A COMPUTERIZED PREDICTION MODEL FOR EGG PRODUCTION MANAGEMENT DECISIONS

A Dissertation
for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY

James Leslie Dale

1974

This is to certify that the

thesis entitled

A Computerized Prediction Model
For Egg Production Management Decisions

presented by

James Leslie Dale

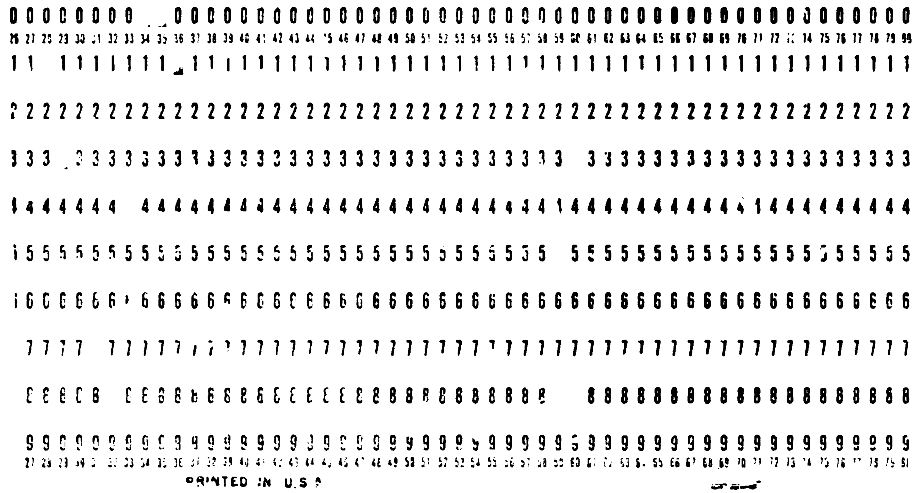
has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Poultry Science

Charles C. Sheppard
Major professor

Date August 5, 1974

O-7639



310

ABSTRACT

A COMPUTERIZED PREDICTION MODEL FOR EGG PRODUCTION MANAGEMENT DECISIONS

By

James Leslie Dale

The poultry industry is continuing through a period where producer numbers are declining and number of birds per farm and capital investment per farm are increasing rapidly. Large farm egg production complex and egg production contractor managers are wanting more sophisticated and accurate management tools, particularly tools for planning purposes.

The purpose of this research was to 1.) test the hypothesis that egg production, egg size distribution and mortality could be predicted and 2.) if the hypothesis was true, to incorporate the prediction equations into a dynamic simulation model to aid farm managers in their flock replacement decisions.

Performance records of 210 commercial egg laying flocks representing about 2.5 million birds were obtained. Information such as flock size and numbers of birds per cage pertaining to each flock was also obtained. Recycled flocks and flocks with incomplete data input were excluded from the statistical analyses.

The data were analyzed by the least squares method. The dependent variables for all analyses were mortality,

total eggs produced per hen housed, and the total number of large size, medium size, small size and undergrade eggs produced per hen housed.

Initially, the effects of the total number of 28-day periods of production, starting age of production and flock size were measured. The results indicated that, generally, these three independent variables significantly affected the dependent variables. The data were then adjusted (standardized) for the three independent variables.

A second least squares analysis was undertaken to measure the effect of five other independent variables and seven interactions on the adjusted data. The total number of eggs produced per hen housed and the total number of small size eggs produced per hen housed were the only dependent variables significantly affected by the independent variables and interactions of this study.

The results of the statistical analyses were used as the bases for the development of multiple variable, multiple regression prediction equations for each of the dependent variables. The equations were developed to give 28-day, period by period predictions. The equations that were developed did not perform satisfactorily and were abandoned.

The Gavora-Parker-McMillan model for egg production prediction was introduced at that point. Following their stated procedure, decreasing lay rate coefficients were obtained. The model was slightly modified and tested. The results were very favorable.

The egg distribution coefficients developed for predictive purposes were the average distribution rates per period by strain. The mortality rate for predictive purposes was determined to be a constant rate: an average of the first three periods of production.

The simulation model developed, using the prediction equations and the manager's expected cost-revenue relationships, performed very satisfactorily. Like any other forecasting and planning tool, the results obtained, compared to actual results, were only as good as the input data.

A COMPUTERIZED PREDICTION MODEL FOR EGG PRODUCTION MANAGEMENT DECISIONS

By

James Leslie Dale

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Poultry Science

1974

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of and express appreciation to:

Dr. C. C. Sheppard for his sincere interest, guidance and counseling during the course of graduate study.

Dr. W. H. Vincent, Dr. H. C. Zindel, Dr. T. H. Coleman and Dr. T. R. Pierson for their interest and assistance as members of the guidance committee.

The Poultry Science Department for research financial assistance.

Dr. J. L. Gill and Dr. R. R. Neitzel for their statistical analysis expertise.

Ms. Jacqueline Grossman and Mr. Bruce Johnson for their computer programing expertise.

My wife, Judy, for her support and encouragement during the course of graduate study.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF APPENDIX I TABLES

INTRODUCTION

The egg industry in the United States has been and is expected to continue through a reduction in producer numbers. The same number of birds are being controlled by fewer and fewer individuals or firms. A recent example of this is the arrival of the egg production complex; 300,000 or more birds in side-by-side houses of 50,000 or 60,000 birds each.

The larger production units have lower building and equipment costs per bird than their smaller predecessors. However, the overall total investment is greater, possibly reaching into the millions-of-dollars category.

As total investment increases, the need for accurate management information that is readily available becomes more important. This, of course, includes all aspects of the operation. Paramount, is the need for information on how the flock will perform. Flock performance then serves as the base from which overall flock financial performance is derived.

Generalized cash flow and production simulation models exist that can be utilized to make flock projections using a standard production curve given current input-output cost relationships. Accounting programs also exist that give an indication of how the current flock is performing compared to past or standard flocks. However, in the literature, there is no program currently available that gives the producer an accurate, comprehensive projection of his current flock's overall performance.

It was the hypotheses of this research that 1.) egg production, egg size distribution and mortality could be predicted on a 28-day period by period basis reasonably accurately using multiple regression equations, and 2.) that a dynamic simulation model could be developed that would incorporate the prediction equations along with a flock managers expectations to generate data useful in making flock management decisions.

Therefore, the objectives of this research were:

1. to determine the factors that affect mortality, egg production, and egg size distribution based upon recent commercial flock data (flocks started and completed in the 1970-1973 period).
2. to develop prediction equations that, on the basis of 12 weeks of actual data, will project reasonably accurately, the future patterns of egg production, mortality and egg size distribution over the remaining periods of production of the flock.

3. to develop a computer simulator to incorporate the prediction equations as a function and simulate all cost-revenue relationships and flock financial performance over the remaining periods of production to help poultry producers in their flock replacement decision actions.

LITERATURE REVIEW

Bell (1972) reported that "hen day production was significantly affected by...cage density..." He also reported that "the four-bird cages had a significantly higher rate of mortality when compared to the three-bird cages." Bell's experiment involved 1,120 SCWL birds housed half in three birds per 12" x 18" cage and half in four birds per cage (same dimensions).

Adams and Jackson (1970) measured the effect of cage size and bird density on the performance of six commercial strains of layers. They found that the differences between the strains' hen housed egg production were significant. The birds housed at the lower densities performed better than the birds housed at the higher densities (less square inches per bird). In addition, birds housed at two and three birds per cage performed better than birds housed at more birds per cage. The effects of cage density, cage size and strain on mortality were mixed with no definite pattern evolving.

Marks, Tindell and Lowe (1970) reported that significant differences in egg production existed between the six commercial strains under study. They reported that the only significant effect of cage density was the 560 day body weight.

Hill and Binns (1971) measured the effects on the performance of varying densities and numbers of birds per cage. They reported that egg production, feed efficiency, mortality, increased body size and net egg returns tended to be linearly related to size of cage; the greater the space per bird, the better the performance.

Plumart, Carlson and Holmquist (1972) housed birds at 552, 414, 331 and 276 square centimeters per bird. This represented 3, 4, 5 and 6 birds per cage, respectively. They reported that the 414 cm^2 per bird density (4 birds per cage) was "...detrimental to egg production compared to the other groups..."

Feldkamp and Adams (1973) measured the effects of rearing relationships, cage size, and bird density on the performance of two commercial strains of egg-type chickens. They reported that as the square centimeters per bird decreased, egg production significantly decreased. Mortality, however, was not significantly affected.

Latimer's and Bezpa's (1970) projections and cash flow for a 30,000 bird commercial table egg operation utilized a "standard" production curve and a "standard" egg size distribution for calculation purposes. These respective values were derived from the 1966-67 New Jersey Random Sample results.

Ruggles (1971) published a handbook to help Northeastern poultry producers prepare cash flow projections. The egg production pattern used a "standard" curve. The producer would develop his best estimate of egg production based on his flock's historical annual dozens of eggs produced. Egg size distribution was calculated by a similar procedure.

Bell (1971) published a handbook to help Southern California poultry producers prepare cash flow projections. Bell utilized a "typical production curve for White Leghorn chickens" to project egg production. Egg size distribution was calculated utilizing a table of typical egg weights (as a percent) by age of bird.

Muir (1972) developed a computerized cash flow for market egg farms. The program projected production on the basis of five input values supplied by the producer. These values were flock age at the start of production, flock age at peak production, flock age at the date of sale, flock peak production level and flock production at the date of sale. The model used the five points to establish two linear lines (one increasing and one decreasing) which it moved along, simulating the egg production level per production period. Projections simulated after the flock's peak production required estimates of egg production at the date of sale and flock age at the date of sale. The model established a linear line between the known peak egg production and the anticipated ending egg production. It then simulated the egg production per period and calculated costs and revenues per production period for the remaining periods of the flock.

Gavora, Parker and McMillan (1971) applied a mathematical model of egg production originally developed by McMillan, et al., for predicting egg production in the "Drosophila Melanogaster" to chickens and turkeys. The model was described as follows:

$$N(t) = M\left(1-e^{-\xi(t-t_o)}\right) e^{-\alpha t}$$

where

$N(t)$ = the number of eggs laid in a 28 day period

M = the potential maximum egg production in a 28 day period

t_o = the initial age of egg laying

ξ = the rate of increase in egg laying

α = the rate of decrease in egg laying

They reported that the α value was -0.0340 for egg-type chickens, groups of hens, based on 17 records. When the formula was applied to one example flock (12,000 birds) the model explained 96.5 percent of the total variation in egg production for that flock.

Ruggles (1968), Vincent and Sheppard (1970) and Dale, Vincent and Sheppard (1974) developed poultry farm management game-simulators. Each game functioned somewhat differently regarding the answers given. However, in the area of egg production and egg size distribution, all three utilized "standard" production curves and egg size distribution tables. The Dale, et al., model allowed a limited amount of prediction by asking the player to specify an estimated yearly average production rate. The model responded by raising or lowering the "standard" egg production curve to obtain the desired results.

Bird mortality in all of the above mentioned cash flow handbooks and programs and simulator games, was calculated as a constant rate throughout the production cycle.

Latimer and Bezpa (1970), Ruggles (1968), Ruggles (1971) and Bell (1971) calculated feed requirements for the flock on the basis of a "standard" amount of feed consumed per bird per period of production. Dale, et al., (1974) and Vincent and Sheppard (1970) utilized a formula incorporating a maintenance level of feed intake and a variable amount of feed intake directly related to egg production. This sum amount was considered to be the amount of feed consumed per bird per period.

RESEARCH METHODOLOGY

Preface

The flock data that was considered necessary to develop the prediction equations was available from two sources. One was from controlled experimental units. The second was from commercial flocks.

The decision to select either of the sources was difficult. If controlled experimental flocks were sampled, most of the intangible factor of flock-care management effect may have been removed. However, it was questionable that enough flocks and birds within flocks could be obtained to develop credible equations for direct application to commercial flocks.

It was believed that if a large cross-sectional sample of commercial flocks could be obtained, the flock-care management factor would be reduced to a minimum. In addition, prediction equations developed from actual commercial data would be more readily accepted by industry for management planning use.

Thus it was determined that as much recent commercial flock data as possible would be obtained. The periods of 1970-1973 were selected as the sample years, with the emphasis on 1972-1973 flocks. The emphasis was on those two years because of the introduction of Marek's vaccine and continuing breeder development of improved commercial strains.

Many organizations were contacted as possible data sources. The following organizations were most cooperative and supplied this research with data:

DeKalb AgResearch, Inc., DeKalb, IL.

Michigan Farm Bureau Services, Inc., Lansing, MI.

Landmark Foods, Inc., Columbus, OH.

Babcock Poultry Farms, Inc., Ithaca, NY.

Hyline International, Inc., Des Moines, IA.

The first three organizations listed above maintain up-to-date egg production, egg size distribution and mortality on many commercial flocks as part of their organizations' business or as a service to their customers. The other two organizations had limited amounts of data available.

The actual collection of data from the first three sources required the researcher to visit their respective corporate headquarters and physically transcribe data from 28-day period reports to summary forms.

The following information was sought from each set of records:

1. starting age of egg production,
2. number of birds per cage,

3. starting month of egg production,
4. windowed or windowless house,
5. commercial strain of layers (e.g., DeKalb),
6. location (state),
7. total number of 28-day periods of production,
8. size of flock, and
9. for each 28-day period of production:
    a. mortality (total number of birds),
    b. total eggs produced, and
    c. egg size distribution.

Information items 1 through 8 were sought because of their believed possible effect on mortality, total egg production and egg size distribution.

The information gathered was taken from each set of records as presented by the records.

It was not possible to obtain square inches per bird from the record sets surveyed. Number of birds per cage, however, was obtained and therefore used. The general assumption was that as the number of birds per cage increased, the area per bird declined.

The total number of record sets surveyed was 210, representing more than 2.5 million birds.

Table 1 in Appendix I contains the results of one surveyed flock's record set.

Statistical Analysis

Procedures

The start of egg production ranged from 18 weeks to 26 weeks and was coded from 1 to 9 (recycled flocks were coded 0). The recycled flocks were not included in the final analyses. Numbers of birds per cage ranged from two birds to ten birds. The five or more birds per cage category was established because of the few number of records in the individual categories beyond five birds per cage.

All 12 months were used as starting months. The months were grouped into quarters (quarter I being January, February and March) for analytical purposes as a method to reduce the total number of variables involved.

Windowed houses were coded as 1 and windowless houses were coded as 2 for analytical purposes. The data included both types, however, the windowless was predominate.

Data were collected on seven strains. They were DeKalb, Hyline, Babcock, Heisdof and Nelson (H&N), Shaver, Kimber and Arbor Acres. All strains were egg-type chickens. No attempt was made to differentiate specific identifications within the commercial name. Nearly 70 percent of the total sample was accounted for by one strain. It was difficult to obtain information for some strains.

Flocks surveyed were located in seventeen states. The states were divided into regions for statistical analyses purposes. The majority of the flocks surveyed were in region 1. The following was the region break down by state:

Region 1 - East North Central

Michigan	Illinois	Indiana
Wisconsin	Ohio	

Region 2 - West North Central

Minnesota	Iowa	South Dakota
Missouri	Wyoming	North Dakota
Colorado		

Region 3 - Northeast

New Jersey	Pennsylvania

Region 4 - Southeast

North Carolina	Maryland	Virginia

Initially, the data were subjected to least squares multiple regression, measuring the effects of flock size, the total number of 28-day production periods and the starting age on the following dependent variables: mortality, the total number of eggs per bird housed and the total number of large, medium, small and undergrade eggs, per bird housed.

Based on the significance levels, the data were adjusted (standardized) to reduce the number of variables involved in later analyses. The three variables had a significant or near significant affect on most of the dependent variables listed. Thus, as a matter of convenience, all the data were adjusted before further analyses. Table 14, Appendix I, presents the adjustment formula utilized.

The adjusted data were analyzed utilizing the general least squares multiple regression method. The dependent variables were again those listed above. The independent variables were numbers of birds per cage (four groups--2, 3, 4, 5 or more), quarter of start (four groups), windowed or windowless house, strain, region (four groups--West North Central, East North Central, Northeast, and Southeast) and the following selected interactions:

number of birds per cage by quarter of start,
number of birds per cage by strain,
number of birds per cage by region,
quarter of start by windowed-windowless house,
quarter of start by strain,
quarter of start by region,
windowed-windowless house by region, and
strain by region.

Those interactions that were believed to have no influence were excluded to facilitate a more manageable matrix for the analysis.

The variables and interactions having a near significant or a significant effect on each dependent variable were noted. A third general least squares analysis was undertaken. The dependent variables were the above listed, on a 28-day period by period basis beginning in the fourth period of production and continuing through period fifteen. Beyond the fifteenth period, the amount of data was too small to allow a meaningful analysis. The independent variables included were those that had a near significant or significant effect on the dependent variable under study. Other independent variables included the summed data for the dependent variable category through the i-1 period. An example would be predicting egg production in the fourth period. The summed data would then be the total number of eggs produced through the third period. This process was undertaken to establish a periodized prediction equation for mortality, egg production, and egg size distribution.

The formula outlined by Gavora, et al., for estimating the egg production rate of decrease (α) and potential maximum monthly egg production was applied to the data collected. The formula was a log-linear regression equation as follows:

$$\ln N(t) = \ln M - \alpha t$$

where

$N(t)$ = the number of eggs produced per hen housed in time period t (28-day period)

M = the potential maximum monthly (28-day period) egg production per hen housed

α = rate of decrease

t = time period.

The regression was performed on the data in periods where $t \geq t_o max$, $t_o max$ being the time period (number) of actual maximum (peak) production.

The analysis was performed on each strain. Analyses on strain 1, which composed 70% of the data, were done by quarter of start. The other strains did not have sufficient amounts of data to allow analyses by quarter of start.

Results and Discussion

When the data were initially collected, recycled flocks and flocks with no answers to some of the questions (birds per cage, for example) were included. During the analyses recycled flocks and those with missing data were not included. This action reduced the sample size to 163 flocks with a total of 2.2 million birds.

Table 1 presents the minimum, maximum and means of the data asked for in the initial survey. The average lay rate of 229.01 eggs, per bird hen housed, in 397 days (14.18

Table 1. Base statistics on the collected flock data

Item	Minimum	Maximum	Mean
Total number of 28-day periods of production	8	18	14.18
Starting age (weeks)	18	26	21.18
Flock size (000)	1	41	12.85
Mortality (total percent)	6.8	41.8	17.90
Total eggs per bird housed	119.02	365.99	229.01
Large eggs per bird housed	55.74	234.44	145.07
Medium eggs per bird housed	7.7	111.16	49.64
Small eggs per bird housed	.22	41.22	10.30
Undergrade eggs per bird housed	3.11	42.69	21.65

28-day periods) expressed as a percentage, was 57.68 percent. The egg size distribution was as follows: large eggs were 63.35 percent, medium eggs were 21.68 percent, small eggs were 4.50 percent, undergrade eggs were 9.45 percent and lost eggs (unaccounted, loss eggs, etc.) were 1.02 percent of those produced. The average mortality rate for the flock data was 1.26 percent per period. The information in Table 1 was not analyzed by strain.

It was noted that a very wide range existed for some of the variables. An example was the 246.97 difference in total eggs produced per hen housed. Similar ranges were evident for all the items except starting age.

The purpose of the following statistical analysis was to determine how the data should be adjusted for further analyses. The effects of the total number of 28-day periods of production, starting age and flock size (independent variables) on mortality, total egg production and egg size distribution are presented in Table 2. The regression coefficient and significance level of each independent variable are listed. The total number of periods of production had a highly significant ($p<.01$) positive effect on all the dependent variables except on the total number of small size eggs produced per hen housed. One would expect this type of response due to the increased production cycle length and the natural response of more eggs and increased mortality. Since the vast majority of

Table 2. The effects of the total number of 28-day periods of production, starting age and flock size on mortality, total eggs produced and egg size distribution

Independent Variable	Dependent Variables					
	Mortality	Total Eggs[b]	Large Eggs[b]	Medium Eggs[b]	Small Eggs[b]	Undergrade Eggs[b]
Periods						
Reg. coef.[a]	0.007	14.913	10.332	2.375	0.102	1.65
Significance	0.006	<0.001	<0.001	<0.001	0.667	<0.001
Starting age						
Reg. coef.[a]	0.004	3.281	0.425	3.149	0.414	-0.657
Significance	0.113	0.004	0.752	<0.001	0.132	0.096
Flock size						
Reg. coef.[a]	0.003	- 1.358	- 0.845	-0.451	-0.113	0.219
Significance	<0.001	< 0.001	0.014	0.01	0.104	0.029

[a]Regression coefficient

[b]Hen housed basis

small size eggs would be produced in the first few periods of production, one would also expect the insignificant effect of a longer production cycle. Recent literature did not refer to the effects of production cycle lengths on the dependent variables studied.

Starting age had a mixed effect on the dependent variables. The delaying of egg production (delaying sexual maturity) seemed to slightly increase the amount of flock mortality. However, the effect was not significant. Delaying sexual maturity had a highly significant ($p<.01$), positive effect on the total number of eggs per hen housed and on the total number of medium size eggs produced per hen housed. However, the starting age did not significantly affect the total number of large size or small size eggs produced per hen housed. The negative effect on the number of undergrade eggs produced per hen housed, as the starting age increased, was nearly significant ($p = .096$). Recent literature did not refer to starting age and its effects on the dependent variables.

Increasing flock size had a negative effect on bird performance. Mortality and the total number of undergrade eggs produced per hen housed were significantly ($p<.05$) increased. The total number of eggs per hen housed, the total number of large size eggs per hen housed and the total number of medium size eggs produced per hen housed were significantly ($p<.05$) decreased. Increasing flock size also had a negative effect on the total number of small size eggs produced per hen housed. However, the effect was not significant ($p = .104$). Flock size was measured in 1,000 bird increments. Recent literature did not refer to the effects of flock size on the dependent variables analyzed.

The purpose of the above analysis was to determine how the data should be adjusted for further analyses. The criterion was that if an independent variable had a significant or near significant effect on any dependent variable, the data would be adjusted for that independent variable. The independent variables met that criterion in most of the individual analyses. Thus, for ease of handling, all the data were adjusted for the total number of 28-day periods of production, starting age and flock size.

As previously mentioned, general least squares was used to analyze the adjusted data.

Table 3 presents the selection of independent variable or interaction effect from the least squares analyses. This table presents the information base for the discussions below from mortality through undergrade eggs.

The information in Table 3 is presented as an i/j value with a superscript. The i = the number of separate variables with a significance value of .2 or less. The j = the total number of separate variables in the group. The superscript indicates a significant, or a near

Table 3. Selection of independent variable or interaction effect from the least squares analyses[a]

Independent Variable or Interaction	Dependent Variables					
	Mortality	Total Eggs	Large Eggs	Medium Eggs	Small Eggs	Undergrade Eggs
Region	0/3	2/3[c]	1/3	2/3[c]	3/3[b]	0/3
Quarter of start	0/3	3/3[b]	0/3	0/3	0/3	0/3
Number of birds per cage	0/3	3/3[b]	0/3	0/3	0/3	1/3
Windows-windowless	0/1	0/1	0/1	1/1[c]	1/1[b]	0/1
Strain	0/6	6/6[b]	0/6	0/6	0/6	0/6
Region by number of birds per cage	5/8[c]	5/8[c]	4/8[c]	5/8[c]	6/8[c]	1/8
Region by quarter of start	2/8	1/8	2/8	1/8	2/8	2/8
Region by windows-windowless	0/3	0/3	1/3	0/3	2/3[c]	0/3
Quarter of start by number of birds per cage	1/9	2/9	1/9	1/9	2/9	1/9
Quarter of start by windows-windowless	0/3	0/3	0/3	0/3	2/3	2/3

Table 3 (cont'd.)

Independent Variable or Interaction	Dependent Variables					
	Mortality	Total Eggs	Large Eggs	Medium Eggs	Small Eggs	Undergrade Eggs
Quarter of start by strain	2/11	9/11[b]	0/11	0/11	0/11	2/11
Number of birds per cage by strain	1/10	9/10[b]	2/10	0/10	0/10	2/11

[a] i/j i = the number of separate variables in the group with a significance value $<.2$; j = the number of separate variables in the group

[b] significant effect

[c] a near significant effect or an influence

(NOTE: significance determination was a function of the i/j value and the relativity of the individual significance values in the group. See Table 13., Appendix I for further discussion) significant influence effect. The determination of significance was a function of the i/j value and the relativity of the separate significance values within each group. Table 13 in Appendix I presents an example of the determination of the superscript.

Mortality. The R^2 value (variation or causative value) obtained was .48, thus indicating that the independent variables (region, etc.) and the interactions included, accounted for less than one half of the variation in mortality. The only independent variable or interaction group to have a near significant effect on mortality was the interaction of the number of birds per cage by region. However, the base independent variables (number of birds per cage, region) from which the interaction arose were not statistically significant or near significant. These findings concurred with those reported by Adams and Jackson (1970), Marks, et al. (1970) and Feldkamp and Adams (1973). These findings did not concur with Bell (1972) and Hill and Binns (1971), each of whom reported significant effects on mortality due to decreasing area per bird.

Egg production. The variables and interactions of this study accounted for about 77 percent of the variation (R^2) in total eggs produced per hen housed.

Region tended to influence total egg production per hen housed. The regression coefficient indicated that the

North Central states had a negative effect on total production, while the Northeast and Southeast regions had a positive effect.

The quarter of start of production had a highly significant effect on total egg production per hen housed. The regression coefficients indicated that quarter three (July, August, September) was the most favorable quarter to start while quarter two (April, May, June) was the most unfavorable.

The number of birds per cage significantly affected total egg production per hen housed. This concurred with Bell's (1972) findings. The regression coefficient ranked the effect of the number of birds per cage as follows (on the basis of preferential performance): three, two, four and five or more. These results concurred with Adams and Jackson (1970), Hill and Binns (1971) and Feldkamp and Adams (1973). Each of these teams reported that as the area per bird decreased, egg production significantly decreased. The reversal of the two and three birds per cage in ranking in this study tended to counter the above findings. However, the overall general trend of reduced space per bird: reduced egg production was intact.

Strain highly significantly affected total eggs produced per hen housed. This result concurred with the published reports of Adams and Jackson (1970) and Marks, et al. (1970).

Ranking the strains according to regression coefficients (most positive coefficient ranked first) established the following order: 5, 3, 1, 4, 6, 2, and 7.

The region by number of birds per cage interaction tended to affect total eggs produced per hen housed. However, the region by quarter of start interaction and the quarter of start by number of birds per cage interaction had no effect. These results were somewhat confusing given the significant effects of their component independent variables. On the other hand, the quarter of start by strain and number of birds per cage by strain interactions significantly affected total eggs produced per hen housed.

Large eggs. The R^2 value of this study was .5 indicating that the independent variables and interactions accounted for about half of the variation in the total number of large size eggs produced per hen housed.

No independent variable or interaction significantly influenced the total number of large size eggs produced per hen housed. The region by number of birds per cage interaction had a very slight influence.

Medium eggs. The independent variables and interactions of this study accounted for about 46 percent of the variation in the total number of medium size eggs produced per hen housed.

Region tended to affect the total number of medium size eggs produced per hen housed. The North Central and Southeast states had a negative impact while the Northeast states had a positive impact.

The absence of windows in the house tended to have a negative effect on the total number of medium size eggs produced per hen housed. The presence of windows tended to have a positive effect.

Similar to the total number of large size eggs produced per hen housed, the region by number of birds per cage interaction had a slight influence on the total number of medium size eggs produced per hen housed. Again, the component independent variables had no effect.

Small eggs. The independent variables and interactions of this study accounted for about 52 percent of the variation in the total number of small size eggs produced per hen housed.

Region had a significant effect on this dependent variable. As with the medium size, the North Central and Southeast states had a negative impact while the Northeast states had a positive impact on the total number of small size eggs produced.

The presence or absence of windows had a significant effect on this dependent variable. The presence of windows had a positive effect. The absence of windows had a negative effect.

The region by number of birds per cage interaction tended to affect the total number of small size eggs produced per hen housed. A similar effect was indicated for the region by windows-windowless house interaction.

Undergrade eggs. The R^2 value for this dependent variable was .58. However, none of the independent variables or interactions included in this study indicated any influence on the total number of undergrade eggs produced per hen housed.

None of the literature searched referred to the independent variables that might influence the egg size distribution studied here. Some of the results of this study were rather confusing. Particularly the question of why a specific interaction exhibited tendencies to influence egg size when its component independent variables clearly had no influence. Other results tended to follow the line of commonly accepted knowledge of climatic and light effects on egg size distribution and egg production.

Regression prediction equations. The next step in the analytical process was an attempt to establish multiple variable, multiple regression prediction equations based on the statistical information obtained. These equations would be for mortality, total egg production per bird and egg size distribution per bird. The equations would give an estimate for each value for each 28-day period from period four (assuming peak production in period three) through the expected number of production periods for a given flock.

The first equation developed was for total egg production per 28-day period, from period four through the production cycle. The equation was developed by strain by region. Results of the equation were very poor. The equation accounted for about 32 percent of the variation in egg production in period four. The percent of variation accounted for increased with each period to about 80 percent in periods thirteen and fourteen.

Equations for mortality and individual egg size distribution were also developed. Results of these equations were similar to those found from the egg production equation. The percent variation in the dependent variable accounted for by the equation was very low in period four. However, as the production cycle progressed, the percent variation that the equation accounted for increased.

Gavora-Parker-McMillan model. The results of the multiple regression equations were not acceptable to use for prediction purposes. At this point, the Gavora-Parker-McMillan model was introduced to this study. The rate of decrease of lay from the peak period of production through the end of production was the concern of this study. Gavora's, *et al.*, procedure to obtain the rate of decrease (α) was followed within each strain. Different α values for each quarter of start for strain 1 were also obtained.

Table 4 presents the α values and potential maximum egg production on a hen housed basis for each strain. The rate of decrease was the slope of the production curve from peak production through the end of production. Strain 2 had the least declining rate of production, but also had the lowest potential peak. On the other hand, strain 4 had the highest potential peak production, but its rate of decrease was the greatest.

Gavora, et al., (1971) reported the potential maximum 28-day period egg production to be 26.41 eggs per bird housed. None of the values from this study were that specific value. Three of the strains' values were higher than 26.41 while two values were below that level.

The α value from Gavora's, et al., work was -.034. All of the α values from this study were more negative. The closest to Gavora's reported value was the -.051 of strain 2.

Table 5 presents the α values and potential maximum production for the four quarters of start for strain 1. Those flocks started in quarter 2 had the lowest potential peak, and the least rapid decrease in egg production. Those flocks started in quarter 1 had the second highest

Table 4. Potential maximum egg production and rate of decrease of lay by strain

Strain[a]	Potential Maximum[b]	Rate of Decrease (α)	Number of Flocks
1	25.517	-.055	115
2	24.674	-.051	8
3	28.544	-.058	13
4	28.980	-.071	12
5	27.628	-.063	9

[a]Two strains included in the statistical analyses were dropped from this analysis due to an insufficient number of flocks

[b]Hen housed basis

Table 5. Potential maximum egg production and rate of lay decrease by quarter of start for strain 1

Quarter	Potential Maximum[a]	Rate of Decrease (α)	Number of Flocks
1	25.421	-.0598	27
2	24.689	-.0467	17
3	25.086	-.0497	35
4	25.866	-.0570	36

[a]Hen housed basis

potential peak production and the most rapid decline in egg production.

The prediction equation utilized for this study was as follows:

$$P(t) = MAXEG(1 - INC(t))DEC(t)$$

where

$P(t)$ = predicted eggs per 28-day period per hen housed in period t, where $t \geq 4$ (assume peak production in period 3)

MAXEG = actual peak production per hen housed

INC(t) = rate of lay increase coefficient for period t

DEC(t) = rate of lay decrease coefficient for period t

Gavora, et al., specified the rate of increase of lay to be 2.9011 for egg-type chicken flocks. The coefficient referred to above (INC(t)) was $e^{-2.9011\ (t-t_o)}$, where t = current period of production and $t_o = 1$. The coefficient for period four was 1.68×10^{-4}. The coefficient for periods five and forward was set at zero.

The rate of lay decrease coefficient for each period was $e^{-\alpha(t-3)}$, where t = current production period. This equation was different than its Gavora, et al., (1971) counterpart. The difference in the formulas correspond to the great differences in the α values previously discussed. If the α values found in this research were applied to Gavora's formula ($e^{-\alpha t}$) to obtain the lay rate decrease coefficients, erroneous prediction results were obtained.

These results were rather confusing since Gavora's procedure, as reported, was duplicated. Thus, the adapted formula developed by this research was utilized later for simulation procedures.

Tables 2 and 3 in Appendix I list the rate of lay decrease coefficients for each strain and by quarter of start for strain 1 for each 28-day period.

The results of the above prediction equation were very favorable when applied to actual data. It did not predict accurately the actual 28-day period egg production for every flock tested. The reason being that every flock was not an average flock. However, the amount of error was about the same for each period of production. That is, if the equation predicted one egg per hen below actual production for a 28-day period, every period was about one egg per hen below actual production. Some deviation occurred from this pattern very late in the production cycle. The great majority of the differences between predicted production per hen housed and actual production per hen housed per 28-day period ranged from virtually zero eggs per hen to about 1.5 eggs per hen. Table 12 in Appendix I offers some examples of actual results.

The success of the slope of the production curve procedure in defining an accurate egg production prediction equation gave rise to speculation that the same type analysis could be applied to egg size distribution and mortality. Such analyses would hopefully generage similar successes. Such research, however, was beyond the means of this project. It was originally believed that viable regression prediction equations could be developed. However, attempts to develop such equations failed and in the process engulfed much of the resources of this study. Therefore, to obtain a prediction model for egg size distribution, the following was undertaken. The actual flock data were segregated by strain. An average egg size distribution per period (expressed as a percentage) per strain was calculated. The same procedure was followed by quarter of start for strain 1. Tables 4 through 11 in Appendix I contain the period by period egg size distributions for each strain and by quarter of start for strain 1.

Table 6 presents the average egg size distribution by strain. Strain 1 had the lowest average undergrade percentage (10.04 percent) and the highest average percentage of large size and medium size (84.4 percent). Strain 4 had the lowest average percentage of large size and medium size eggs with 77.7 percent. Strain 4 also had the lowest average percent of large size eggs. Strain 5 had the highest average percent of undergrade eggs.

Table 7 presents the average egg size distribution by quarter of start for strain 1. The flocks started in quarter 2 had the highest average percent of large size eggs.

Table 6. The average egg size distribution by strain

Strain No.	Large %	Medium %	Small %	Undergrade %
1	63.32	21.08	5.56	10.04
2	63.40	15.66	5.86	15.08
3	65.44	17.30	5.87	11.39
4	55.21	22.50	8.97	13.32
5	60.89	17.13	6.63	15.35

Table 7. The average egg size distribution by quarter of start for strain 1

Quarter	Large %	Medium %	Small %	Undergrade %
1	61.99	22.13	5.81	10.07
2	66.52	19.64	4.24	9.60
3	62.58	20.47	6.81	10.14
4	62.17	22.10	5.39	10.34

Those flocks started in quarter 1 had the lowest percent of large size eggs. Comparing the average percent of large size eggs with the α values of Table 5, one finds an association. The flocks started in quarter 2 which had the highest average percent of large size eggs also had the least rapid rate of lay decrease (smallest α value). Similarly, those flocks started in quarter 1 had the lowest percent of large size eggs and the most rapid rate of lay decrease (highest α value).

Comparison of the percentages of large eggs and α values among the strains did not yield the same association. Strains 4 and 5, the two lowest large size egg percentage strains, had the correspondingly two most rapid rates of lay decrease. However, strain 3 with the highest percent of large size eggs, did not have the least rapid rate of lay decrease.

It is conceivable that the slope of the line procedure can be affectively utilized to predict mortality. The prediction process for mortality selected for use, however, would give a constant percentage value for each 28-day period. This type function concurred with methods reported by Ruggles (1971), Bell (1972), Muir (1972), Ruggles (1968), Vincent and Sheppard (1970) and Dale, Vincent and Sheppard (1974). The process to specify the actual rate, used the following equation:

MRT = MORTD/NOB/3

where

MRT = the mortality rate,

MORTD = total mortality through period 3, and

NOB = the number of birds housed.

The Simulation Model

Procedures

The third objective of this study was to develop a computer simulation model that would project overall flock performance after the peak production period. The model would predict mortality, egg production and egg size distribution. The overall projection would involve the application of expected costs and revenues to those projected production estimates. The resultant data would be useful for management planning and decision making.

The model itself became an accounting exercise once the predictions were made. Excluding the prediction equations, virtually all the data that were used in making calculations were supplied by the individual manager for his specific flock. The specific flock flexibility did, however, require a large amount of input data. The more information that was available to the manager allowed him to make a better decision.

This section will explain the subroutines of the computer model.

UPDATE. The UPDATE subroutine was responsible for bringing the model on line with the farm's position at the end of the third production period (12 weeks of production). The manager supplied the specific aspects of working capital loans during the first three periods and the specifics of loans to pay for birds, house and equipment. The specifics for each loan included the amount of the loan, the interest rate, the total number of 28-day periods to repay the loan, the number of periods remaining to be paid, the number of periods previously paid and the monthly repayment amount. The model established a loan repayment table for each specific loan. This allowed the model to separate the 28-day period repayment into interest paid and principal paid. On long term loans (more than one production cycle), the model applied interest paid and principal paid in the amount applicable to the current flock. The interest calculations were based on the simple interest on the unpaid balance method.

If all or a portion of the birds, building and equipment were owned, the manager supplied prices per bird for each, the expected life of the building and equipment, and the present age. The model then charged the current flock a non-cash depreciation charge on the owned assets.

The manager supplied the total medication costs expected, maintenance, utilities, taxes, insurance and any mixcellaneous expenses, each on an annual basis. These expenses were prorated evenly to each production period.

The labor calculations required the total operator hours per week, the total hired labor hours per week and the hourly rate for each. The number of extra man hours needed to place the birds in the house and that hourly rate was also required.

Egg production data supplied included peak egg production per hen housed, total mortality, total dozens of eggs produced, total dozens of eggs sold and the total value of those eggs sold. The three previous items were also supplied on an egg size distribution basis. The average prices received per size per period were also needed. The relationships between the average prices per size to date, as a percent of the large size price, became the relationships between prices for the remainder of the production cycle. The model required the manager's expected price for large size eggs per quarter for the next four quarters. The model then generated the anticipated prices for the remaining egg sizes. The manager was to then submit the spent hen price that he anticipated.

If the firm had "booked" its feed, the model would use that price in its calculations. If not, the model required the manager's anticipated feed price by quarter for the next four quarters.

The model also needed the current interest rate. The model was constructed to handle interest rates by 1/4 percent increments from five percent to fifteen percent. The strain of birds used, the quarter of start, the calendar period (1-13) of start, the number of birds housed, the expected number of 28-day production periods and the amount of cash on hand were also included in the input data.

The model used all the above information to update itself to the farm's production, operating income and expenses and net worth position at the end of the first three periods of production.

<u>TCYCLE</u>. This subroutine was the time keeper for the model. It functioned to keep account of the production period number and the calendar period number. If the production period number was less than or equal to the expected production period number, TCYCLE called the remaining subroutines and, thus, simulated another period of production. If the opposite case was true, TCYCLE terminated the simulation.

<u>PREDICT</u>. PREDICT was responsible for estimating the total egg production level, the egg size distribution levels and the mortality rate for each period of the remaining periods of the production cycle. The procedures of calculating the estimates were explained in the Results and

Discussion portion of the Statistical Analysis section of this report.

Table 8 presents a sample computer print-out. The reader may find it helpful to refer to Table 8 while reading the description of each subroutine beginning with subroutine BIRDINV.

BIRDINV. This subroutine kept the physical count of the flock size. The estimated mortality rate was applied to the beginning inventory of each period. The subroutine then calculated the period's mortality, the ending inventory, mortality to date and the average number of live birds during the period.

EGPROD. This subroutine took the projected total eggs per hen housed per period from PREDICT and calculated the total dozens produced during the period. The egg size distribution from PREDICT (expressed in large, medium, small and undergrade size eggs per hen housed per period) was expanded to dozens of each size produced. The model assumed that 98 percent of the eggs produced would be sold. The two percent difference was caused by loss or unaccounted for eggs.

The price received per size (calculated in UPDATE) was applied to the dozens of eggs sold per size to arrive at a value of eggs sold per size. The four egg size values were

```
                                          MSU POULTRY SIMULATOR II
FARM MSU TEST 3        PERIOD  9  OF  13  PERIODS   YEAR PERIOD  7    EGG BLEND   .2604  FEED   80.00  PULLETS   1.85
*****
BIRD           HOUSED    BG INV    MORTALITY    SOLD         ED INV    AVG NO.   MORT RATE   TOTAL MORT
INVENTORY      65000.    46228.      1897.           0.       44331.    45279.      .0410        20669.

*****                                 THIS PERIOD                                  ******
EGG                    LRG       MED        SML      UND        TOTAL              *OPERATING EXPENSES
PRODUCTION     DOZ    64259.     2913.       59.    11696.      78935.             *                   THIS PERIOD        TO DATE
AND            PCT      .814      .037      .001     .148                          * CASH             TOTAL     DOZ       TOTAL     DOZ
SALES          SOLD   62973.     2854.       67.    11462.      77357.             *   FEED           10632.   .1374     129103.   .1947
               PRICE   .2900     .2666     .2402    .0967        .2604             *   LABOR           1392.   .0180      13128.   .0200
               VALUE18262.25    760.90     16.17  1107.98     20147.29                 MEDICATE         231.   .0030       2077.   .0032
                                                                                       MAINT            385.   .0050       3462.   .0053
                                      TO       DATE
                       LRG       MED        SML      UND        TOTAL                  UTILITY          200.   .0027       1869.   .0028
               DOZ   413380.    98627.    92427.    71018.     675452.                 TAXES             96.   .0012        865.   .0013
               PCT      .612      .146      .137     .105                              INSURE            38.   .0005        345.   .0005
               SOLD  404706.    95923.    87938.    69313.     657880.                 MISC              77.   .0010        692.   .0011
               PRICE   .2960     .2911     .2721    .0985        .2698                 SUB-TOTAL      13059.   .1688     150548.   .2288
               VALUE 119811.    26965.    23925.     6626.     177527.
                                                                                       STORED             0.  0.0000          0.  0.0000
*****                                                                                  BIRDS              0.  0.0000          0.  0.0000
LAY                  HEN HSE   DAY AVG                                                 BLD                0.  0.0000          0.  0.0000
RATE           PERIOD   .5204     .7471                                                EQUIP              0.  0.0000          0.  0.0000
               TO DATE  .4948     .5884                                                INTEREST           0.  0.0000          0.  0.0000
                                                                                       SUB-TOTAL          0.  0.0000          0.  0.0000
*****
FEED                 LBS/DOZ   TONS CONS                                               TOTAL COSTS    13059.   .1688     150548.   .2288
FACTS          PERIOD   3.357     132.399                                              NET CASH INC    7089.   .0916      26979.   .0410
               TO DATE  4.535    1531.991                                              NET CASH FLOW   7089.   .0916      26979.   .0410

*****                                                                                NON-CASH
LABOR                OPERATOR   HIRED   BD-MOVE   BDS/MAN HR                             DEPRE          10160.   .1313      91440.   .1390
HOURS          PERIOD    200.     48.       0.        183.                             INT ON EQT       496.   .0064       3871.   .0059
               TO DATE  1800.    432.     300.
                                                                                       TOTAL COSTS    23714.   .3066     245860.   .3737
*****                  THIS  PERIOD                 TO DATE                            NET INCOME     -3567.  -.0461     -68332.  -.1039
CASH                  TOTAL     DOZ              TOTAL       DOZ
INCOME         EGGS   20147.   .26045           177527.    .26985                    ASSETS
               SPT HEN    0.  0.00000                0.   0.00000                      BIRDS          46250.          9250.        37000.
               BORROW     0.  0.00000                0.   0.00000                      BLDG           16380.           910.        15470.
               ON HAND 44791.  .57901                0.    .00000                      EQUIP              0.             0.            0.
               TOTAL   64938.  .83946           177527.    .26985
                                                                                       CASH           44791.          7089.        51879.
                                                                                       TOTAL         107421.         -3071.       104349.

                                                                                     LIABILITIES
                                                                                       STORED             0.             0.            0.
                                                                                       BIRDS              0.             0.            0.
                                                                                       BLD                0.             0.            0.
                                                                                       EQUIP              0.             0.            0.
                                                                                       TOTAL              0.             0.            0.

                                                                                     NET WORTH       107421.         -3071.       104349.

                                                                                                                   PERIOD     TO DATE
                                                                                     RATE OF RETURN     ASSETS         -.03        -.65
                                                                                                        NET WORTH      -.03        -.65
```

Table 8. Sample output of the computer model

summed and divided by the total number of dozens sold to arrive at the blend price for all eggs sold per period.

CASH. The CASH subroutine maintained the cash inflow to the checkbook of the flock. The two sources of income were egg sales and spent hen sales. The subroutine checked the flock's cash balance at the end of the previous period and, if necessary, it established a working capital loan. The loan amount would bring the flock's checkbook cash level back to zero for the start of the new period. This action insured that all cash outlays were paid each period.

EXPENSE. The EXPENSE subroutine in addition to its named functions calculated the lay rate percentages, the labor hour situation, and the feed conversion information.

The lay rate percentages were a direct function of information that originated in the egg production prediction equations and the bird inventory information. The labor hour situation and cost was a direct function from input information.

Feed consumed per period was a function of a maintenance level intake, an intake amount directly related to egg production level and the average number of birds per period.

The formula used for feed intake was as follows (as adjusted from Vincent and Sheppard (1970)):

FDC = (.1537*28) + (10.75*28/100) * LAYRATE * AVGBD

where

FDC = the pounds of feed consumed,

LAYRATE = the percent hen housed egg production, and

AVGBD = the average number of birds.

The (.1537*28) term gave a base feed intake of 4.3036 pounds per bird. The middle term of (10.75*28/100) * LAYRATE gave a feed intake level directly related to egg production. This equation gave an average feed conversion of 3.85 pounds per dozen at a 72 percent rate of production (hen housed basis).

The feed expense varied by quarter. The labor, medication, maintenance, utilities, taxes, insurance, and miscellaneous expenses were constant each period.

The loan repayment and interest expenses were taken directly from the loan repayment tables established in UPDATE or CASH.

Net income over cash costs resulted from cash income minus summed expenses minus short term loan repayment. If the short term loan repayment value was included in the expense figure, a double charge arose since cash borrowed was used to meet other cash expense commitments.

Net cash flow was the difference between cash income (egg sales and spent hen sales) and cash outlay. This procedure was used to determine the net effect of each production period's operations on the firm's cash balance.

Non-cash depreciation was calculated only on owned assets. If the assets were older than the anticipated length of the useful life, depreciation was not charged. The model calculated depreciation using the straight-line method.

The second non-cash cost calculated was an opportunity cost--interest on owned equity. It was calculated at an annual rate of six percent. The equity value used in any period was the ending net worth value from the previous period.

NETWTH. This subroutine maintained the flock's balance sheet. The three sections were assets, liabilities and net worth. Within each section a beginning, change and ending balance was maintained for each item per period. The flock asset was depreciated (the change value) over the expected periods of production. The building and equipment were depreciated in value on a straight-line basis over their expected life. The change in the cash balance was equivalent to the net cash flow of the current period.

The change values in the liability accounts were directly related to their respective loan repayment amounts portrayed in EXPENSE.

Net worth was equal to assets minus liabilities.

This subroutine also calculated rates of return on total assets and net worth, for both the current period and for the production cycle to date. The rate of return was calculated by dividing net income by either total assets or net worth. If net worth was negative, its two rates of return were not calculated.

Results and Discussion

Projecting the future is extremely difficult. The degree of difficulty is increased when biological functions are added as a parameter of the decision model.

The simulator developed from this research could not predict accurately the outcome of every flock. There were two major factors that affected the outcome. Each had sub-factors that increased the complexities of the problem. One of the major factors was predicting flock egg production performance. The other was the accuracy of the prices anticipated by the flock's manager.

The egg production prediction equation coefficients and the egg size distribution coefficients were developed from a series of independent flocks having a spectrum of production. As a result, the coefficients may be considered to have represented the average of each strain's performance. If the simulation model was used to project an average or near average flock, it performed well in projecting egg production and size distribution. On the other hand, if the flock was actually non-average, the model performed poorly. In those poor performance circumstances, the model tended to "miss" by a near constant amount each production period (unusual events excluded--power failure, sudden disease, etc.). That feature (constant miss) gave the user an added benefit. Analyzing production of the fourth period and the fifth period predictions against actual production data gave an average adjustment factor. Quick hand calculated updates of the predicted information then gave the manager an even more accurate projection of his flock.

The other major factor involved in the accuracy of the projections was the anticipated prices of the individual manager. They included expected annual flock expenses, such as medication costs and maintenance, among others, the anticipated price to be received for large eggs and the anticipated price to be paid for feed if feed was not "booked" at a constant price. That area posed the greatest uncertainty. If the price information supplied was "good", relative to actual occurrences, the output would similarly be good and vice versa.

A sub-factor of the price question was the relationship between the large size price and the other sizes' prices. The model calculated the relationships between the prices during the first three periods of production. Those relationships were then applied throughout the remainder of the production cycle. Those relationships were also subjected to the uncertainty of the future. If they held true, the model's performance in that regard was excellent.

Table 9 presents an example of actual farm results compared to predicted results. The dozens sold and dozens of large size eggs sold were both accumulated annual values. The model predicted egg production and dozens sold reasonably accurately. However, the model did not do well on egg size distribution, indicating that the specific flock was not a near average flock compared to others of the same strain.

The manager's anticipated prices for eggs and feed were different than actual values. These differences along with the production and egg size differences led to the $3,446 difference in net income.

Table 9. A comparison of predicted and actual flock performance

Dozens Sold		Large Size Dozens Sold	
Predicted	Actual	Predicted	Actual
450,403	478,775	293,420	343,760

Price of Large Eggs			Price of Feed		
Quarter	Predicted	Actual	Quarter	Predicted	Actual
(cents per dozen)			(dollars per ton)		
1	50	52	1	115.00	115.50
2	45	43	2	110.00	112.50
3	45	42	3	105.00	107.50
4	42	40	4	100.00	105.00

Price of Spent Hens	
Predicted	Actual
(cents per bird)	
60	55

	Predicted	Actual
Income	$209,107	$206,901
Expenses	194,889	196,129
Net Income	$ 14,218	$ 10,772

SUMMARY

Recent records (1970-1973) on 210 commercial laying flocks were obtained from primary breeders and contract and independent producers. The total number of birds involved was in excess of 2.5 million.

Information on each flock included egg production, mortality and egg size distribution (each by 28-day period), starting age of egg production, strain, number of birds per cage, size of flock, starting month of egg production, location, total number of 28-day periods they produced and whether they were in a windowed or windowless house.

The data were collected to meet three objectives. They were:

1. to determine the factors that affect mortality, egg production and egg size distribution,
2. to develop prediction equations that, on the basis of 12 weeks of actual data, would project reasonably accurately, the future patterns of egg production, mortality and egg size distribution, and
3. to develop a simulator to incorporate the prediction equations as one function and simulate all

cost-revenue relationships and flock financial performance over the remaining periods of production to help poultry producers in their flock replacement decision actions.

The number of birds involved in the statistical analysis was 2.2 million from 163 flocks. Flocks were eliminated due to an incomplete data list or because they were recycled.

Seven strains were involved. They were DeKalb, Hyline, Babcock, H&N, Shaver, Kimber and Arbor Acres. The Kimber and Arbor Acre strains were later dropped because of too few flocks.

Two separate least squares multiple regression analyses were conducted. Mortality, total eggs produced per hen housed, and total eggs produced per hen housed as distributed among large, medium, small and undergrade sizes were the dependent variables for both analyses. The first analysis tested the effect of flock size, total 28-day periods of production and starting age of production. The total number of 28-day periods of production significantly ($P < .05$) affected all the dependent variables except the total number of small size eggs produced per hen housed. Starting age of production significantly ($P < .05$) affected only the total number of eggs produced per hen housed and the total number of medium size eggs produced per hen housed. Flock size significantly ($P < .05$) affected all the dependent variables except the total number of small size eggs produced per hen housed. The significance value for that dependent variable was 0.104, a near significant effect.

The data were adjusted for flock size, the total number of 28-day periods of production and starting age of production. The second analysis had as independent variables the remaining input factors requested and selected interactions. The determination of a significant effect from the least squares results was primarily intuitive.

None of the independent variables had a significant effect on mortality. However, the interaction between number of birds per cage and region seemed to have some effect on mortality.

The total number of eggs produced per hen housed was significantly affected by quarter of start, number of birds per cage, strain, quarter of start by strain interaction and number of birds per cage by strain interaction. Region and region by number of birds per cage interaction seemed to have an effect although it was not significant.

The total number of large size eggs produced per hen housed was not significantly affected by the independent variables and interactions of this study.

Region and the absence of windows had some effect on the total number of medium size eggs produced per hen housed.

The total number of small size eggs produced per hen housed was significantly affected by region and the presence or absence of windows. The region by number of birds interaction had some effect.

None of the independent variables or interactions of this study indicated any influence on the total number of undergrade eggs produced.

An attempt was made to develop multi-variable, multiple regression prediction equations for each of the dependent variables. The hope was to develop equations to predict the values from period four of the production cycle through the end of the cycle. The attempt failed.

The procedure outlined by Gavora, et al. (1971) was utilized to determine α values for each strain for use in the Gavora, et al. model. The α value measured the production curve's slope from the peak through the end of the cycle. Strain 2 had the least slope while strain 4 had the steepest production curve slope among the five strains. Strain 1 was separated by quarter of start and α values were determined for each quarter. Quarter 1 had the steepest slope while quarter 2 had the least slope.

Gavora's model was slightly modified and tested. The results were very favorable.

The success of the production curve slope concept gave rise to speculation that a similar process could be applied to egg size and mortality. This research, however, could not undertake that venture.

The egg size distribution model for simulation purposes became the actual average (per 28-day period) percentages of large, medium, small and undergrade sized eggs. The mortality model became a constant rate as determined by the following equation: mortality rate = total mortality through period 3 of production/number of birds housed/3.

The three prediction models became one of the major inputs to the simulation model. The other major input was specific to-date flock production and financial characteristics, plus, expected egg and feed prices as supplied by the flock manager.

The simulator was designed to project flock production and financial performance by 28-day period from period four through the end of the production cycle with 15 periods being the maximum.

The simulator was basically an accounting routine with the exception of the three prediction models. The results of the simulator when compared to actual results were heavily dependent on the accuracy of the manager's input data and whether or not the flock involved was average or near average. The egg production and egg size distribution models performed at a near constant deviation from the actual of the non-average flocks, assuming they followed that strain's pattern. The models were highly inaccurate compared to the actual performance of flocks subjected to short-term abnormalities, such as a power stoppage.

If the manager's expectations were near accurate, the financial results of the model were very favorable. If his expectations were erroneous, the simulator's financial results were erroneous.

CONCLUSIONS

The results of the statistical analyses and the simulation modeling of this study led the researcher to the following conclusions:

1. Wide variations existed in the performance of the actual commercial flocks surveyed. The average total number of 28-day periods of production for the commercial flocks was 14.18. The average hen housed rate of egg production was 57.68 percent.
2. Total mortality was significantly effected by the total number of 28-day periods of production and by flock size.
3. The total number of eggs produced per hen housed was significantly effected by the total number of 28-day periods of production, starting age of production, flock size, quarter of start, number of birds per cage, strain, quarter of start by strain interaction and number of birds per cage by strain interaction.
4. The total number of large size eggs produced per hen housed was significantly effected by the total number of 28-day production periods and flock size.

5. The total number of medium size eggs produced per hen housed was significantly effected by the total number of 28-day periods of production, starting age of production and flock size.
6. The total number of small size eggs produced per hen housed was significantly effected by region and the presence or absence of windows.
7. The total number of undergrade eggs produced per hen housed was significantly effected by the total number of 28-day periods of production and flock size.
8. Multiple variable, multiple regression prediction equations were not acceptable for predicting period by period values (from period four of production through the end of the production cycle) for mortality, total egg production and egg size distribution.
9. The Gavora-Parker-McMillan model, as adapted, was an excellent predictor of period by period total egg production for average or near average flocks within a given strain. If it was inaccurate, it was by a generally constant amount.
10. The potential peak number of eggs produced per hen housed was different for each strain and for each separate quarter of start for strain 1.

11. The rate of lay decrease was different for each strain and for each quarter of start for strain 1. The rate of lay decrease was less for those strains with the lower potential peak number of eggs compared to the other strains.

12. The simulation model developed gave excellent planning results if (1) the prediction equations' results were reasonably accurate and (2) if the manager reasonably accurately projected cost-revenue relationships.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adams, A. W. and M. E. Jackson, 1970. Effects of cage size and bird density on the performance of six commercial strains of layers. Poultry Sci. 49: 1712.

Bell, D., 1971. Cash flow for commercial egg farms. University of California, Agricultural Extension Service, Riverside County, California.

Bell, D., 1972. Cage density, housing and nutrition. Poultry Scratch, University of California Agricultural Extension Service, Riverside County, California.

Dale, J. L., W. H. Vincent and C. C. Sheppard, 1974. Eggman--A computerized egg production management game. Unpublished.

Feldkamp, J. F. and A. W. Adams, 1973. Effects of rearing relationships, cage size, and bird density on the performance of two commercial strains of egg-type chickens. Poultry Sci. 52: 1329-1334.

Gavora, J. S., R. J. Parker and I. McMillan, 1971. Mathematical model of egg production. Poultry Sci. 50: 1306-1315.

Hill, A. T. and M. R. Binns, 1971. Effects on the performance of varying densities and numbers of birds per cage. Poultry Sci. 50: 1585.

Latimer, R. G. and J. Bezpa, 1970. Projections and cash flow for a 30,000 bird commercial table egg operation. No. 1/71/700, Cooperative Extension Service, Rutgers University, New Brunswick, New Jersey.

Marks, H. L., L. D. Tindell and R. H. Lowe, 1970. Performance of egg production stocks under three cage densities. Poultry Sci. 49: 1094.

Muir, F., 1972. A computerized cash flow for market egg farms. No. 570, Cooperative Extension Service, University of Maine, Orono, Maine.

Plumart, P. E., C. W. Carlson and C. E. Holmquist, 1972. Cage density and laying hen performance. Poultry Sci. 51: 1850.

Ruggles, L. H., 1971. Projecting a cash flow for an egg production firm. No. 68, Department of Agricultural and Food Economics, University of Massachusetts, Amherst, Massachusetts.

Vincent, W. H. and C. C. Sheppard, 1970. An application of computer simulation to the feed-integrated poultry industry. Abstracts of Scientifique Communications, XIV World's Poultry Congress, Madrid, Spain.

APPENDIX I

Table 1. Actual raw data - example

Starting Age: 20 weeks | Starting Month: February

Birds per Cage: 3 | Windows: yes

Strain: H&N | Size of Flock: 10,340

			Dozens Sold			
Period	Mortality	Eggs Produced	Large	Medium	Small	Undergrade
1	50	69,198	29	34	956	1,651
2	115	210,730	350	2,492	9,869	4,009
3	312	225,035	3,284	7,562	5,073	1,000
4	146	244,590	8,977	15,206	1,710	1,434
5	137	299,730	7,774	7,602	646	988
6	333	221,231	9,383	5,676	310	1,421
7	100	207,985	10,661	6,931	267	1,620
8	71	187,565	8,241	4,642	264	1,253
9	42	163,530	8,887	3,331	150	952
10	77	151,040	11,884	2,802	152	1,062
11	73	151,755	10,118	905	39	1,088
12	85	147,325	11,409	957	53	1,021
13	99	128,415	6,819	782	23	401
14	101	105,210	9,657	871	22	692

(THERE WERE 210 DIFFERENT RECORDS OF THIS TYPE.)

Table 2. Rate of lay decrease coefficients for each period for strains 2, 3, 4 and 5

Period	Strain			
	2	3	4	5
4	.950283	.943654	.931463	.938949
5	.903038	.890484	.86763	.881622
6	.858139	.840304	.80816	.827791
7	.81547	.79295	.75277	.77725
8	.774925	.74826	.70119	.7298
9	.736398	.706106	.65313	.685234
10	.699783	.666318	.60836	.643399
11	.664984	.6268768	.56667	.604118
12	.631915	.593336	.52782	.567234
13	.6005	.5599	.49164	.53259
14	.570642	.52835	.45795	.500083
15	.542268	.498586	.42656	.46955

Table 3. Rate of lay decrease coefficients for each period by quarter of start for strain 1

Period	Quarter			
	1	2	3	4
4	.94195	.954414	.95153	.944222
5	.88998	.910894	.910476	.89155
6	.83577	.86936	.861575	.841814
7	.787262	.829719	.81975	.7948496
8	.741564	.7198835	.78	.750516
9	.69852	.75578	.742308	.7086548
10	.657974	.7213132	.70623	.66891194
11	.619775	.6884217	.67199	.631788
12	.5838	.65705	.6394184	.59655
13	.5499	.6270724	.608421	.563278
14	.517994	.5984848	.5789278	.531946
15	.487924	.57121	.5508635	.5021848

Table 4. Egg size distribution coefficients for each period for strain 2

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	56.92	31.66	1.96	9.46
5	72.26	16.80	1.03	9.92
6	75.25	12.87	1.06	10.83
7	80.50	7.60	.26	11.65
8	81.97	5.25	.18	12.61
9	84.41	3.69	.09	14.82
10	79.10	3.50	.09	17.32
11	78.31	3.22	.11	18.36
12	75.56	3.12	.13	21.19
13	76.46	3.96	.12	19.45
14	79.01	3.30	.14	17.56
15	79.01	3.30	.14	17.56

Table 5. Egg size distribution coefficients for each period for strain 3

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	61.78	29.06	2.35	6.82
5	71.44	18.98	1.07	8.51
6	76.28	13.73	.57	9.41
7	77.34	11.84	.51	10.31
8	78.60	10.05	.37	10.98
9	79.49	8.82	.32	11.38
10	80.63	7.78	.24	11.35
11	81.20	6.22	.19	12.39
12	81.80	6.73	.24	11.23
13	80.15	7.30	.25	12.31
14	77.92	7.80	.28	14.00
15	77.92	7.80	.28	14.00

Table 6. Egg size distribution coefficients for each period for strain 4

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	41.34	47.40	4.45	6.82
5	57.36	33.72	1.94	6.98
6	64.04	25.50	1.49	8.97
7	67.54	20.52	.84	11.10
8	69.17	17.64	.65	12.54
9	72.99	14.25	.49	12.26
10	72.16	12.41	.50	14.93
11	72.80	10.50	.47	16.24
12	75.10	8.75	.43	15.72
13	77.26	8.74	.38	13.61
14	76.84	10.70	.55	11.92
15	76.84	10.70	.55	11.92

Table 7. Egg size distribution coefficients for each period for strain 5

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	56.58	32.79	2.31	8.32
5	66.50	22.72	1.34	9.42
6	70.43	17.02	1.43	11.12
7	72.66	15.08	.99	11.28
8	75.90	11.37	.58	12.15
9	79.02	6.75	.42	13.82
10	79.21	5.31	.68	14.80
11	79.18	4.27	.10	16.46
12	78.47	3.77	.14	17.63
13	75.02	5.36	.16	19.46
14	71.50	3.39	.11	24.99
15	71.50	3.39	.11	24.99

Table 8. Egg size distribution coefficients for each period for strain 1 for quarter of start 1

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	54.53	34.43	3.70	7.33
5	61.22	28.80	2.16	7.82
6	66.82	23.08	1.69	8.41
7	70.22	19.56	1.24	8.98
8	73.64	16.06	.63	9.66
9	77.28	12.37	.54	9.81
10	78.15	11.08	.40	10.37
11	79.13	9.14	.29	11.44
12	78.62	8.12	.21	13.05
13	78.63	7.78	.37	13.22
14	78.00	7.56	.32	14.12
15	78.00	7.56	.32	14.12

Table 9. Egg size distribution coefficients for each period for strain 1 for quarter of start 2

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	55.35	35.00	2.13	7.52
5	64.67	26.18	1.56	7.59
6	73.22	17.70	.76	8.32
7	76.92	13.80	.54	8.74
8	78.62	10.40	.21	10.77
9	78.47	10.16	.17	11.20
10	82.17	7.67	.34	9.82
11	82.94	6.07	.13	10.87
12	81.54	6.16	.25	12.05
13	80.92	7.58	.16	11.34
14	78.53	8.04	.28	13.15
15	78.53	8.04	.28	13.15

Table 10. Egg size distribution coefficients for each period for strain 1 for quarter of start 3

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	55.45	34.09	3.53	6.94
5	65.36	25.67	1.47	7.50
6	73.09	18.14	.72	8.05
7	77.28	13.80	.43	8.50
8	77.51	11.74	.42	10.33
9	76.18	13.22	.35	10.25
10	78.71	9.33	.30	11.67
11	78.57	8.95	.42	12.06
12	76.94	9.68	.45	12.93
13	76.86	8.75	.38	14.01
14	76.74	8.25	.43	14.58
15	76.74	8.25	.43	14.58

Table 11. Egg size distribution coefficients for each period for strain 1 for quarter of start 4

Period	Large	Medium	Small	Undergrade
	(Percentages)			
4	55.23	34.64	2.48	7.65
5	64.88	25.68	1.19	8.26
6	70.91	19.22	.89	8.98
7	73.91	15.29	.82	9.98
8	75.67	13.44	.79	10.09
9	75.83	13.03	.77	10.38
10	75.47	12.77	.76	11.01
11	75.44	11.96	1.10	11.51
12	75.58	11.17	.86	12.39
13	77.02	9.05	.65	13.28
14	78.72	7.36	.38	13.54
15	78.72	7.36	.38	13.54

Table 12. Two examples of the egg prediction model

Period	Actual	Estimated	Difference
	Eggs Per Hen Housed		
Producer Number 1			
4	19.96	19.58	.38
5	19.13	18.49	.64
6	18.28	17.46	.82
7	17.24	16.48	.76
8	16.28	15.56	.72
9	15.45	14.69	.76
10	14.68	13.87	.81
11	13.79	13.10	.69
12	12.47	12.37	.10
13	11.73	11.68	.05
14	11.13	11.03	.10
Producer Number 2			
4	16.52	18.09	-1.57
5	15.81	17.19	-1.39
6	13.98	16.34	-2.36
7	11.84	15.53	-3.69
8	11.62	14.75	-3.13
9	11.91	14.02	-2.11

Table 13. An example of the measurement of an independent variable's effect on a dependent variable from the least squares analysis

(Dependent Variable - Total Eggs Produced Per Bird Housed)		
Variable Group	Variable Number	Significance Level
Region:	15	.017
	16	.218
	17	.150
Region by Quarter of Start:	41	.609
	42	.951
	43	.149
	44	.956
	45	.222
	46	.915
	48	.429
	49	.604

Explanation:

Region: Two of the three listed variables had significance levels less than .2, however, one of the two was relatively high (.15). The third variable was outside the specified significance range, although close. Thus, the variable region was determined to have some effect, although not a significant effect.

Region by Quarter of Start: A quick scan of the significance levels indicated that this interaction had no effect on the dependent variable.

Table 14. The data adjustment formula

$$yad_{(j)} = yob_{(j)} - \beta_1\, x_{1(j)} - x_1 - \beta_2\, x_{2(j)} - x_2 - \beta_3\, x_{3(j)} - x_3$$

where

$yad_{(j)}$ = each adjusted mortality, egg production and egg size distribution value

$yob_{(j)}$ = each observed mortality, egg production and egg size distribution value

β_1 = the estimate of the effect of the total number of 28-day production periods

β_2 = the estimate of the effect of the starting age of production

β_3 = the estimate of the effect of flock size

$x_{1(j)}$ = the total number of 28-day periods of production related to each $yob_{(j)}$

$x_{2(j)}$ = the starting age of production related to each $yob_{(j)}$

$x_{3(j)}$ = the size of flock related to each $yob_{(j)}$

x_1 = the mean number of total 28-day periods of production

x_2 = the mean starting age of production

x_3 = the mean flock size