FOWLERS GAP ARID ZONE RESEARCH STATION

A FEED INDEX SYSTEM FOR SIMULATING STOCKING RATE ADJUSTMENTS IN ARID AREAS

P.D. CHUDLEIGH
and
S.J. FILAN

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FOWLERS GAP ARID ZONE RESEARCH STATION

UNIVERSITY OF NEW SOUTH WALES

This Field Station of 98,000 acres (39,200 hectares) is situated 70 miles (110 kilometres) north of Broken Hill in western New South Wales. It was leased to the University in 1966 to facilitate arid zone research, particularly into problems concerning the pastoral industry in the region. With an average rainfall of 8 inches (20 centimetres) distributed through the year, the Station is climatically representative of much of the southern Australian arid zone. The Station carries some 5,000 sheep, and has a small laboratory as well as residential facilities for scientists. Its policy is guided by a Consultative Committee which includes representatives of the pastoralists and of other local interests, of the New South Wales Departments of Lands and Conservation, and of C.S.I.R.O., as well as of the University. The Station is presently administered through the University's Robinson College at Broken Hill.

Enquiries should be addressed to:
The Technical Secretary,
Institute of Rural Technology,
University of New South Wales,
P.O. Box 1, Kensington, 2033, N.S.W.

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NOTE: It is suggested that readers who are not familiar with the research technique known as "simulation" will find this publication more understandable if they first read Appendix I.

CHAPTER ONE

INTRODUCTION

In the first publication of this Fowlers Gap Research Series, Chudleigh (5)* reported results of two surveys and of budgetary analyses of pastoral management problems in the West Darling region of New South Wales. This early work suggested a need for more detailed examination of factors affecting the economic performance of grazing properties in this region.

The method used in this further examination was construction of, and experimentation with, a simulation model of a case-study property in the region. The potential value of simulation models in technical and economic research for the pastoral industries of Australia has been discussed by a number of writers, such as Anderson (2 and 3), Goodall (9) and Waring (14).

In the development of this simulation model of a West Darling property, a central problem was found to be the definition of that sector of the model concerned with factors which affect feed growth, utilisation and deterioration, and which consequently exert a major influence on the timing and magnitude of adjustments to livestock numbers. This publication reports the development of the sub-model used in this sector of the simulation. Other aspects of the simulation model are reported by Chudleigh (4) and by Chudleigh and Filan (6).

Three classes of sub-models of feed conditions were considered in the West Darling study. Two classes, which were not found to be satisfactory for this application, are reviewed briefly in Chapters 2 and 3. The balance of this report is devoted to the third class, which is here labelled as a "feed index system".

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* References, numbered as in Appendix II at the end of this publication, are cited by numbers in parentheses.

CHAPTER TWO

BIOLOGICAL SUB-MODELS

In a study of pastoral management in Central Australia, Waring (14) has reported use of a soil moisture balance model similar to that published by Fitzpatrick *et al*. (8). Results from this type of model seem very useful for indication of periods of feed growth and for definition of significant droughts, but they do not appear to reflect quantitative feed availability within periods as short as one month with the precision desired in the study reported here. One factor inhibiting the use of this type of model for the West Darling region is the lack of local data available for use in re-estimation of the parameters of the Fitzpatrick model: such re-estimation would seem necessary, as Perry (13) has run the Fitzpatrick model using Broken Hill meteorological data and found that the original parameters lead to estimates of unrealistically long periods of feed growth.

Quantitative models of the detailed biological relationships amongst factors which determine feed growth, utilisation and deterioration in the arid zone would be extremely useful because their incorporation in more general simulation models would permit examination of the effects of many potential changes in management of the grazing system. Unfortunately, data are simply not available from the pastoral areas of New South Wales for the estimation of parameters of models like those reported by Fitzpatrick *et al*. (8), Goodall (9) and Jones and Brockington (12). Examples of data which are desirable but unavailable are information on the relative responses of different vegetation communities to soil moisture changes and on the long-run effects of different stocking policies on the proportion of different species in a given vegetation community.

CHAPTER THREE

SUB-MODELS BASED ON HISTORICAL RECORDS

Halter and Dean (10 and 11) used their interpretation of reports published by the Crop Reporting Service of the United States Department of Agriculture over the years 1922 to 1964 to assign monthly values to an index of pastoral conditions. The frequency distributions of levels of this index were then used to construct continuous probability distributions which were subsequently sampled as part of a simulation model. The official data on which this model was based referred to a relatively small and homogeneous region, the Sacramento Valley of California.

The Halter and Dean approach cannot readily be used for simulation of individual properties in the arid zone of Australia. While pastoral conditions are regularly reported in qualitative terms in New South Wales, for instance by the State Department of Agriculture (1), the reports refer to relatively large and heterogeneous regions and cannot be expected to reflect the conditions experienced by individual properties with any precision. As it was desired, in the present study, to examine the performance of a specific property, an alternative approach was sought.

An attempt was made to use an alternative source of historical data as a basis for the sub-model. Records of monthly rainfall and of the number of sheep shorn in the years 1934 to 1968 were collected from nine properties in the West Darling region. Chudleigh (4, pages 69 - 74) estimated parameters for a range of functions based on this data for the nine properties collectively and for the case-study property alone. As these functions explained only eight to twenty per cent of the observed variance of sheep numbers, they were not considered to be adequate bases for the simulation model. Even if these functions had been found to explain a high proportion of the variance of numbers of sheep shorn, their use would have been limited in two ways: they refer only to numbers on hand at shearing, and so ignore within-year variation in sheep numbers; and they subsume the graziers' decision policies, so that sub-models based on them could not readily be manipulated for testing of alternative decision rules.

CHAPTER FOUR

THE FEED INDEX SYSTEM

The sub-model finally adopted in the West Darling simulation study is based on an empirical representation of feed conditions on a pastoral property. This representation is used in conjunction with the grazier's policies on decisions relating to stocking rate adjustments. Whilst this feed index system is imperfect, and has less flexibility than might be expected in a "biological" sub-model, it has proved to be an effective basis for simulation of one property, and may be of value in other studies.*

In this system the basic unit of measurement is a unit of an index: one unit is defined as the availability of sufficient feed to carry normal sheep numbers for one month. "Normal sheep numbers" are defined for a specific property as the long-term-average number of adult sheep which the grazier desires to carry. The phrase "to carry" in this context is defined as implying maintenance of levels of body weight and of rates of wool growth considered by the grazier to be "normal" for the type of sheep run on the property under his management.**

Simulation of operation of the feed index system involves a recursive pattern of estimation of the level of the feed index. The approach is summarised in equation 1.

$$A_i = A_{i-1} + B_{i-1} - C_{i-1} \qquad \text{(Equation 1)}$$

where: A_i = feed index level, in units, at the start of month (i);

B_i = effect of climatic conditions in month (i) on present and future feed production, measured in units of the index; and

C_i = feed consumption and deterioration during month (i), measured in units of the index.

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* This simulation model is already being used for research purposes in at least two other institutions.

** This definition is associated with one of the limitations of the feed index system. The parameters would need to be re-estimated if it were desired to use the simulation model to examine policies which involved changes in the type of livestock run or in the long-run average level of wool production per head sought by the grazier.

4.1 Opening Level of the Feed Index

For testing and validation, the model was run for the period July, 1953 to December, 1968, as data on performance of the simulated property over this period were available. A feed index level for 1st July, 1953, was assigned by the authors on the basis of their interpretation of the New South Wales Department of Agriculture reports (1) on pastoral conditions in the region during the first half of 1953.

In use of the model for other purposes, such as the testing of alternative management strategies, several approaches to the choice of an initial value for (A_i) are available. A level might be drawn at random from the distribution of levels observed in the validation run of the model; the opening level of (A_i) might be systematically varied as a "treatment" variable in experiments using the simulation model; or the model might simulate operation from a given point in "real time", with the opening level of (A_i) set in the same way as was followed in the case of the validation run. An attempt to eliminate bias due to choice of the opening level of the variable might be based on the practice of discarding, for purposes of experimental analysis, results for the first few years of each simulated period.

The general principles of selection of initial values for variables in a simulation model are discussed by Conway (7).

4.2 Feed Production

The graziers who co-operated in this study were able to make estimates of (B_i) for specified climatic conditions when this variable was described to them (after general discussion of the objectives and methods of the study) as "the response......in terms of the number of months of feed that you could see ahead for your average sheep numbers".* Thus (B_i) was defined as a total response (to climatic conditions) in terms of feed growth during both current and future months, rather than simply as feed growth during the current month.

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* The major doubt or reservation expressed by graziers in making these estimates was that actual availability of the expected feed response could be seriously restricted if windy conditions were experienced in subsequent months.

4.2 Feed Production (Cont.)

In operation of the simulation model, (B_i) was calculated as a function of temperature, rainfall, and pastoral conditions at the start of month (i). The parameters of this function were estimated by regression analysis of a set of estimates, by the grazier, of the level of (B_i) which he would expect for his property under a range of specified conditions.

In making these estimates, the grazier was explicitly asked to consider rainfall during month (i) and "growing conditions" at the start of month (i).

As interviews became unduly complicated if attempts were made to specify detailed rainfall parameters such as the intensity of individual falls, the grazier was asked to base his estimate on a total number of points of rain for a month, assuming a "normal" distribution of the rainfall over the property and during the month.

The grazier was asked to consider pastoral conditions at the start of a month as "good", "average" or "poor", with these terms being defined as a function of total rainfall over the preceding four months. This basis was considered to be more relevant than the opening level of the feed index for the month: a given feed index level might represent either a large volume of old, standing feed, or a smaller but more rainfall-responsive volume of new and actively growing feed. Thus recent rainfall history was considered the best available indicator of the responsiveness of herbage to current rainfall.*

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* For the properties studied, mean annual rainfall was about 750 points. "Good" conditions were stated to exist if rainfall over four months exceeded 300 points; "average" conditions for 200 to 300 points; and "poor" conditions for less than 200 points. As four-month total rainfalls in excess of 600 points are rare for this area, the mid-points of the three ranges were taken as 450, 250 and 100 points respectively. In regression analyses, "good", "average" and "poor" conditions were coded as 4.5, 2.5 and 1.0 respectively.

4.2 Feed Production (Cont.)

Temperature was not discussed explicitly in the interviews, but was considered by asking the grazier to relate his estimates to specific calendar months, and to assume "normal" temperature and wind conditions for that month.*

After some experimentation, which involved collection of sets of estimates from a number of graziers, it was assumed that for a given property sufficient data would be provided to allow consistent estimates of parameters if the grazier was asked to estimate (B_i) for each of the 24 situations shown in Table 1.

The estimates collected for the situations listed in Table 1 were used as regression data to estimate parameters for a function:

$$B_i = f(X_1, X_2, X_3) \qquad \text{(Equation 2)}$$

where X_1 = coded value for growing conditions;

X_2 = rainfall, in points, for month (i); and

X_3 = sine (1.32 x mean Broken Hill temperature for month (i) in degrees Fahrenheit).

The sine function was considered to be an appropriate representation of the form of the temperature effect as, over the observed range of temperature levels, efficiency of photosynthesis increases with temperature, but this advantage is offset by high levels of evaporation at high temperatures. The factor by which temperature is multiplied is a parameter calculated from the grazier's reply to

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* For regression analyses the temperature variable was measured as mean temperature at Broken Hill, in degrees Fahrenheit, for the month in question. Individual property temperature records were not available, but it is thought that use of Broken Hill data for this variable leads to negligible bias.

TABLE 1

Situations for which Graziers Were asked to Estimate Feed Responses

Month of year	Points of Rain for Month	Initial Growing Conditions	Month of year	Points of Rain for Month	Initial Growing Conditions
January	150	Good	July	60	Good
January	30	Average	July	200	Average
February	30	Average	August	200	Average
February	300	Poor	August	80	Poor
March	40	Poor	September	175	Poor
March	250	Good	September	20	Good
April	350	Good	October	50	Good
April	70	Average	October	300	Average
May	20	Average	November	90	Average
May	100	Poor	November	50	Poor
June	150	Poor	December	125	Poor
June	250	Good	December	100	Good

4.2 Feed Production (Cont.)

the question "Which do you consider to be the best months to receive rain, from the point of view of adding most to the long-term feed supply?" In the case studied in detail, the months mentioned indicated that the maximum of the growth function, with respect to temperature, should be at 68 degrees Fahrenheit.[*]

A simple linear function of the three variables explained 96 per cent of the variance of the grazier's estimates of (B_i) for the case study property.[**]

$$\begin{array}{rcl} B_i & = & -6.25 + \underset{(4.63)}{0.177X_1} + \underset{(20.74)}{0.012X_2} + \underset{(2.98)}{6.176X_3} \end{array}$$

(Equation 3)

On biological grounds some interaction amongst the variables would be expected. A function with interaction terms explained 98 per cent of observed variance of estimates of (B_i).[⊕]

$$\begin{array}{rcl} B_i & = & 9.692 - \underset{(2.68)}{3.618X_1} - \underset{(0.93)}{0.024X_2} - \underset{(1.59)}{9.888X_3} \\ & & + \underset{(1.36)}{0.0005X_1X_2} + \underset{(2.74)}{3.822X_1X_3} + \underset{(1.31)}{0.034X_2X_3} \end{array}$$

(Equation 4)

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[*] We want (k) which yields sine (68k) = 1.0, the maximum of the sine function. This implies (68k) = 90, so k = 90/68 = 1.32.

[**] Values of Student's "t" are shown in brackets beneath the regression coefficients in equations 3 and 4. For equation 3, "t" for twenty degrees of freedom and the 95 per cent significance level is 2.09.

[⊕] For equation 4, t = 2.11 for seventeen degrees of freedom and the 95 per cent significance level.

4.2 Feed Production (Cont.)

As it gave recognition to interactions which were thought a priori to be important, Chudleigh (4) chose to use equation 4 in his simulation model, in spite of the unexpected sign, and low level of significance, of some coefficients. While the function is not wholly in accord with a priori biological concepts, within the observed range of the variables involved* it served as an adequate basis for prediction.

4.3 Feed Consumption and Losses

The definition of the variable (C_i) in equation 1, and the definition of a unit of the feed index, together imply that (C_i) should equal 1.0 if "normal" sheep numbers are being carried: an index unit provides for both consumption and deterioration of feed. While (C_i) may be expected to vary with the ratio of actual to normal sheep numbers, one may hypothesise that (C_i) will vary less than proportionately with this ratio, because at high stocking rates a higher proportion of feed will be used within a short period after its growth, so that less feed is left to be lost by ageing and deterioration.

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* In operation of the simulation model, monthly rainfall in excess of 350 points was considered to be lost by evaporation and runoff, so X_2 was re-set to 350 before equation 4 was solved. Similarly, rainfall of less than 20 points was regarded as ineffective: where monthly rainfall was less than 20 points, X_2 was set equal to zero. These "cut-off" levels were selected after consultation with the grazier involved.

4.3 Feed Consumption and Losses (Cont.)

An arbitrary definition of (C_i) as the square root of the ratio of actual to normal sheep numbers was adopted.* In comparison of actual and simulated performance of the property for the period 1953 to 1968 this definition of (C_i) was found to yield more realistic results than alternative definitions based on assumptions that feed is lost at a constant rate over time, regardless of stock numbers, or that feed supply is reduced at a rate directly proportional to stock numbers.

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* The major difficulty with this definition is that the calculated rate of feed deterioration falls to zero if sheep numbers are reduced to zero. However, empirical evidence is that sheep numbers rarely fall to this level. The definition appears, in the judgement of the authors, to be satisfactory for sheep numbers of more than about five per cent of "normal" numbers: for example, even at four per cent of "normal" numbers this definition indicates feed disappearance as twenty per cent of the rate observed when full "normal" numbers are carried.

CHAPTER FIVE

GRAZING MANAGEMENT DIVISION RULES

The form of graziers' decision policies on stock number adjustments postulated in this system is very similar to that discussed by Waring (14). However, the approach under discussion here is more closely related to the measure of feed availability; it incorporates the possibility of a more complex set of adjustment policies; and it permits more frequent adjustments.

The grazier whose property was to be simulated was interviewed on his stock number management policies.* Within this interview feed conditions were described in the same terms as were used in collection of data for the basic construction of the feed index described above.

The interview was used to define the limits of a set of "sheep number states", which are characterised by the discrete steps by which the grazier would envisage enlarging or reducing his flock to adjust to changing feed conditions. Information collected in the interview was then used to determine the feed conditions which would induce the various possible adjustments between sheep number states: in the interview the same phraseology (for example "number of months of feed ....") was used as had previously been used in collection of data for fitting the parameters of the feed production component of the feed index. Consistency of terminology permitted the grazier's policy to be restated in terms of the feed index.

The sheep number states considered relevant by the manager of the property with which the simulation study was mainly concerned are shown in Table 2. This table also summarises the manager's policy by indicating the feed index levels which would induce specified degrees of destocking or restocking.

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* The schedule of questions for the interview, and details of the calculations which use the answers to these questions as data, are given by Chudleigh (4) pages 286-288 and pages 91-96.

TABLE 2

Sheep Number States and Stock Number Policies for Case Study

Sheep Number State	Typical Sheep Nos. as % of "normal"	Range of Sheep Nos. as % of "normal"	Management Policy	
			Destock to this State if Index Falls to:	Restock to this State if Index Rises to:
6	125	112½-137½	-	16.72
5	100	87½-112½	11.72	12.72
4	75	62½-87½	6.72	9.32
3	50	37½-62½	4.12	6.24
2	25	12½-37½	2.0	3.0
1	0	0 -12½	0.0	-

An important limitation of the system as used by Chudleigh (4) is that the grazier's policy on stock number adjustments is treated as one of concern only for feed conditions, with disregard for current livestock prices and livestock price expectations. Lack of a suitable series of livestock price data prevented incorporation of profitability calculations such as those postulated by Halter and Dean (10 and 11). However, it is felt that the actions of managers in the arid zone of New South Wales are so dominated by feed conditions that the major effects of allowing for current and expected prices in the simulation model would be to alter slightly the timing of a proportion of livestock purchases and sales, and to modify the relative contributions of livestock trading profit and wool sales to net income.

CHAPTER SIX

VALIDITY OF THE FEED INDEX SYSTEM

The system has been tested extensively for the property on which the main simulation model was based, and less extensively for another property in the West Darling region. For the first of these properties, early tests of the system indicated unrealistically frequent occasions of complete destocking. Extensive discussion with the grazier resulted in the conclusion that the structure of the system was satisfactory, and that the grazier's policy had been represented correctly. The grazier maintained that his estimates of feed responses (see Table 1 and associated discussion in Section 4.2) were correct relative to each other, but overall were rather conservative. After subsequent discussion and testing, it was found that the system appeared to operate satisfactorily,if food production, as estimated by equation 4, were increased by twenty-five per cent. (Similar adjustments were not found to be required for the second property to which the feed index system was applied.)

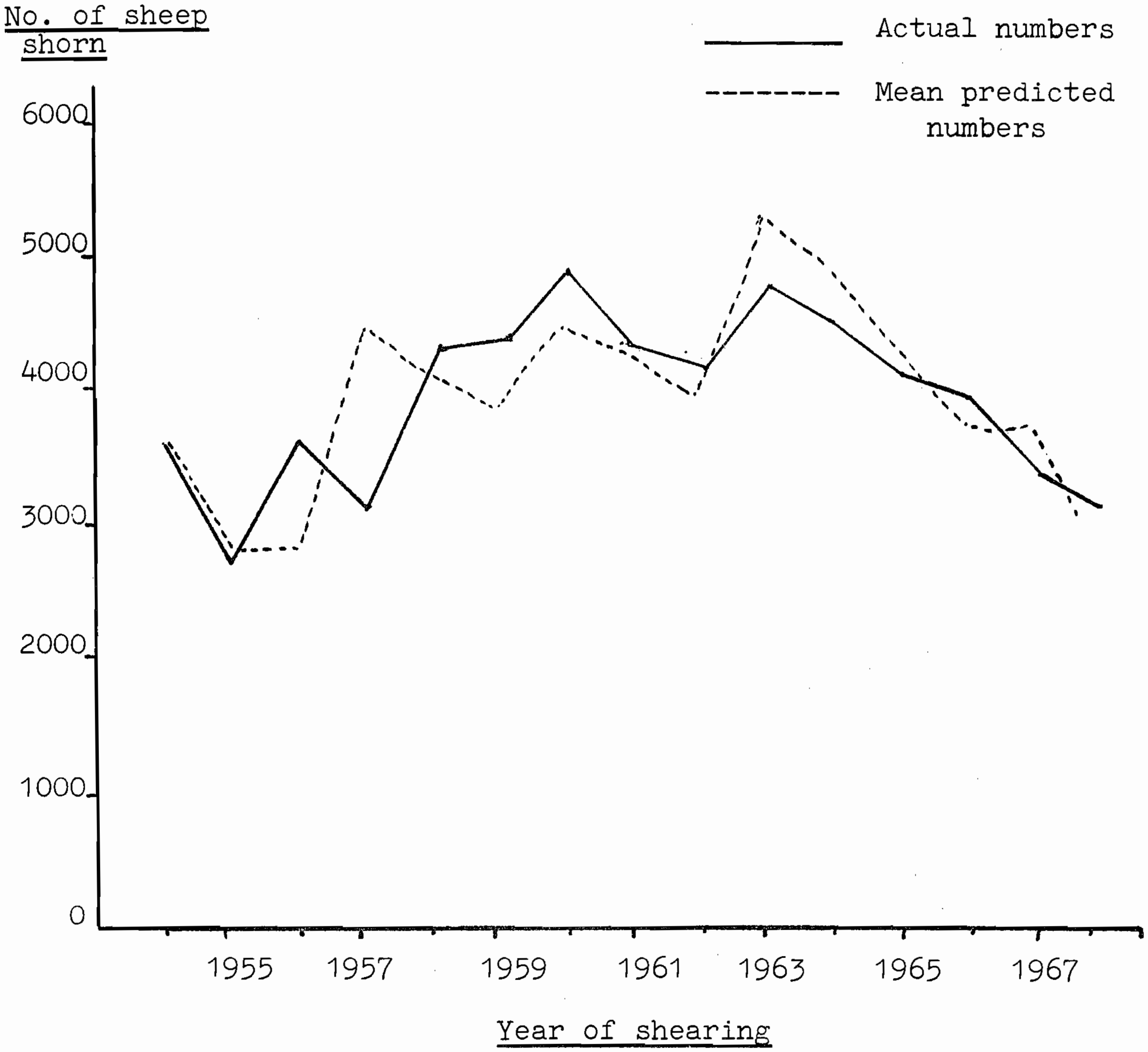
In early stages of testing, the feed index sub-model was operated, in isolation from other elements of the general simulation model, for the period January, 1953 to December, 1968. In the case of the property of primary interest, the feed index model correctly predicted seven out of nine "forced sales" which had actually occurred, and three out of four actual purchases. A similar degree of success was achieved for the second property.

When a full simulation model, incorporating the feed index system, had been constructed for the first property it was possible to conduct a more extensive test. Thirty replications of simulated operation of the property for the period July, 1953 to December, 1968 were run, using actual 1953 to 1968 rainfall data. Simulated results were compared with recorded actual performance of the property.

Unfortunately, complete records of number of sheep on hand at times other than shearing were not available. Figure 1 shows a comparison of actual number of sheep shorn with the mean predicted number.

FIGURE 1

Number of Sheep Shorn, 1954 to 1968: Actual Numbers, and Mean of Numbers Predicted in Thirty Simulation Runs



The data shown in Figure 1 are also presented in Table 3 together with data on the standard deviations of the predicted number of sheep shorn and a statistic designed to test for differences between observed and predicted numbers: the hypothesis tested is that the observed number in any year can be regarded as a sample from the population of numbers predicted for that year.

Let X be a member of the predicted population which is normally distributed with mean (u) and variance (σ^2); then the mean predicted number ($\bar{X}$) will also be normally distributed, with mean (u) and a variance ($\sigma^2/30$), given that the mean is estimated from 30 predictions. ($X - \bar{X}$) will then be normally distributed with mean zero and variance ($31\sigma^2/30$). Then we have:

$$\frac{(X - \bar{X})\sqrt{30}}{\sigma\sqrt{31}}$$ is a standard normal variate, so that

$$\frac{(X - \bar{X})\sqrt{30}}{s\sqrt{31}}$$ will follow Student's "t"

distribution with 29 degrees of freedom (where "s" is the standard deviation of the thirty predictions). Consequently, $(X - \bar{X})/s$ will be approximately as Student's "t" for twenty-nine degrees of freedom. We may use this statistic to test the probability that the number of sheep actually shorn in a year could have been chosen from the corresponding population of predicted numbers. Noting that Student's "t" for twenty-nine degrees of freedom and for the 95 per cent significance level is 2.04, we observe from the final column of Table 3 that in none of the simulated years do we have evidence that the actual number of sheep shorn is significantly different from the mean predicted number.

TABLE 3

Actual and Predicted Numbers of Sheep Shorn on Case-Study Property, 1954 to 1968

Year to June 30	Actual No. of Sheep Shorn X	Average of 30 Predictions of No. of Sheep Shorn $\bar{X}$	Standard Deviation of Predicted No. of Sheep Shorn s	t-test $(X - \bar{X})/s$
1954	3719	3719	4.2	0.00
1955	2674	2898	401.0	0.56
1956	3616	2834	907.6	0.86
1957	3077	4517	1316.5	1.09
1958	4299	4255	1072.3	0.04
1959	4323	3938	745.7	0.52
1960	4952	4534	1108.1	0.38
1961	4349	4328	731.4	0.03
1962	4112	3967	457.6	0.32
1963	4847	5309	256.9	1.80
1964	4509	4943	411.2	1.06
1965	4153	4284	707.4	0.19
1966	3984	3755	370.2	0.62
1967	3411	3579	498.2	0.34
1968	3184	3146	647.4	0.06
Average:	3947	4000		

CHAPTER SEVEN

CONCLUSION

The validation tests reported in Chapter Six have since been supplemented by use of the complete simulation model to explore the economic effects of some potential changes in management of the case-study property.* This experience suggests that the feed index system provides a practical means for representation of feed production and disappearance, and for expression of arid zone graziers' management policies.

Undoubtedly, refined models based on the biology of the plants and animals involved would allow more precise simulation of the arid zone grazing system, and would avoid the need for much of the subjective assessment inherent in use of the feed index system. However, it is suggested that the feed index system will serve as a basis for useful simulation studies of arid zone pastoral industries until improved "biological" models become available.

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* These applications are described by Chudleigh (4) and by Chudleigh and Filan (6).

APPENDIX I

GLOSSARY OF TERMS

This report deals with a method of representing pastoral feed conditions in a simulation model, and so involves a certain amount of "jargon" associated with simulation and with statistics. It is hoped that the following simple explanations will allow non-specialist readers to follow the discussion without being lost by the jargon.

Conventional research in agriculture is based on experimental methods. In areas such as the Western Division many experiments would involve very long time periods before the effect of climatic variation could be assessed; and even in areas of greater climatic stability some experimental research could be prohibitively expensive because of the need to control and/or systematically vary a large number of interacting factors.

One approach to research problems which would otherwise involve time-consuming and expensive physical experiments is the construction and use of simulation models. In the present context, a simulation model means a symbolic (e.g., mathematical) representation of some "real" system such as a pastoral property. If the model can be manipulated in some way so that it "behaves" in the same way as the real system (at least insofar as some relevant aspects are concerned), we may conduct experiments to see how the model "behaves" so that we may predict how the real system might behave if similar experimental treatments were applied to it. With the assistance of computers we may make such a model simulate many years of real farm experience in a few minutes of computer time: thus we may, if we have sufficient confidence in the realism of the model, inexpensively and quickly gain improved understanding and knowledge of the real system.

The term validation refers to the process of checking whether the simulation model does respond to changing conditions in the same way as the real system. In this report we discuss a simulation model of a West Darling pastoral property: part of the validation of this model is reported in Chapter Six, where we see if the model's behaviour, as indicated by its predictions of sheep numbers, is similar to the real-life behaviour of the property. If we have confidence in the validity of this model after such tests, we may apply experiments to the model and have confidence that the results would be similar to what would happen if we carried out similar experiments on the property itself.

A simulation model is largely made up of equations or functions which provide a description of the relationships amongst various factors affecting the performance of the pastoral property (the "real" system). For example, we might observe that the yield of a crop was 20 bushels without fertilizer, and increased by five bushels for each hundredweight of fertilizer applied: this relationship between yield and fertilizer application could be described by the equation:

$$Y = 20 + 5X$$

where Y and X are symbols representing the variables (yield and fertilizer application) and where the numbers 20 and 5 are the parameters of the equation. The mathematical form of the equation determines whether it will show a straight-line or a curved relationship: the example just shown would appear as a straight line if we plotted Y and X on a graph; if the equation included a variable X^2 (the square of the number of units of fertilizer) the corresponding graph would be curved; similarly in Chapter Four we refer to use of a variable involving the "sine" relationship, which results in a particular shape of graph which we believe to be the form of the relationship between vegetation growth and temperature.

Once we have decided which variables are involved in a relationship and have selected an appropriate mathematical form capable of showing the pattern of the real relationship, we need to select or estimate a set of numbers (the parameters) so that the equation used will provide realistic estimates or predictions of the "dependent variable" (Y in our example) for given values of the "independent variable(s)" (X in our example). If we have data, a set of observations, on actually corresponding sets of the variables in real life, we may apply a statistical technique called regression. Regression is simply a tool for selecting a set of parameter values which will give, for the selected mathematical form of equation, better predictions of the dependent variable than can be obtained with any other set of parameter values.

As it is rare in practice for a mathematical model to fit real-life data perfectly, we use some statistical tests of significance to assess whether our equation is meaningful; one of the more common of these tests is Student's t-test. Another aspect of the evaluation of a set of parameter estimates is a comparison between explained and observed variance: variance is the name used for a particular way of measuring variability of something such as yield, and it is useful to know whether or not our equation explains or predicts most of the variability which we observe in real life.

An alternative way of describing variability is to draw a figure called a <u>frequency distribution</u> or <u>probability distribution</u>: this is a diagram showing the probability of occurrence, or the relative frequency of occurrence, of alternatives. For example, if we wished to describe the variability of rainfall, we might find from historical records that the following pattern existed over the last fifty years.

<u>Rainfall in April in Points</u>	<u>No. of years that this Rainfall Level Occurred</u>	<u>Probability (= column 2 Divided by Total No. of Years Considered</u>)
Nil	15	0.3
1 - 50	15	0.3
51 - 100	10	0.2
101 - 150	7	0.14
over 150	3	0.06

This information can be used in this tabulated form, or it can be summarised on a graph. In either case, probability distributions may be used for many purposes. One application is to compare some observation which occurs in practice, to see whether it "fits in" with the pattern of the probability distribution: in Chapter Six we report on tests to see if actual farm performance "fits in" with the behaviour predicted by the simulation model. Another application of probability distributions is in "operating" the simulation model: by tossing coins, shuffling cards, or by some more sophisticated mathematical methods, we can select numbers at random to decide which of the events shown on the distribution will "happen" in the simulation; if the random numbers are forced to follow the same probability distribution, we can ensure that the simulation model operates as though there were a realistic pattern of such events as rainfall, without being forced to operate the model only under, for example, exactly the same set of rainfall conditions as was observed over the last fifteen years.

In validation of the model reported here (see Chapter Six), we ran the model thirty times (thirty "replications") assuming the same sequence of rainfall but allowing other chance factors to vary at random (within the limits of the probability distribution), so that we could assess the range of different ways in which the property might have behaved under the same rainfall conditions.

APPENDIX II

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