ROYAL STATISTICAL SOCIETY
DATA | EVIDENCE | DECISIONS

GRADUATE DIPLOMA IN STATISTICS

MODULE 4: MODELLING EXPERIMENTAL DATA

READING LIST

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General Texts

Sokal, RR, & Rohlf, FJ (2012) Biometry: the principles and practice of Statistics in Biological Research (Fourth Edition). W.H.Freeman and Co, New York

Although this text is focussed on the application of statistics in biological research, it does include material that will be of general value for this module. Chapters 8 to 11 are concerned with the Analysis of Variance, including the computational formulae for the sums of squares for different forms of design. Chapter 12 then focusses on the calculation of appropriate samples size, while Chapter 13 is concerned with the assumptions underlying the linear model and transformation approaches to enable these assumptions to be satisfied. Chapter 14 covers Linear Regression, including the comparison of regression lines, and Chapter 16 extends this to both multiple linear regression and some forms of curvilinear regression (mostly polynomials).

Chatfield, C (1983) Statistics for technology: a course in applied statistics (Third Edition). Chapman & Hall/CRC, Boca Raton, Florida

Focussed more on engineering applications, this text also includes some useful material that will be of general value for this module. Chapter 8 covers material on linear regression including multiple and curvilinear extensions. Chapters 10 and 11 are then concerned with concepts associated with the design and analysis of experiments.

Snedecor, GW, & Cochran, WG (1989) Statistical Methods (Eighth Edition). Iowa State Press, Ames, Iowa

A number of chapters in this general text are of relevance to this module. Chapter 9 introduces linear regression including calculation of the analysis of variance and prediction. Chapter 12 introduces the Analysis of Variance for a fixed effects model with a one-way classification, Chapter 13 considers the equivalent approach with a random effects model, with up to three stages of sampling, and Chapter 14 extends the approach to a two-way classification and, briefly, a Latin square design. Chapter

15 addresses failures in the assumptions including a range of possible transformation approaches, and Chapter 16 covers the analysis of factorial experiments, including split-plot designs and repeated measurements. Chapter 17 covers the ideas of multiple linear regression, and Chapter 19 introduces a range of non-linear models, including both exponential and polynomial regression.

Hocking, RR (2013) Methods and Applications of Linear Models: Regression and the Analysis of Variance (Third Edition). Wiley, New York.

Another comprehensive coverage of the linear model approach, combining theoretical concepts with intuitive ideas. Chapter 1 introduces the linear model, with the application for the simple linear regression model (including some model checking) covered in Chapter 2. Chapter 3 is focussed on transformations and weighted least squares, with Chapter 4 extending the approach to multiple linear regression, including methods of variable selection. Issues of collinearity are covered in Chapter 5, and the concepts of leverage and influence presented in Chapter 6. A brief coverage of non-linear regression and Generalized Linear Models is included in Chapter 8. Chapter 9 introduces the analysis of variance method for classified data, with the mathematical theory of linear models covered in Chapter 10.Chapters 11 to 14 extend the analysis of variance approach, initially to cope with multiple crossed and nested treatment factors, and then to consider a wider range of mixed effect models (finally introducing methods for unbalanced data that are beyond this module). Some useful mathematical background is included in Appendix A.

Design of Experiments and Analysis of Variance

Mead, R, Gilmour, SG, & Mead, A (2012) Statistical principles for the design of experiments: applications to real experiments. Cambridge University Press, Cambridge, UK

This recent text provides a modern and comprehensive approach to approaches to the design of experiments. Early chapters are focussed on the elementary ideas of blocking (Chapter 2) and treatment structure (Chapter 3), before Chapter 4 covers the general principles of linear models for the analysis of experimental data (least squares, extra sums of squares, contrasts, treatment comparisons). Chapters 5 to 11 focus on the experimental resources, covering experimental units, replication, blocking and control, multiple blocking systems, randomisation (including restricted randomisation) and multiple levels of information (including ideas of mixed models and the REML algorithm). Chapters 12 to 18 then focus on the treatments, discussing experimental objectives, factorial structure, fractional replication and incomplete blocks, designs for quantitative factors, and split-unit designs.

Cochran, WG, & Cox, GM (2005) Experimental Designs (Second Edition). Wiley, New York

This well-established text provides considerable material about different classes of design. Chapter 3 contains details about the general method of analysis for data from designed experiments, and Chapter 4 introduces the simplest forms of design (Completely Randomised Design, Randomised Complete Block Design, Latin Square Design). Chapters 5 to 8 are focussed on factorial experiments, including ideas of

confounding, fractional replication, and split-plot designs. Chapter 9 is concerned with the construction of both balanced and partially-balanced incomplete block designs, and later chapters then introduce more complex design structures.

Cox, DR (1992) Planning of Experiments. Wiley, New York

Another well-established text provides a readable account of the ideas underlying modern work on the statistical aspects of designing experiments. Chapter 3 focusses on ideas about blocking to reduce error, Chapter 4 on the use of analysis of covariance to reduce error, and Chapter 5 on the principles and practice of randomisation. Chapters 6 and 7 are concerned with factorial treatment structures, with extensions to fractional replication and confounding covered in Chapter 12. Chapters 8 and 9 are concerned with the determination of sample size and the choice of both appropriate experimental units and appropriate treatment sets.

Cassella, G. (2008) Statistical Design. Springer, New York

This relatively recent text provides good guidance on the statistical principles for the design of experiments and the analysis of data from designed experiments using linear models. Chapter 2 is focussed on the Completely Randomized Design, including contrasts and factorial treatment structure, while Chapters 3 and 4 extend these ideas for blocked designs. Chapter 5 considers approaches associated with split-plot designs, and Chapter 6 includes some material concerned with incomplete blocks (both balanced incomplete block designs and fractional factorial designs).

Box, GEP, Hunter, JS & Hunter WG (2005) Statistics for Experimenters: Design, Innovation and Discovery (Second Edition). Wiley, New York.

Aimed at experimenters, this text teaches the concepts of statistical design and the analysis of designed experiments through the use of examples, graphical tools and the appropriate use of computers, based on a problem-solving approach. Chapter 4 considers the use of completely randomized designs, randomized complete block designs and Latin squares, while Chapter 5 explores the benefits of factorial treatment structure, and Chapter 6 considers a range of fractional factorial designs. Chapter 8 includes material on data transformation, with Chapter 9 focussing on multiple sources of variation including both split-plot designs and variance components estimation. Chapter 10 is focussed on the method of least squares and the relationship with designed experiments.

Montgomery, DC, (2012) Design and Analysis of Experiments (Eighth Edition). Wiley, New York.

Focussed more on engineering applications of statistical methods, this text provides a comprehensive coverage of issues of the statistical design and analysis of experimental data. Chapter 3 provides a comprehensive exploration of the method of analysis of variance for both fixed effects and random effects models, including approaches for the checking of assumptions, and assessment of contrasts. Chapter 4 considers designs incorporating blocking factors, including the recovery of interblock information, and Chapters 5 to 9 consider factorial experimentation, including fractional replication and confounding. Chapter 13 considers random effects models in more

detail, with Chapter 14 exploring nested treatment factors and ideas related to split-plot designs. Chapter 15 includes a little on transformation and Chapter 10 provides an introduction to regression modelling approaches (including multiple linear regression).

Clarke, GM & Kempson, RE (1997) Introduction to the Design and Analysis of Experiments. Hodder Arnold, London.

This text provides a good general introduction to the statistical design of experiments and the application of analysis of variance to analyse data from designed experiments. Chapter 3 covers the principles of the design of experiments, with Chapter 4 describing the approach to the analysis of data from orthogonal designs (including the use of residuals to examine assumptions and the use of transformations). Chapters 5 and 6 are concerned with factorial experiments, including confounding and fractional replication, with Chapter 7 considering the confounding of main effects in split-plot designs. Balanced incomplete block designs are introduced in Chapter 11, together with extensions to row-and-column designs. Chapter 13 is concerned with random effects models and the use of variance components to determine sampling schemes.

Hinkelmann, K, & Kempthorne, O (2008) Design and Analysis of Experiments: Volume 1 – Introduction to Experimental Design (Second Edition). Wiley, New York.

This modern texts presents much of the key information on the design and analysis of experiments relevant for this module. Chapter 2 presents the principles of the design of experiments, including the linear model and an outline of analysis of variance, with Chapter 4 covering in considerable depth the theory of linear models, including the notions of fixed, mixed and random models. Chapter 5 discusses issues of randomisation, with chapter 6 focussed on the design and analysis of the completely randomized design. Chapter 7 is concerned with comparisons of treatments including the use of contrasts. Chapters 9 and 10 introduce the randomized complete block design and Latin square design respectively, with Chapter 11 presenting the key ideas of factorial treatment structure, including fractional replication and confounding.

Regression Analysis

Draper, NR, & Smith, H (1998) Applied Regression Analysis (Third Edition). Wiley, New York.

This text covers most of the material associated with regression analysis in the syllabus for this module (including topics listed under both "General linear model" and "Multiple regression"). Chapter 1 introduces the approach of fitting a straight line relationship by least squares, including the summary using analysis of variance, with Chapter 2 focussed on checking the fit using residual plots. Chapter 5 extends the least squares approach to the general linear regression situation, with Chapter 6 introducing the extra sums of squares principle associated with multiple linear regression. Issues of serial correlation are considered in Chapter 7 (including the Durbin-Watson test), with the Hat matrix and further model checking approaches covered in Chapter 8. Chapter 9 focusses on multiple linear regression, including weighted least squares, with model selection methods covered in Chapter 15. The

use of transformation of the response variable are covered in Chapter 13, and issues with multicollinearity are covered in Chapter 16. A brief introduction to Generalized Linear Models is included in Chapter 18, but other more detailed texts (see below) are probably better for this topic. Chapters 20 and 21 provide an interesting geometrical view of the least squares method. Chapter 24 then introduces least squares approaches for non-linear models, including growth curves.

Weisberg, S (2014) Applied Linear Regression (Fourth Edition). Wiley, New York.

Another text providing a fairly practical approach and covering most of the material on regression analysis witin this module. Chapter 2 covers simple linear regression with Chapter 3 extending the approach to multiple linear regression, and Chapter 4 focussed on the interpretation of the fitted model and model fit. Chapter 6 considers the analysis of variance to summarise the fitted model. Chapter 7 introduces various issues concerned with variances, from weighted least squares to variance stabilizing transformations, with more on transformations in Chapter 8. Chapter 9 is focussed on diagnostic tools and residual plots for assessing the linear model assumptions, with Chapter 10 considering issues of variable selection. Non-linear regression approaches are introduced in Chapter 11, while Chapter 12 provides a brief introduction to Generalized Linear Models through binomial and Poisson regression approaches (though, again, there are better texts identified below for this topic).

Montgomery, DC, Peck, EA & Vining, GG (2012) Introduction to Linear Regression Analysis (Fifth Edition). Wiley, New York.

A comprehensive and up-to-date introduction to the fundamentals of regression analysis. Chapter 2 introduces the simple linear regression model, extended to multiple linear regression (including issues of multicollinearity) in Chapter 3. Methods for checking model adequacy are introduced in Chapter 4, and the use of transformations or weighted analysis to correct model inadequacies described in Chapter 5. Diagnostic tools to assess leverage and influence are covered in Chapter 6. Polynomial regression approaches are covered in Chapter 7, with more general non-linear regression models described in Chapter 12. Multicollinearity is revisited in more detail in Chapter 9, with variable selection methods covered in Chapter 10. A brief introduction to Generalized Linear Models is contained in Chapter 13, with issues with serial correlation covered in Chapter 14. Appendix C contains a considerable collection of technical material associated with these topics.

Cook, RD, & Weisberg, S (1994) An Introduction to Regression Graphics. Wiley, New York. *(an e-book version is also available, published in 2009)*

Although focussed around implementation using Xlisp-Stat, this text provides some useful material on graphical approaches associated with regression analysis. Many of the early chapters are concerned with graphical approaches not directly associated with the module syllabus, though encouraging the use of graphical approaches to explore possible and fitted models. Chapter 9 is focussed on transformations of the predictor variables and Chapter 10 on transformations of the response variable. Chapter 11 and 12 then provide a range of graphical approaches for checking models,

including added variable plots, with Chapter 13 focussed on the assessment of leverage and influence.

Statistical Modelling/Generalized Linear Models

Krzanowski, WJ (1998) An Introduction to Statistical Modelling. Hodder Arnold, London.

This text covers a range of statistical modelling approaches, starting with a general introduction to statistical modelling and then covering the application of the general linear model for quantitative variables (regression – Chapter 3) and qualitative variables (analysis of variance – Chapter 4). Chapter 5 then introduces the theory of generalized linear models, with logistic regression (binomial data) covered in Chapter 6 and log-linear models (Poisson or multinomial data) covered in Chapter 7.

McCullagh, P, and Nelder, JA (1989) Generalized Linear Models (Second Edition). Chapman & Hall / CRC Press, Boca Raton, Florida.

The original text on this topic, providing both the underlying theory for this class of models, and some specific applications. Chapter 1 provides a general introduction and motivation for the set of methods included in this generalized approach, with Chapter 2 providing an outline of the approach including the different processes in model fitting, the components of the GLM, assessment of goodness of fit and a discussion of different types of residuals. Chapter 3 then presents the general linear model within this framework to introduce ideas about model formulae and estimation using least squares. Chapter 4 is focussed on applications for binary or binomial data (including logistic regression), while Chapter 5 considers approaches for polytomous (multinomial) data. Log-linear models, for analysing both Poisson count data and multinomial data, and then described in Chapter 6. Later chapters introduce further, more complicated, development of the approach, material that is beyond the syllabus for this module, except that Chapter 12 is focussed on methods for model checking, including residual plots and assessment of leverage and influence.

Dobson, AJ & Barnett, AG (2008) An Introduction to Generalized Linear Models (Third Edition). Chapman & Hall/CRC, Boca Raton, Florida.

A slightly more accessible introduction to the approach introduced by McCullagh and Nelder, covering much the same material. Chapter2 covers general aspects of statistical modelling, with Chapter 3 introducing the exponential family f distributions and GLMs. Chapter 4 is concerned with estimation and Chapter 5 with inference and hypothesis testing. Chapter 6 considers general linear models, including multiple linear regression , analysis of variance and analysis of covariance. Chapters 7 and 8 are concerned with models for binary responses, leading to logistic regression model, and extensions for nominal and ordinal data. Chapter 9 introduces the log-linear model for both Poisson regression and the analysis of contingency tables. Later chapters cover more advanced techniques that are not included in the syllabus for this module.

Agresti, A (2015) Foundations of Linear and Generalized Linear Models. Wiley, New York.

A new book in 2015 providing a comprehensive guide to the key concepts and results of linear statistical models. Chapter 1 provides a general introduction, with Chapter 2 focussed on linear models and least squares theory, and Chapter 3 considering the general linear model with Normally distributed errors. Chapter 4 presents the general approach for Generalized Linear Models, with Chapters 5, 6 and 7 introducing models for binomial data, multinomial response and Poisson data respectively. Chapter 8 is concerned with ideas of overdispersion and variance inflation, with later chapters covering more advanced development sbeyond the syllabus for this module.

Online learning materials

There do not appear to be many online courses or materials particularly focussed on the content of the syllabus for this module.

A useful glossary of statistical terms, including quite a bit of material related to this module was developed as part of the STEPS programme some years ago, and this glossary can be found online at http://www.stats.gla.ac.uk/steps/glossary.

The Institute of Statistics Education (http://www.statistics.com) provides a series of statistics training courses, usually run over a 4-week period. Courses that include material that is relevant for this syllabus are "Regression" (covers simple linear regression, multiple linear regression and various ideas associated with model building), "Design of Experiments" (covers basic concepts and factorial experimentation – mainly from an engineering perspective), "Statistics 3 – ANOVA and Regression" (no additional detail available), "Introduction to Statistical Modelling" (regression, anova, ancova), and "GLM" (models for continuous responses and both binomial and Poisson data).

The web-site http://www.onlinecourses.com/statistics provides access to open online courses in statistics, with four courses currently (March 2015) advertised. "Introduction to Statistics and Data Analysis" includes material on analysis of variance and simple linear regression, but doesn't really cover the more advanced material included in the syllabus for this module.

The Coursera web-site (http://www.coursera.org) also contains links to some online statistical courses, including one on "Regression Models" offered by Johns Hopkins Bloomberg School of Public Health. This covers regression analysis, least squares, ANOVA and ANCOVA, including assessment of residuals, and extensions to Generalized Linear Models, though possibly not in sufficient depth for this module without reference to additional texts. Another course on "Data Analysis and Statistical inference" offered by Duke University also provides some content relevant to this module - a little on designing studies, a simple introduction to analysis of variance, and sessions on both simple linear regression and multiple linear regression (including model selection and model diagnostics), though possibly not in sufficient depth for this module without reference to additional texts.