police force and its claim for extra funding.

Imagine that, this afternoon you must attend a meeting at which you must present a brief report in which you:

- Critically review the work already done on sparsity effects;
- Discuss the claim made by Hippocreek that they need an extra 243 police constables;
- Discuss other ways in which the effects of population sparsity on the policing of rural areas might be tackled and consider the contribution that operations research might make to this.

Your task is to write this report.

1.0 INTRODUCTION

Bushland has no national police force, instead it is policed by local forces operating within geographical districts. However, most of the funding received by these forces comes from the Bushland Government, which is itself funded from national taxation. The funding received by each force is mainly the result of a formula which is applied to them. The idea of this formula funding is to ensure equity and to encourage the police forces to be economical in their operations. The formula in use in 2000/01 gives the following weightings to the different factors thought relevant to expenditure on policing.

	%
Call management	15.5780
Crime Management	15.5780
Traffic Management	6.2310
Public order management / public reassurance	6.7490
Community policing management	2.0770
Pensions expenditure	12.3000
Security-related expenditure	0.9870
Sparsity	0.5000
Police establishment	40.0000
TOTAL	100.0000

A particular concern has been expressed about the treatment of sparsity in this formula and there has been much debate about its effect.

In Bushland there is much variation in population density across the country, particularly between the Wetlands and the Drylands. Urban areas are very densely populated, whereas rural parts tend to be sparsely populated. This, it is claimed by some, has a great effect on the cost of policing in the different areas. The current funding formula attempts to take some account of this by working with adjusted population figures – increased in rural areas and decreased in others using an index number.

Sparsity is perceived to add extra cost to rural forces in their Transport, Communications and Operational Capacity. Each of these is discussed in turn in the following sections.

2.0 TRANSPORT

Total national expenditure for Police Transport is about HE 250M per annum (the currency in Bushland is the High Ena). Of this, about HE 200M is revenue expenditure and about HE 50 M is for the purchase of vehicles from the capital budget. One important question is whether it is reasonable to distribute this money using the formula or on some other basis of need.

Previous research (see below) has established the link between sparsity and the fleet mileage and an attempt was made to convert this to cost per kilometre travelled. This seemed to suggest a link with density, but the analysis was based on correlation and not causation. It is also possible to question some of the estimates that were used.

2.1 Previous Research

Appendix 1 shows a regression analysis that attempts to derive an actual cost per kilometer, using actual cost data from 1996 / 97 for fuel, oil and tyres. The results shown exclude the capital city of Lionden, which would have a major distorting effect.

There is a better link (see Appendix 2) between cost and the percentage of the fleet that uses diesel or small petrol cars on built-up major roads. This seems to show that some forces are more cost conscious than others in their use of transport. The choice of vehicles and of fuel clearly adds "noise" to any analysis based on actual data.

The best predictor of fleet mileage comes from linking the following factors:
- Average fleet mileage (1995 – 97) per head of population;
- A distance factor: this being the square root of (area / population);
- Built-up major roads per head of population.

A regression analysis for this is shown in Appendix 3. It implies that mileage increases with distance but reduces when population per kilometer of built-up major roads falls, reflecting higher activity in urban areas.

It seems reasonable to distribute the HE 250M for forces on the basis of predicted mileage, though it might be argued that fewer vehicles are needed for areas of high population density – thus the HE 50M capital might be allocated by some other means. Appendix 4 shows a regression of:
- Number of vehicles per 100 officers;
- Density of population;
- Traffic on non-built-up roads.

This seems to reflect the intuitive view that, in urban areas, police officers can walk.

2.2 Down-Time

Rural forces argue that because their officers often travel greater distances without actually adding any value, this adds to officer down-time. In urban areas, journeys help meet the Government Key Objective of High Visibility Policing. But in rural areas, a patrol may be seen by relatively few people even though the journey may be long – and these people have already been accounted for in the population element of the allocation model. The logic being that the regression equations would identify three elements making up the fleet mileage's predicted for each force as follows:

a) A constant down-time per head of population. This should be the same for each force and can be derived by using the model to reduce each force to the same status.
b) An increase in down-time to allow for extra distance in some areas.
c) A reduction in down-time to allow for lower levels of activity in rural forces.

It is possible to quantify the downtime for each force by multiplying a unit cost per hour by the ratio of average speed divided by the extra distance traveled. For the four Wetlands police forces, the cost of down-time ranges from about HE 500,000 to over HE 1,5M if calculated this way.

3.0 COMMUNICATIONS

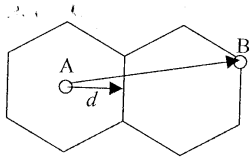
Communications represented the lifeblood of any police force and hilltop sites are needed to provide radio cover. Current accounting systems provide no way of untangling these communications costs and it is suggested that future accounts might show communication costs separately. In addition, some standard for radio cover must be established. Once costs and standards are available, it should be possible to establish the extra communications costs of rural policing.

4.0 OPERATIONAL CAPACITY

Given a travelling speed and a response time, it is possible to calculate the area that can be covered by a single officer working from a known base. It is also important to ensure that each officer has a back-up available for Health and Safety reasons (the *need* hypothesis) and this is best achieved by ensuring that each officer can cover part of the neighbouring area. The *need* hypothesis provides a safety net for forces that have large areas and / or extraordinary distributions of population to consider. Other factors, such as the country borderlines, are also relevant.

A hexagon-based model, as shown below, provides one way of analysing this situation. In such a model, a force area is divided into hexagons using standard data. This might, for example, specify:

- Square kilometers covered by each force.
- Response times for calls for assistance by another officer (say 20 minutes).
- An attainable average travelling time for reaching the scene (say 60 km per hour).
- A squiggle factor (the ratio of road distance to straight-line distance between two points). This is 1.38 for Hippocreek, for example.
- The population in settlements above some threshold size (say 3 000).



Hexagon model: Officer based at A, worst case call at B.

The distance (A, B) represents a call in which the officer, based at A, must travel the maximum distance to B, the extreme point of the adjacent hexagon.

Hence,

$$(A,B) = \sqrt{\frac{28}{3}}d$$

and the area of the hexagon must not exceed:

$$\frac{3\sqrt{3}V^2t^2}{14\lambda^2}$$

where V = average speed
t = maximum response time
λ = squiggle factor

APPENDIX 1

MULTIPLE REGRESSION

Listwise deletion of missing data
Equation Number 1 Dependent variable. . ACTPKILM
Block Number 1. Method: Enter EDDENS97

Variables entered on step number
1. EDDENS97

Multiple R	0.38648
R square	0.14937
Adjusted R square	0.12810
Standard Error	0.59453

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	2.48270	2.48270
Residual	40	14.13849	0.35346

F = 7.02395 Signif F = 0.0115

Variables in the equation

Variable	B	SE B	Beta	T	Sig T
EDDENS97	0.183947	0.069407	0.386484	2.650	0.0115
(Constant)	3.727139	0.292033		12.763	0.0000

End Block Number 1 All requested variables entered.

Note:
Variable ACTPKILM represents cost per kilometre.
Variable EDDENS97 represents population density.

APPENDIX 2

MULTIPLE REGRESSION

Listwise deletion of missing data
Equation Number 1 Dependent variable. . ACTPKILM
Block Number 1. Method: Enter BUMA98 PET_DEI

Variables entered on step number
1. PET_DEI
2. BUMA98

Multiple R	0.64135
R square	0.41133
Adjusted R square	0.38114
Standard Error	0.50088

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	6.83672	3.41836
Residual	39	9.78447	0.25088

F = 13.62526 Signif F = 0.0000

Variables in the equation

Variable	B	SE B	Beta	T	Sig T
PET_DEI	-0.024079	0.007209	-0.432691	-3.340	0.0019
BUMA98	0.001000	3.6430E-04	0.355686	2.746	0.0091
(Constant)	5.477782	0.432884		12.654	0.0000

End Block Number 1 All requested variables entered.

Note:
Variable ACTPKILM represents cost per kilometre.
Variable BUMA98 represents kilometres of built-up, major roads.
Variable PET_DEI represents the percentage of the fleet that is diesel or small petrol.

APPENDIX 3

MULTIPLE REGRESSION

Listwise deletion of missing data
Equation Number 1   Dependent variable. .   FLEET_P
Block Number 1.   Method: Enter   BUMA98_P   DIST_POP

Variables entered on step number
1. DIST_POP
2. BUMA98_P

Multiple R	0.83348
R square	0.69469
Adjusted R square	0.67943
Standard Error	1621.34051

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	239528269.96219	119629134.98110
Residual	40	105149802.20813	2628745.05520

F = 45.505808   Signif F = 0.0000

Variables in the equation

Variable	B	SE B	Beta	T	Sig T
DIST_POP	4.833563	0.588325	0.719036	8.216	0.0000
BUMA98_P	-3.376577	0.775433	-0.381904	-4.354	0.0001
(Constant)	13409.079140	512.491807		26.164	0.0000

End Block Number 1   All requested variables entered.

Note:
Variable FLEET_P represents average fleet mileage per head of population.
Variable BUMA98_P represents kilometres of built-up, major roads per head of population.
Variable DIST_POP represents the distance factor.

APPENDIX 4

MULTIPLE REGRESSION

Listwise deletion of missing data
Equation Number 1 Dependent variable.. VEH_STR

Variables entered on step number
2. TN98

Multiple R	0.76865
R square	0.59082
Adjusted R square	0.56984
Standard Error	1.99158

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	223.36008	111.68004
Residual	39	154.68864	3.96638

F = 28.15670 Signif F = 0.0000

Variables in the equation

Variable	B	SE B	Beta	T	Sig T
EDDENS97	-1.619296	0.232764	-0.713381	-6.957	0.0000
TN98	0.001023	4.1241E-04	0.254392	2.481	0.0175
(Constant)	26.035426	1.128996		23.061	0.0000

End Block Number 1 POUT = 0.100 Limits reached

Note:
Variable VEH_STR represents number of vehicles per 100 officers.
Variable EDDENS97 represents population density.
Variable TN98 represents traffic on non-built-up roads.

THE HEXAGON MODEL APPLIED TO HIPPOCREEK: WHY WE NEED MORE POLICEMEN

1.0 BASIC DEMOGRAPHICS

Hippocreek covers an area of approximately 4250 square kilometres and would thus be covered by approximately 123 such hexagons, using values for the parameters suggested in section 4 of the first report. The borderline means that this is a conservative estimate of the number needed.

The population of Hippocreek is approximately 475,000 and of this, about 200,000 people live in 21 settlements of 3,000 or over. The 200,000 people in the 3,000+ settlements would be funded by the normal formula (these being equivalent to urban areas). The remaining 275,000 people would therefore occupy 102 hexagons.

2.0 CONSTABLES NEEDED

2.1 Hexagon model for rural areas

The aim is to provide 24 hour cover 365 days per annum, with constables working 3 shifts per day, making 1,095 shifts in all. Each constable has 104 rest days per annum, 26 days annual leave, 10 days training, 24 days for court / escort duties and 20 days for reports and interviews. This leaves 181 days for patrolling and dealing with incidents. Hence, each hexagon needs (1095 / 181) constables; that is 6.05.

With 102 rural hexagons this means that (102 x 6.05) constables, that is 612, would be needed even if there were no cover for sickness. In addition, the other 21 hexagons would need police constables.

2.2 Current position

The entire Hippocreek police force currently has 614 constables available for these general duties. If the national formula, based purely on population figure were to be applied to the whole area, then the force would have 636 constables.

If the national, population-based formula were to be applied just to the 21 urban hexagons, then they would need 267 constables just for these areas. If the 612 needed for the rural hexagons is added, this implies that the Hippocreek force would need 879 constables. This implies that the force's funding is penalised by the national formula by an amount equivalent to 243 constables.

3.0 CONCLUSION

On the basis of the hexagon model, the Hippocreek police force is under-staffed by about 243 constables. The national funding allocations should be modified to take account of the special circumstances faced by rural police forces such as Hippocreek.

END OF QUESTION PAPER