THE UNIVERSITY OF
WARWICK

Course Guide for the

Undergraduate Degrees

in

MORSE

(Mathematics, Operational Research, Statistics and Economics)

2009 - 2010

Contents

1. GENERAL INFORMATION

This booklet is an unofficial guide prepared by the Department of Statistics for students on the MORSE degrees (Y602, Y604, G300). The official statement of degree regulations is set out in the current issue of the University of Warwick Course Regulations Handbook which is available for consultation in the Library. A further extremely valuable source of information is the University's online information site (insite) available at: *http://www2.warwick.ac.uk/insite/*

From here there are links to all student information and specifically to my.warwick where you can access information and resources that are personal to you.

Further information is available from the department's webpage at:

http://www2.warwick.ac.uk/fac/sci/statistics/

You should retain this booklet, as you will need to consult it from time to time throughout the year. You may also need it when you apply for exemptions from various professional examinations. It is expensive to produce and if you require a replacement you will have to download it from the webpage at your own expense.

1.1 Background

Over the past thirty years mathematics has begun to realise some of its enormous potential for application in management, finance, industry, government, education, medicine and other areas. Consequently, the demand for people skilled in mathematics and its applications has accelerated rapidly. It was in response to this demand that MORSE was created and, more recently, the 4-year integrated Masters degree.

MORSE and the integrated Masters degree are honours degrees involving four departments: Mathematics, Statistics, Economics, and the Warwick Business School. Students following these degrees are exceptionally fortunate in that all four departments have been consistently graded very highly in the exercises undertaken by HEFCE to assess the quality of university research.

The degrees are administered by the Statistics Department. They provide fully integrated courses leading to a solid grounding in the four component subjects and offer an excellent basis for a multitude of careers.

1.2 Aims

The MORSE and the integrated Masters degree set out to provide three things: firstly, courses which will stimulate interest in mathematical concepts, with particular reference to the major application areas; secondly, to improve the quality and quantity of mathematically skilled people working, researching and teaching in these areas; thirdly, to satisfy the needs of those students who seek a continuous development of mathematics from school through university to postgraduate application.

In common with other mathematical science degree courses at Warwick we aim to:

- Attract well-qualified students.
- Provide an intellectually stimulating environment.
- Help students develop key intellectual skills.
- Provide a challenging education in mathematics/statistics and their applications.
- Produce high quality graduates who are well prepared for the next step of their professional lives whether this involves further research training or moving directly into a career.

Specific aims of statistics degree courses are to:

- Provide courses based on mathematics and its applications in statistics, operational research and economics suitable for students aiming for a career involving one or more of these areas.
- Enable students on the integrated Masters degree to study these areas more deeply.

Detailed objectives for each year are to be found at the start of the relevant section.

1.3 BSc in MORSE

The first two years of this three year MORSE degree follow a (mainly) fixed set of courses, laying the foundations of the four main subjects. For part of the first two years, and the whole of the third, students are free to choose from a wide range of topics. Final year students can elect to specialise in one or two of the main subject areas or can continue a balanced programme by selecting topics from all four departments.

1.4 Integrated Masters Degree in MORSE

The first two years of this four year integrated Masters degree follow that for the BSc degree. From the third year onwards, students specialise in one of the following four areas:

- Actuarial and Financial Mathematics.
- Operational Research, Systems and Statistics.
- Econometrics and Mathematical Economics.
- Statistics with Mathematics.

1.5 Careers

Naturally, there is a correspondingly wide choice of career opportunities for MORSE graduates in the spheres of application described above. See Section 6 of this Course Guide for detailed information on Careers. Students interested in the possibility of pursuing a career as an actuary should note that the MORSE/integrated Masters degrees are well received and can exempt them from a number of examinations (see section 6.9).

2. TEACHING AND LEARNING

2.1 Lectures and Tutorials

The main form of teaching is the traditional lecture course. (No one has yet come up with a better alternative, although a few students do work better from books). Lectures are usually very condensed and you are unlikely to understand everything the lecturer does at the time. As a result, most lecture courses in the first two years are supplemented by tutorials, supervisions, seminars or classes (the name varies according to the department concerned). Because the number of students in each group is usually quite small, these tutorials form your main opportunity for asking questions and clearing up difficulties. Most lecturers hand out question sheets; if there are any questions you cannot answer, you should use the tutorials to ask about these as well.

For first year students the Mathematics Department arranges supervisions of one hour per week with a research student. These supervisions cover all Mathematics courses. For other courses and departments, the arrangements are usually made by individual lecturers. The lecturing style in Economics is somewhat different from that of other departments: background reading and the preparation of additional notes which amplify and explain the lectures are usually essential.

Of course, you are not forced to attend lectures or tutorials. However, if a candidate's examination mark is near a borderline between two grades, evidence that they have worked hard and consistently throughout the year can affect the outcome of an examiners' meeting. If you are not satisfied with your subject tutor then arrange with the appropriate Undergraduate Support Officer to change groups.

2.2 'Our Contract'

Our duty as a department is to deliver a coherent degree course with well-presented lectures backed up by support, usually in the form of small classes. Your duty is to try hard to learn, and not to impede the attempts of others. In particular this means that you should attend lectures and support classes, having prepared for them by revising prerequisite material and by attempting all example sheets promptly. A failure to do this usually leads to boredom (through lack of understanding) and an inadequate performance.

2.3 The Personal Tutor System

Every student has a member of staff assigned as their personal tutor. Your tutor is there to help sort out any problems connected with your university career, and **you must make a point of seeing them at least twice a term,** ***(the first week and last week)*** so that they know how you are getting on. You must respond promptly if they ask to see you and it is advisable to keep your personal tutor informed of any academic or personal problems.

Some specific ways in which your personal tutor can help are:

- Providing general academic advice on progress and development, including discussing possible option choices and disclosing exam marks and their implications.
- Giving you help and advice about pastoral and non-academic matters insofar as they are able and advising you about where to find further help on the campus if you need it.
- Writing a letter of reference when you apply for jobs or grants.

Personal Tutors should:

- Advertise two ‘office hours’ each week, starting on the half-hour, when students can consult them.
- Communicate with their students regularly, including via email.
- Be available in the event of an emergency.

In addition your personal tutor has certain formal duties to represent you at exam boards and in disciplinary matters.

If you wish to change your personal tutor for any reason, the Undergraduate Support Officer will assign you a new one.

The Mentor System

The Statistics SSLC administers a mentor system, where older students help first year students settle in to their university life. A mentor provides an informal point of contact to students where they can ask questions about their course, modules and wider university issues such as nights out, accommodation, societies and sports.

The mentor system in no way replaces the Personal Tutor system. Students **must** meet with their personal tutors at least twice a term and keep their personal tutors informed of any academic or personal problems.

2.4 Personal Transferable Skills

As well as supporting your academic studies, the preparation of assessed work and your active participation in seminars and tutorials will also help you develop skills which will be invaluable in your later career and in job applications and interviews. These "personal transferable skills" include the ability to write clearly and concisely, to explain your work clearly to others and to present your work in a professional manner through the use of word processing and other computer packages.

After completing your degree you will have:

- Acquired basic skills in IT and had the opportunity through the choice of options and other activities to develop these further.
- Acquired independent study and working skills.

2.5 Personal Development Plan (PDP)

The university is currently encouraging Personal Development Plans as an integral part of the learning process. PDP is a structured process undertaken by an individual to reflect upon their own learning performance and achievement and to plan for their personal, educational and career development.

PDP is essentially designed to help students to become more effective, independent and confident self-directed learners; understand how they are learning and relate their learning to a wider context; improve their general skills for study and career management; articulate their personal goals and evaluate progress towards their achievement; and encourage a positive attitude to learning throughout life. To find out more about PDP: *http://go.warwick.ac.uk/pdp*

2.6 Study Skills

It is important to understand that university education is based on ***independent study***. Lecture courses are very compressed. You will not learn everything from the lectures. You will need to spend time supplementing the lecture material, filling in the gaps, working through examples, and studying textbooks. Each module has an associated CATS weighting which you can use as a guide: a CAT represents 10 hours notional work so a 12 CAT course may contain 30 hours of lectures, 60 hours of independent study and 30 hours of revision.

Here are some specific recommendations to think about:

- Plan to spend 35-40 hours per week on academic work in term-time. However be flexible in order to give more time to any core modules which you are finding difficult.
- Be prepared! Ensure lecture notes are re-read/understood before the next lecture. Always consult textbook(s).

- Attempt example sheets as soon as possible - easy questions check/aid comprehension, harder ones deepen it.
- Attempt to understand the direction of a course (read the Aims and Objectives) - try to write a brief narrative or commentary on your notes at the halfway mark and again at the end.
- Praise and reward yourself when you perform well or understand something difficult.
- In accounting for study time, each hour between 10pm and 8am should only count as 30 minutes!

If you feel in any doubt about your study skills you should consult your personal tutor, seek advice from the University Senior Tutor's office, and look out for notices advertising special study skills sessions which are posted on departmental notice boards.

If English is not your first language, it is important to practice at every opportunity. This department encourages the use of English at all times. If you wish to improve your skills, you should visit the English Language Teaching Unit who offer both Pre-sessional and In-sessional courses in English

http://www.warwick.ac.uk/fac/soc/CELTE/

2.7 Warwick Skills Programme

As part of your Personal Development Plan (PDP) you might like to consider taking the WARWICK SKILLS CERTIFICATE (WSC) over the course of your degree programme. The WSC offers you the chance to fine tune your existing academic and personal skills and to develop new ones. For further information see: *http://www2.warwick.ac.uk/study/csde/underg_programme/*

2.8 The Library

8 THINGS TO DO TO HELP WITH YOUR STUDIES

1. Register with **IT Services** to use the University computer network. Registration also enables you to access a range of electronic resources to assist with your studies.
2. Explore the **Library Web site**, where you will find the Library Web Catalogue, your subject pages, details of Library services and a wide range of electronic resources, including online journals and databases.
3. Find out what study resources and facilities the **Learning Grid** offers.
4. Find out the name of the **Librarian responsible for your subject area** and the location of the **Service Desk** for general Library enquiries. Your Subject Team will be happy to help with any subject research queries you have.

5. Find out where the **journals and books for your subject** are in the Library, and how to **borrow material**.
6. Find out **how many Library books** you may **borrow** at any one time and **how long** they can be borrowed for.
7. Find out where the **Short Loan Collection** is situated in the Library and how it can help you with material on your course reading lists.
8. Learn how to use the **Library Web Catalogue** so that you can find out whether a book or journal is available in print or electronically, can access our electronic resources and can renew and reserve Library books online.

2.9 Information Technology

The department expects to be able to communicate with you via **your University email** - and you should check your account regularly. Please go to the University's Information Services to find out more. You should also check your pigeon hole and departmental notice board at least **once a day**.

2.10 Staff Student Liaison Committee (SSLC)

The Department of Statistics has a Staff/Student Liaison Committee covering its entire undergraduate programme. The committee brings together a group of academic staff with approximately fifteen elected student representatives – selected from each year of each degree course. The electoral process is designed to ensure that the views and interests of male and female students, from both the UK and overseas, are fairly represented. The SSLC meets twice a term to discuss a variety of academic issues, student welfare and social activities.

The SSLC is one of the most important places for staff and students to evaluate and comment on the teaching, the resources, the student guidance and support, and the social environment provided to undergraduates by the department. Its key functions include:

- Monitoring and receiving comments on the strengths and weaknesses of modules offered to undergraduates in the department.
- Contributing to the discussions concerning module and course development.
- Commenting on relevant aspects of department policy developed and discussed by the Undergraduate Teaching Committee. Recent examples include major course revisions, guidelines on timetables for the return of assessed work and the procedures surrounding cheating in assessed work.
- Providing feedback on all Statistics modules (see notes below)
- Looking at the computing, library and other resources and discussing ways of improving student familiarity with and access to these.
- Helping to arrange social events.

The effectiveness of the SSLC depends largely upon the ability of student representatives to reflect the problems and interests of all students, but also upon the willingness of students to approach their representatives. We hope that you will be prepared to identify problems and make suggestions that your representatives can raise at meetings of the SSLC, and that you want to find out about the committee's discussions and activities (see SSLC notice board).

2.11 Student Feedback

Introduction

Student feedback is important to the department. Lots of feedback is given informally to personal tutors and lecturers (and this is very useful to us), but there is also a formal mechanism for collecting it.

Halfway through, and at the end of the lecture courses taught by Statistics staff, you will be asked to complete a questionnaire (feedback form). This gives you the opportunity to express your view on various aspects of the course. However, feedback is only useful if it is provided in a considered and thoughtful way. These notes have been prepared to answer some of the questions students often ask about the feedback process, and to help ensure that the feedback you give provides a really helpful input to the Statistics Department's teaching. **Please take a few minutes to read them.**

Why is feedback collected?

The Department is constantly looking for ways to improve the learning experience we provide for our students. We can only do this if you let us know your reactions to our courses – not only to identify problems, so that members of staff can take steps to eliminate them, but also to learn about the things you find helpful, so that we can disseminate best practice in teaching and learning throughout the Department and further.

What constitutes useful feedback?

You are accustomed to being on the receiving end of feedback when your work is returned with comments from the marker. If you think about what you do like and don't like as feedback on work, you will be in a good position to provide helpful feedback on courses. Here are some points to start you thinking:

Be specific – be constructive: For example, a bare mark on a piece of work is not very helpful, since it gives no guidance as to what was wrong with it. In the same way, just saying that you did not like a course does not give any indication to the lecturer as to what steps he/she should take to improve the course. Was the pace too slow? Too fast? Did you find it hard to see the relevance of the material? Or is the fact that you didn't enjoy the course perhaps nothing to do with the teaching, but rather means that you made a mistake in an option choice and chose a course which turned out not to fit in with your personal interests? Make good use of opportunities for open-minded comments to explain these points.

Mention the positive as well as the negative: It is always good to know what you got right and discouraging to read comments on work which only mentions what went wrong with it. When a lecturer is doing something well, and you let them know that, then it gives them encouragement to do it again. So when you comment on a course, try to mention any features which you particularly enjoyed or found helpful.

Be honest with yourself: People often talk about 'teaching and learning' to show that the educational process requires participation from two people – the teacher and the student. You cannot expect to get full benefit from a course if you simply attend lectures and do the assessment – you need to do the course reading, participate fully in example classes, etc. So before you indicate that you did not get much out of a course, ask yourself honestly what you put in.

Try to separate personality from content: During your time at Warwick you may be taught by several dozen members of staff. It would be surprising if you liked all of them equally as people, or if there weren't some who had habits and mannerisms which irritated you! But try to keep your reaction to lecturers' personalities separate from your reaction to their teaching. It's possible for you to regard someone as extremely irritating but still get a lot out of their teaching.

Be considerate: Lecturers are people with feelings just like students. Sometimes you may need to be critical of aspects of a course, but you should try always to offer criticism in a sensitive way. Comments such as 'X is the worst lecturer I've ever had' are neither useful nor constructive.

Be conscientious: PLEASE complete feedback forms for all your courses. If we only get a small number of forms returned, then we may well get a biased idea of students' views – and that idea may not coincide with yours. So don't loose your opportunity to be heard!

What happens to the feedback?

1. Questionnaires are distributed by a member of the Staff Student Liaison Committee (SSLC). They collect completed questionnaires and produce a one-page summary.
2. The summary and questionnaires are passed to the Undergraduate Support Officer who forwards them for comment to the relevant lecturer(s).
3. The lecturer writes a response and returns everything to the Undergraduate Support Officer who forwards it to the Head of Department.

4. The Head of Department checks the questionnaires and response, noting for wider dissemination particular compliments or suggestions and returns everything to the Undergraduate Support Officer.
5. The response is copied to the SSLC, and then filed.
6. The SSLC considers the response and passes unresolved items to the Department's Teaching Committee for further action/assessment.

Thus your constructive feedback is seriously considered and is essential to monitoring and improving teaching.

2.12 Choice of Optional Modules

MORSE offers an enormous range of optional modules. Compulsory modules and the more popular options are described in the body of this handbook. However, in principle, you may take most modules available anywhere in the University as *unusual options*.

In considering which options to take, the following points may help:

- Think about where your interests lie and what the module might lead to later.
- Check the prerequisites.
- You can try a module and deregister later if you decide not to offer it for examination.
- Talk to your personal tutor and to your friends (especially those who have taken the module before!).
- The method of calculating the overall examination mark (see below) gives credit for taking extra options - but an extra module is a big commitment and you must be careful not to take on too much.
- Final year students are not allowed to register for first and second year modules.

Some specific advice for second year MORSE students on the integrated Masters:

- Every stream will require the use of the statistical programme SPLUS in the third year (and for many projects in the fourth year). The programme is taught in the optional second year course ST215 Forecasting and Control. If you do not do this course, then you will have to become familiar with SPLUS on your own – there will be notes available from the department; also the programme is on the campus network and can be purchased from IT services for a token amount.
- The mathematical models used in Financial Mathematics make very extensive use of stochastic processes. Indeed the whole subject is a combination of knowledge about finance and financial instruments, probability theory and stochastic processes (for the mathematical models) and statistics (for fitting models to data). It follows that if you are contemplating a career in this area,

then you should take the second year optional course on ST202 Stochastic Processes.

- The second year module MA244 Analysis III is useful preparation for certain theoretical modules in the final two years of the integrated Masters.

Unusual Options:

To take a module as an unusual option you need to fill in a special form available from the Statistics Undergraduate Office. You will need the agreement (and signatures) of the module organiser, your personal tutor and the Undergraduate Course Tutor. Don't be put off by this - it's quite straightforward. In most cases there are no problems in obtaining everyone's agreement however there are some restrictions that you should note:

1. First and second year modules may not be taken by final year students with the exception of Language Centre modules or when the regulations give explicit permission to do so.
2. In the final year of a degree (year 3 of a 3 year degree and year 4 of a 4 year degree) students may not take a language option intended for a complete beginner.
3. No more than 24 CATS credit of unusual options may be taken in any one year.
4. The CATS credit for a module taken as an unusual option may differ from the credit awarded when the option is taken as a normal option. The amount of credit you will be awarded is decided when you are granted permission to take the option.

2.13 Foreign Languages

In their first two years, students may take most modules offered by the Language Centre which are listed with CATS credits in the University Programme Regulations. A few of these modules count as usual options and are listed in the Regulations, many count as unusual options and you must follow the procedure described above to register for them. Take particular note of those rules which restrict unusual language options during the final years of the degree.

LANGUAGE CENTRE:

The Centre offers academic courses for exam credit in French, German, Russian, and Spanish at a wide range of levels. Pick up a leaflet listing the courses from the Centre, on the ground floor of the Humanities Building. Full course descriptions are available on request.

There is also a full programme of leisure courses for which, after 6 terms of successful study, students may be eligible for the award of an Open Studies Certificate. There is a discounted fee for undergraduates on these leisure courses. These leisure courses carry no exam credit.

The Centre also offers language laboratory audiovisual and computer assisted self-access facilities with appropriate material for individual study (carrying no exam credit) in Arabic, Chinese, Dutch, English, French, German, Greek, Italian, Japanese, Portuguese, Russian and Spanish.

Important note for students who pre-register for Language Centre modules: It is essential that you confirm your module pre-registration by going to the Language Centre as soon as you can during week one of the new academic year. If you do not confirm your registration, your place on the module cannot be guaranteed. If you decide during the summer NOT to study a language module and to change your registration details, please have the courtesy to inform the Language Centre of the amendment.

The Italian Department offers modules in Italian language for all university students, whether they intend to take up Italian from scratch or to continue learning the language (and culture) at intermediate and advanced level. All modules are taught over three terms and fully accredited. Assessment consists of regular tests as well as oral and written examinations at the end of the year.

3 WELFARE *http://www2.warwick.ac.uk/insite/topic/healthsafety/welfare/*

3.1 Illness

If your work is affected by illness get a sick note from your doctor; ensure that your personal tutor is informed; that lecturers expecting assessments know; and that a copy of the sick note is given to the Undergraduate Support Officer. **This is most important in relation to Boards of Examiners who require legitimate evidence before making due allowance for adverse circumstances.**

3.2 The University Senior Tutor and Counsellors

The University Senior Tutor and University Counsellors provide help and advice to students from all departments. The help and advice can take the form of both individual counselling and group sessions on topics ranging from study skills to relaxation. These services are entirely confidential and nothing is passed to any third party (e.g. your department) without your permission. The Senior Tutor (telephone extension 23761) and the Student Counsellors, are both located in the Student Development and Support Section of University House.

3.3 Sexual and Racial Harassment

Sexual and racial harassment is totally unacceptable, we will support those subjected to it and, when appropriate, will take disciplinary action against offenders. Within the department help and support will be provided by all members of staff. Outside the department you may seek help from the University Senior Tutor, the Student Counsellors and the Student Union Welfare Staff.

The University and the Students' Union have prepared Guidelines on Sexual, Racial and Personal Harassment (which can be seen on *insite* in the Campus Life [Health and Welfare] section). The guidelines include advice on identifying and addressing harassment, formal procedures which can be followed and details of sources of support. The guidelines are also available from the office of the Director of Student and Ancillary Services.

If you feel able to make it clear to the person causing you offence that their behaviour is unacceptable that may be enough to stop it. But if you do not feel able to tackle the person, you should feel free to seek assistance from those listed above or from fellow students to put an end to it.

3.4 Special Examination Arrangements

If, as a first year student you are aware that you will require special arrangements during the examination period, e.g. extra time to compensate for a particular condition, would you please contact the Undergraduate Support Officer as soon as possible. The University has a system for requesting special arrangements for eligible students while taking their examinations.

These arrangements are only for students whose requirements are due to a medical condition or other significant reason. **In all cases, any requests needing approval for the first time must be supported by properly documented and appropriate medical/psychological evidence.** Once accepted this arrangement will continue for the duration of your degree course.

Cases of temporary illness or injury will be granted a temporary arrangement at the time, which will not carry over to the following year. If you have any questions relating to this please contact the Undergraduate Support Officer.

For referral to the University's Disability Coordinator, please speak to your Personal Tutor or the Undergraduate Support Officer.

3.5 Health and Safety

The Departmental Safety Officer is the Departmental Secretary and any matters relating to safety within the department should be referred to her.

4 COURSE REGULATIONS

4.1 Transferring to Another Degree

It is possible, with the permission of the relevant department, to transfer from the first year of MORSE to closely related degree schemes such as Mathematics, Mathematics and Statistics, Mathematics and Economics, and so on. In every case it is necessary to fill in and sign an official change of course form. Course transfers are only permitted during term 1, the first week of term 2 and at the end of the academic year when examination results are known.

Transfers from MORSE to the integrated Masters or *vice versa* can take place at any time during the first two years. However where LEA funding for the fourth year is a consideration, it is advisable to make this decision earlier rather than later. During the third year of study, we will not permit any changes between degrees after the end of the first term.

4.2 Intercalated Year

Statistics students may apply to take a degree course entitled MORSE (with Intercalated Year)(Y603), which entails four years of study, rather than the usual three or the integrated Masters degree (with Intercalated Year)(Y605/G301), which entails five years of study instead of the usual four. Registration for these degrees should take place as early as possible in the previous year, otherwise local authorities may object to giving financial support for the final year. For MORSE students the intercalated year takes place at the end of the second year and for integrated Masters students the intercalated year takes place at the end of the third year. On their return, students join the final year of study. The intercalated year entails either working in industry, or studying at a university abroad and **must be approved by the student's Personal Tutor and Head of Department.** Approval is not guaranteed and largely depends on current academic achievement (no less than 2:1). A Course Transfer form will have to be completed. Please also be aware that, as this intercalated year forms part of your formal degree programme, half 'home' student fees are payable. For further information about this contact Student Finance in University House.

Undergraduates who have in the past succeeded in finding a job in industry have found this a very helpful experience. There is unfortunately no help available from the department in finding a job, and students who are interested in this are recommended to seek help from the Careers Office. The main criterion is that the job should provide learning experiences which are related to the degree course. After your return from the Intercalated Year, you will be required to file a report with the Department during the first week of the first term on this learning experience.

Socrates, a European Union educational scheme, provides an opportunity for Warwick students to spend a year at a partner university in another European country.

Socrates pays travel funds, and sometimes a bit extra. If you are interested in the Socrates scheme, you will get advice and help from the International Office in University House.

5 EXAMINATIONS AND PROGRESSION

5.1 Registration of Modules

We use the University Online Module Registration System (OMR) which is accessed via **my.warwick** on the University's *intranet,* insite. First year students will find that their 'core' subjects are already registered on OMR, only requiring the addition of any chosen optional modules. Adjustments can be made to this initial list of modules at key times during the academic year. As a student **it is your responsibility** to ensure you are registered for the correct modules and assessment methods and that you do this at the correct specified times. Details of registration procedures will generally be sent to you via the department at the appropriate points in the academic year. You must check your pigeonhole and your Warwick email address regularly and follow the instructions provided.

The initial information you supply to OMR does not involve you making a permanent commitment to take the selected modules, nor stop you from following other modules. **However**, you must ensure that all details held on OMR are correct at the time of the final deadline for registration as these details constitute your final examination timetable. Full details will be circulated at the start of the academic year and at the beginning of each term.

Pre-registration of modules for the following year: At the beginning of Term 3, both the Economics Department and Warwick Business School (WBS) distribute their own pre-registration forms for completion by our students. This encourages you to start planning and choosing your options in advance and also assists these departments with timetabling. Some departments will 'cap' a module if the numbers reach capacity, so pre-registration on popular modules is recommended. As WBS and Economics also run their own registration systems alongside OMR, they request that if you decide to register or deregister from a module at some stage mid-term, you advise them in person as well as changing your registration on OMR.

You must adhere to the deadline for registering for modules – otherwise we may ignore any marks awarded for that module. You must adhere to the deadline for deregistering - absence from any examination for which you are registered means a credit of zero. **Anyone failing to meet these deadlines will be charged £150 for any amendments made. Students are advised not to leave finalizing the registration until the last day.**

5.2 Module Codes by Department

ST	Statistics	CS	Computer Science

MA	Mathematics	PX	Physics
IB	Warwick Business School	PH	Philosophy
EC	Economics	LL	Language Centre

5.3 Examinations

University examinations are mostly held in term 3 in all three years. The University webpage at
http://www2.warwick.ac.uk/services/gov/calendar/regulations/examregs/
contains important information on examination regulations and academic appeals.

Personal Tutors are allowed to disclose to their tutees provisional marks (as a percentage) for each exam/assessment taken by that tutee. Please note that such marks are provisional and are subject to ratification/amendment by the Senate of the University and by External Examiners.

Students should also be aware that in deciding a degree classification Boards of Examiners will take note of circumstances other than the candidates' overall mark such as, for example, health of the candidate and exceptional performance on individual courses. In particular students should note that in awarding a first class BSc degree the Examination Board expect to see good first class marks on List A third year papers equivalent to at least 42 CATS points. Similarly in awarding a first class integrated Masters degree the board of examiners expect to see good first class marks in at least 75 CATS (over the 2 years) from (a) modules from core or Lists (A) through (F) taken in Year 3 and (b) modules from core or List (A) through (E) taken in year 4. A student who achieves a final credit higher than 70% but who does not satisfy this requirement or whose overall performance is not of a ‘first class’ standard, will not usually be awarded a first class degree.

Please note: no student is allowed to take courses so that more than 50% of their possible overall degree mark is obtained from assessed work (assessed work means credit obtained by a means other than a conventional university-supervised examination).

5.4 Calculation of Examination Credits

The first year counts 10%, the second year 30% and the third year 60% towards the final BSc degree mark; i.e. if S_1, S_2, S_3 denote the % credits obtained at the end of years 1, 2 and 3 respectively, then the overall degree % mark is:

$$C = (10\, S_1 + 30\, S_2 + 60\, S_3) / 100$$

The credits S_1, S_2, S_3 are calculated by using the Seymour Formula (see below), which is a scheme designed to give fair credit for students taking additional loads.

A corresponding formula is used for the Masters degree with the first, second, third and fourth year programmes carrying weightings in the ratio 10:20:30:40.

Now for each year *k* the % credit is calculated from the Seymour Formula as follows:

$$S_k = \frac{\sum_i x_i c_i}{N + \frac{1}{2}(\sum_i c_i - N)}$$

where:

x_i is the score in the year on module *i* with CATS load c_i and
N is the normal annual load (usually 120 CATS)
An example for a first year student:

x_1 = 54% on MA106 with c_1 = 12 CATS

x_2 = 44% on MA131 with c_2 = 24 CATS

x_3 = 62% on EC106 with c_3 = 24 CATS

x_4 = 44% on ST111 with c_4 = 12 CATS

x_5 = 58% on IB104 with c_5 = 12 CATS

x_6 = 63% on ST104 with c_6 = 12 CATS

x_7 = 61% on ST108 with c_7 = 7.5 CATS

x_8 = 51% on ST113 with c_8 = 7.5 CATS.

This gives $\sum_i x_i c_i$ = 6012, *N* is 120 and the Student's CATS load is $\sum_i c_i$ = 111.

Therefore, S_1 = 6012/(120 – 4.5) = 52.1%

Compare this with a straight mean which is 6012/111 = 54.2%.

This applies **only** provided the actual load taken does not exceed the maximum load permitted in the year (140 CATS in Year 1; 150 CATS in other years). If you exceed these maximums then the capped Seymour Formula applies instead.

In general, a candidate only improves his Seymour percentage by taking an extra paper if his mark on that paper is more than half his average mark on all other papers.

Experience has shown that students who greatly exceed the normal load often regret doing so. Also, Boards of Examiners pay more attention to performance on the important compulsory courses, so make sure you can cope with all the courses you attend.

Of course, when deciding on the class lists, Boards of Examiners take into account considerations other than the straight examination mark. For example, the difficulty of a particular examination, the opinion of the External Examiner, and the number of completed questions can all affect their decision.

5.5 First Year Examinations

The following are designated as main subjects for MORSE:

- Analysis.
- Linear Algebra.
- Introduction to Quantitative Economics.
- Probability.
- Mathematical Programming I

Failing one of these subjects in June will almost certainly entail a September resit.

The possible outcomes of the first year examinations in June are as follows:

a) Class one.
b) Class two (division one).
c) Class two (division two).
d) Class three.
e) Required to resit.
f) Recommended to withdraw.

Students in group (e) have either failed to achieve an Honours mark overall (i.e. an S_1 of about 40%) or have failed at least one main subject, and are required to resit certain papers in September. Students in group (f) have performed so badly that the Board of Examiners feel they have little chance of reaching the required standard in the September resits. Their names are not listed on the official class list; instead they receive a letter from the Registry recommending them to withdraw from the University. However, this is only a recommendation and any students in this category can exercise their right to resit in September.

There are three possible outcomes of the September resits:

a) Permitted to proceed to the second year of an Honours degree course.
b) Permitted to proceed to the second year of a Pass degree course.
c) Required to withdraw.

Students in group (b) take a reduced load of exactly 84 CATS points in their second year. (Deviations from the second year Pass load are not usually allowed. The normal load for second year Honours is 120 CATS points). However, a Pass student who performs sufficiently well on the second year examinations may still be allowed to return to the Honours course for the third year.

For students in both groups (a) and (b) the cumulative credit carried forward (i.e. the value of S_1 used in the calculation of C is the credit obtained in June and not that obtained in September.

5.6 Second Year Examinations

For any second year student (whether on Honours or Pass) the possible outcomes of the second year examinations are as follows:

a) Class one.
b) Class two (division one).
c) Class two (division two).
d) Class three.
e) Permitted to proceed to the final year of an Honours course.
f) Permitted to proceed to the final year of a Pass course.
g) Fail.

In order to proceed to the third and fourth years a Masters student needs to obtain a class one or a class two (division one) result.

Any second year Pass student who achieves a Seymour percentage which is greater than 40% (based on the normal load of 120 Cat points) is awarded Honours in the appropriate class and carries forward this Seymour percentage as S_2. The decision on whether or not a Pass student fails is based on the arithmetic mean of his marks and not S_2.

Students in group (e) have failed to obtain overall Honours classification but have been permitted by the examiners to continue with an Honours course. Students in Group (f) take a reduced load of exactly 90 CATS points in their third year. (Deviations from the third year Pass load are not normally allowed. The normal load for third year Honours is 120 CATS points).

Students in group (g) have the right to resit the second year examinations the following June without residence at the University. Special papers are not usually set, but examiners treat resit students as special cases. The value of S_2 carried forward for the calculation of C is the mark obtained at the first examination and not the resit.

5.7 Final Year Examinations

For any final year student (whether on Honours or Pass) there are 6 possible outcomes of the final examinations. These outcomes are based on the weighted average C of the final years Seymour percentage together with the Seymour percentages of previous years (see earlier).

The outcomes are:

a) Class one.
b) Class two (division one).
c) Class two (division two).

d) Class three.
e) Pass.
f) Fail.

The award of a first class degree depends not only on the value of *C* but also on marks obtained in individual examinations - see paragraph 5.3 above.

Students in group (f) have the right to resit the final year examinations the following June without residence at the University. Special papers are occasionally set and examiners treat resit students as special cases.

A third year Pass student who achieves a credit *C* that is greater than 40% (based on the normal loads in year 2 and 3) is awarded BSc Honours in the appropriate class. The decision on whether a Pass student fails is based on his mean mark over the 90 CATS points taken.

5.8 Examination results

It is **your responsibility** to ensure that you understand what actions are required from you when your results become available.

Examination results are released after the relevant Board of Examiners has finished meeting in week 10 of the summer term.

These are *usually* as follows:

Day	**Year**	**Approx time available**
Wednesday	3^{rd} & 4^{th} year, MSc	4.30 pm
Thursday	1^{st} year	12.00 noon
Friday	2^{nd} year	4.30 pm

It is a University regulation that your examination results may only be released to you **in person**, by your personal tutor. Therefore you should make suitable arrangements with your tutor to collect your marks, in good time, before the last week of the summer term.

Students leaving University before the end of term

You should note that you are expected to be present at University for the full duration of term. Therefore you will **not** receive your marks if you choose to leave University before the end of term. You may collect your marks from your personal tutor at the beginning of the next term in October.

Your results will **not** be posted to your home address.

All letters (in particular, letters informing you of any resits you may be required to take) during the vacation will be sent to your permanent home address unless a "vacation address" form is completed at the Enquiry Desk in the Academic Office. It is **your responsibility** to make sure that any correspondence sent to you during the vacation is directed to the correct address.

You should note that Pass Lists will be displayed on noticeboards on the ground floor of University House, and, for non-first years, in departments, as soon as possible after the marks are released. You may therefore make arrangements for a friend to check the Pass Lists and inform you of your classification (unless, of course, you have exercised your right not to appear on the Pass Lists).

You should be aware that staff dealing with examination results may not always be present at University in the vacations. You should not expect to be able to contact your Personal Tutor in the vacations, or that requests or enquiries will be responded to within a matter of days, as might be expected in term-time.

RESITS (FIRST YEAR ONLY)

First year students who have failed to meet the required standard in their exams will normally be offered the opportunity to resit examinations before the start of the next academic year. These resits are usually around the first week of September. You will be informed by your personal tutor of any resits you are required to take when you collect your examination results in the last week of the summer term.

University requirements are that all students must return to Warwick University to sit their examinations. The only students who are allowed to choose to sit overseas are those students whose registered home address is in India, in which case they are able to sit in New Delhi only, or those whose home address is registered in China or Hong Kong who will be able to resit examinations in Hong Kong. The Exams Office identifies these students and sends a resit letter offering them the option of taking resit exams abroad.

All students who are required to take resits will be notified by post, so if you have left University before the end of term and your contact details are incorrect you may not receive a resit letter in time.

Unless your resit is a ‘first attempt’ (see below) you will carry forward the ‘fail’ mark from your first sitting to the final calculation of your degree result. You are, however, required to pass the resit before you are allowed to proceed to the next year of your degree.

RESITS ‘AS A FIRST ATTEMPT’

In certain circumstances (for example, illness on the day of an exam) you may be permitted to resit ‘as a first attempt’. In this case your ‘resit’ will be treated as the first instance of your sitting that exam, and it is that mark that you will carry forward.

EXTENUATING CIRCUMSTANCES

Circumstances which may have affected your performance in an exam (eg, illness on the day of an exam) are reviewed by the Board of Examiners when considering your exam results. You should, therefore, take care to keep your Personal Tutor informed of anything which may affect your exams, and provide appropriate independent evidence (e.g., a note from your doctor) of any such circumstances if at all possible. Written evidence must be in English.

Such information must be provided as soon as it is available, and if possible **before** the Board of Examiners meets to consider your results in week ten of the Summer Term.

Special Examination Arrangements – See Section 3.4

5.9 Assessed Work

Please note: no student is allowed to take courses so that more than 50% of their possible overall degree mark is obtained from assessed work (assessed work means credit obtained by a means other than a conventional university-supervised examination).

Deadlines

Assessed work usually comes with a deadline for completion. The department and SSLC consider these essential to ensure fairness to all the students doing the work and to the markers. Deadlines are enforced by penalising late work. Different departments have different conventions.

In the Statistics Department the lecturer giving the assessment will name a date as the deadline (this will not be a Friday). Work should be submitted by posting it into the appropriate drawer of the cabinet (situated in the corridor next to the undergraduate pigeonholes) on or before the deadline date. The cabinet will be emptied at 09.00 am on the day following the named date.

A student who misses the deadline must personally hand their work to the Undergraduate Support Officer who will record the date it was received. The lecturer will automatically enforce a penalty of 5% per day late reduction in the credit awarded calculated as follows:

Penalty = N x 0.05 x un-penalised mark where N = number of days (including weekends).

The only circumstances in which this will be waived is if the lecturer has received documented evidence of medical or similar extenuating circumstances which will be communicated to the Statistics Chief Examinations Correspondent.

The penalty will not be waived for bad time management, so plan ahead and make allowances for the possibilities of unforeseen demands on your time, such as job interviews. If you write your work on your computer make sure you regularly save your files. No excuses will be accepted due to problems you may suddenly have with your computer or printer.

Cheating (including Plagiarism)

1. What constitutes cheating?

In the University Regulations cheating is defined as an attempt to benefit oneself or another by deceit or fraud. The department recognises that discussing ideas about how to tackle questions is a valuable part of the learning process. However, **the work you submit must be your own and written in your own words.** Work produced by someone else may be included provided it is appropriately acknowledged or referenced. Unacknowledged copying from either another student or from published sources including the internet threatens the integrity of the assessment procedures and is treated very seriously by the University.

Cheating also covers more obvious sins such as copying in tests, sharing calculators in tests and examinations, stealing work from other students, or taking your mobile phone into an examination. **You are also guilty of cheating if you assist another student to do so, for example by allowing them to copy your work.**

- Cheating is unacceptable and often easily spotted. Lecturers have been instructed to report students to the chair of the department who will give you the opportunity to explain yourself before deciding on a penalty. You have the option of appealing against the decision to the University authorities.
- We keep records! Personal Tutors may be required to write references to prospective employers testifying to honesty and integrity, if your file records that you are guilty of the offence of cheating, then this could lead to serious difficulties for you.
- If the matter goes to an Investigating Committee (and second offences will!) then you could end up thrown out of the university.
- Cheating by students from the Statistics department in modules taught by other departments will be dealt with within that other department and reported back to the Statistics Exam Board. It works the other way round too – the Statistics Department will deal with all cases of suspected cheating in Statistics modules and report the outcome to a student's home department.
- **It is better to hand in no work – than to cheat.**

2. Formal procedures followed in cases of suspected cheating in coursework.

The University sets out the formal procedures in Regulation 11 of the University Calendar. These are briefly described in the following paragraphs:

- No incident of a suspected cheating should be dealt with informally by the lecturers or examiners. All incidents should be reported to the Chair of the Department. In particular no penalty should be imposed on a student outside the formal procedure laid out below.
- The Chair of the Department shall inform the student of the allegations and provide the student with reasonable opportunity to make representation on his/her behalf before determining whether an offence has occurred and, if so, determining the appropriate penalty. In the absence of mitigating circumstances this shall normally be a mark of zero in the piece of work concerned.
- The student may accept the penalty determined by the Chair as a final decision. Then a report of the circumstances of the case and the penalty imposed shall be lodged with the appropriate Board of Examiners and be recorded in the student's file.
- The student may seek the jurisdiction of an Investigating Committee of the Senate as detailed in Regulation 11 of the University Calendar.
- Should the Chair of the Department consider it appropriate then he/she may refer any case to an Investigating Committee of the Senate. Second offences of misconduct shall normally be so referred.

Marks and Marking

The marks given for assessed work are always provisional and may be changed by the Board of Examiners. Students should retain all of their assessed work because it may have to be resubmitted to the department just before the Board of Examiners meeting.

Students may choose to have their major projects and essays marked anonymously, just quoting their University number. However, anonymous marking leads to difficulties in quickly returning marked work: such work cannot be returned via student's pigeon holes and there are further problems when numbers are incorrectly quoted. Consequently, following SSLC and Science Sub-Faculty discussions,
students must quote their names on all individual Statistics, Mathematics and other Science Faculty assessments which account for less than 30% of that particular course's credit.

5.10 Pass Degrees

Students on Pass Degrees may only vary the number of courses from the limits specified above if they obtain permission in writing from the Department of Statistics. You must submit a case in writing to the Chief Examinations Secretary by

Monday of Week 10 of the Autumn Term. In order to submit a case you must have the support of your Personal Tutor. Marks obtained for assessments during the Autumn Term will be an important deciding factor.

Please refer to the handout given to all Pass Students at the beginning of the new academic year.

5.11 Use of Calculators in Examinations

Concerning the use of calculators in examinations the Department of Statistics follows the University rule which states that *except for the display of error or function messages, calculators with non-numeric displays are not allowed*. In other words prohibited calculators are those which can accept alphabetical data. Note that this includes most graphical calculators of the type acceptable in GCSE and A-level examinations. It is your responsibility to ensure that your calculator fulfils the University's criterion and that your calculator is not of the prohibited type. Otherwise you may find yourself denied the use of your calculator and be involved in disciplinary proceedings.

Please remember:
(i) Calculators may not be passed from candidate to candidate during the examination;
(ii) Responsibility for the calculator's proper functioning is entirely that of the student;
(iii) Students taking examinations other than those of the Department of Statistics must ascertain the regulations governing the use of calculators from the Department concerned.

In particular, calculators are not allowed in STIII/112 or examinations organised by the Mathematics Department (these are all MA*** module exams). In general, the same rule applies to tests for credit in MA*** modules, unless students are otherwise informed by the lecturer running the test.

6 CAREERS

6.1 What do Statistics Graduates Do?

Graduates from the Statistics Department enter a diverse range of careers. Many opt to work within the Financial Services sector with the Actuarial, Accounting and Investment Banking opportunities being particular favourites. These roles often involve the study of professional qualifications such as ACA, CIMA, CFA and the actuarial examinations. Alternative career choices include Operational Research, Marketing and IT related fields. Statistics graduates develop a strong range of transferable skills including excellent numerical, problem solving and analytical abilities. These along with your ability to communicate complex ideas effectively are highly sought after by employers.

A number of students decide to continue in academia studying for either a Statistics related Masters or PhD. Alternative study routes have included the study of Management Science & Operational Research or the PGCE teaching qualification.

6.2 Careers Guidance

Making good career decisions involves thinking about your interests and qualities and also spending time researching possible occupations. If you would like to discuss your ideas or feel you need support with working through your options and developing ideas then please contact Karen Barker who is your personal Careers Consultant. Book an appointment online by visiting http://go.warwick.ac.uk/careers.

6.3 Careers Information Resources

A wide range of materials is available in the Careers Hub, based in the Learning Grid at University House. Our website also gives you access to masses of information on career planning, job seeking, interview skills, and much more. You can register online to receive personal news, jobs and events information through 'My Careers – http://go.warwick.ac.uk/mycareers. Don't forget to check out the vacancy database which provides access to hundreds of opportunities for work experience, internships, as well as graduate vacancies.

6.4 Careers Events

An extensive programme of events including skills development workshops, presentations on particular sectors and mock interviews are available throughout the year. Karen will also offer tailored workshops to Statistics students so keep an eye on the events calendar and e-mails publicising upcoming activities.

Don't miss the valuable opportunity to meet employers face to face. Explore your options, compare organisations and find out what skills employers are looking for by visiting the Careers Fairs, employer presentations and alumni evenings. You will need to book online for most events as places are limited.

6.5 Make the Most of Your Time at University

Alongside achieving a good degree, employers are looking for students who have maximised their time at university and got involved in a wide range of extracurricular activities. Many students help in the running of societies which helps to build personal skills such as communication, leadership, problem solving and team working. Some students work toward the Warwick Skills Certificate or take part in Business Challenges. Find something you enjoy and get involved!

Securing work experience and/or internships will also help to develop your employability skills. The Careers Centre has a team dedicated to sourcing work experience opportunities for all students. The team also offer work experience bursaries for students undertaking short term unpaid placements. See http://go.warwick.ac.uk/workexperience.

Both employers and postgraduate course providers will expect you to be knowledgeable and assertive about the intellectual and personal skills which you have gained during your degree course. They are concerned about what you can do, in addition to what you have studied, and will require you to substantiate the claims you make when making applications. They will look at your past experiences, choices and behaviour to find evidence of these skills.

6.6 International Students

If you're hoping to find employment in the UK after graduation, and English isn't your first language, think about ways in which you can improve your conversational English. To be successful at an interview you will need very good verbal communication skills, and sometimes our international students – despite having excellent academic results – will not be able to progress beyond this point because their spoken English isn't good enough. The Centre for English Language Teacher Education (CELTE) runs classes for our non-native speaking students, http://www2.warwick.ac.uk/fac/soc/celte/ and you can apply what you have learnt by joining clubs and societies and regularly mixing with students who are native English speakers.

6.7 Final Thoughts

Make sure you enjoy your time at Warwick and take advantage of the vast array of opportunities on offer. Visit the Careers Centre sooner rather than later. If you have any queries or concerns relating to your career do contact Karen at K.L.Barker@warwick.ac.uk . The Careers Centre looks forward to welcoming you.

6.8 STUDENT ASSOCIATES SCHEME

If you are intending to take a PGCE (Post Graduate Certificate in Education) after your degree;
… or have SECONDARY teaching as one of your career options but you are unsure;
… or if you are a 'high flyer' and want to know if teaching can offer opportunities for you – the SAS could be for you!

As one of the leading providers of Initial Teacher Training, the University's Institute of Education is once again offering undergraduates the opportunity to try a "taster" of teaching. If you join the Student Associates Scheme (SAS) you will receive bursary funded training which will prepare you for the expectations of a professional environment. You will look at some of the issues concerned with effective teaching and learning, and you will be given help and support to prepare for your school visits.

If you do your PGCE at Warwick, you would achieve a 'training credit' which would mean that you could complete the course earlier in the year than normal.

Teaching Maths in Johannesburg
For the last two years Warwick has provided the funding to send SAS students (26 last year) to teach maths in Johannesburg and surrounding townships during the Summer.

Who can apply?

- Statistics students in their penultimate or final year who are able to show that they have a genuine interest in looking at teaching as a career.
- Students planning to opt for the module "Introduction to Secondary Teaching" IE2A6 which carries 24 CATS.

How to Apply

- You can collect an application form from the learning Grid in University House from 8th October, or
- for further information, contact: Pam.Griffiths@warwick.ac.uk

6.9 Actuarial Examinations

Exemptions from the professional actuarial examinations are not given automatically. The Institute of Actuaries only awards exemptions if a student has achieved a satisfactory overall percentage as well as a satisfactory percentage on the relevant University courses. Our current syllabus enables exemptions as follows:

- CT1 Financial Mathematics through ST334 Actuarial Methods
- CT2 Finance and Financial Reporting through ST335 Finance and Financial Reporting
- CT3 Probability and Mathematical Statistics through ST217 Mathematical Statistics (A & B)
- CT4 Models through ST338 Actuarial Models
- CT6 Statistical Methods through ST402 Risk Theory
- CT7 Economics through EC106 Introduction to Quantitative Economics and EC220 Mathematical Economics (A and B) **or**
- CT7 Economics through EC106 Introduction to Quantitative Economics and EC204 Economics 2
- CT8 Financial Economics through ST401 Stochastic Methods in Finance

Recommendations for exemptions from CT1, CT2, CT4, CT6, and CT8 will be made following the third and fourth year examinations. CT3 and CT7 have to be applied for independently. Further information about the actuarial examination system can be found at http://www.actuaries.org.uk .

7. PEOPLE AND DATES

7.1 Dates of Terms

Academic year 2009-2010

Term 1 (weeks 1-10): Monday 5 October 2009 to Saturday 12 December 2009
Lectures commence Tuesday 6 October

Term 2 (weeks 11-20): Monday 11 January 2010 to Saturday 20 March 2010
Lectures commence Monday 11 January

Term 3 (weeks 21-30): Monday 26 April 2010 to Saturday 3 July 2010
Lectures commence Monday 26 April

Academic year 2010-2011

Term 1 (weeks 1-10): Monday 4 October 20010 to Saturday 11 December 2010

Officers 2009-2010

U/G Course Director	Dr Jon Warren
First Year U/G Course Tutor	Dr Larbi Alili
Second Year U/G Course Tutor	Dr Sach Mukherjee
SSLC Academic Convenor	Dr Jon Warren
Undergraduate Admissions Officer	Dr Robin Reed
Undergraduate Publicity	Dr Barbel Finkenstadt
Statistics Department Chair	Professor Saul Jacka
Chief Examinations Correspondent	Dr Sigurd Assing
Second Year Examination Secretary	Dr Sach Mukherjee
First Year Examination Secretary	Dr Larbi Alili
Timetable Officer	Mrs Paula Matthews
Postgraduate Tutor:	Professor Mark Steel
Undergraduate Support Officer:	tba Tel 024 7623 066 (internal 23066)
Postgraduate Support Officer:	tba Tel 024 761 50886 (internal 50886)

COURSE REGULATIONS

for the

MORSE DEGREES

8 FIRST YEAR

After completing the first year the students will have:

- Made the transition in learning style and pace from school to university mathematics.
- Been introduced to the basic concepts in university mathematics, including the notion of proof, and the applications of mathematics to problems outside mathematics.
- Been introduced to basic concepts in economics and operations research.
- Laid the foundations of knowledge, understanding and techniques necessary to proceed to the second year.

The normal load in the first year is **120** CATS points (12 CATS points correspond to the equivalent of one 30 hour lecture module). The maximum load is **140** CATS.

You must take the Core modules listed in the following table, (which gives for each module, the code, the title, the CATS credit and the term in which it is taught) and an appropriate number of optional modules.

Core modules		**CATS**	**Term**
EC106	Introduction to Quantitative Economics	24	1 and 2
IB104	Mathematical Programming I	12	3
MA131	Analysis	24	1 and 2
MA132	Foundations	12	1
MA106	Linear Algebra	12	2
ST108	Applications of Algebra & Analysis	7.5	2 and 3
ST111	Probability (Part A) *and*	6	2
ST112	Probability (Part B)	6	2
ST113	Statistical Computing	7.5	1

Optional Modules		
ST104	Statistical Laboratory	12
ST105	Essay or Project	7.5
ST114	Games and Decisions	7.5
CS126	Design of Information Structures	15
CS128	Further Discrete Mathematics **Not Running 2009/10**	6
MA113	Differential Equations A	6
MA117	Programming for Scientists	12
MA125	Introduction to Geometry	6
MA134	Geometry and Motion	12
MA246	Number Theory	6
PH123	Elements of Scientific Methods	6

PH126	Starting Formal Logic	12
PH128	Descartes and Mill	12
PX101	Quantum Phenomena	6
PX109	Relativity **Not Running 2009/10**	6
PX120	Electricity and Magnetism **Not Running 2009/10**	12
PX121	Thermal Physics 1	6
PX132	Mechanics A	6
PX144	Introduction to Astronomy	6
PX147	Introduction to Particle Physics	6

NB: MA112 Experimental Mathematics, MA133 Differential Equations, MA135 Vectors and Matrices and MA124 Mathematics by Computer are not available to Statistics students in 2009/10

The above lists contain all the options available to First Year students on the Y602/G300 degrees. These are consistent with the University Course Regulations.

Any modules not listed (including Languages) are classed as 'Unusual Options' and permission to take these modules must be obtained by filling in an Unusual Option form available from the Undergraduate office.

Full descriptions of all core modules and some optional modules are given in the section of this handbook entitled: Module Descriptions: first year. Descriptions for other modules can be obtained from the appropriate teaching department, usually via their web pages.

ASSESSMENT AND EXAMINATIONS

Some modules are assessed wholly or in part on written work submitted during the academic year. The deadlines for submission of such work will be announced by the lecturers and tutors responsible for teaching such modules. Failure to obey these deadlines will entail loss of marks. Most examinations are held in term 3. Exceptions are MA132 and MA131 which are partially examined at the start of term 2, and the option ST104 Statistical Laboratory which is held in the last week of term 1.

9 SECOND YEAR

After completing the second year the students will have:

- Covered a range of material in mathematics, statistics, operations research and economics and studied some of it in depth.
- Acquired sufficient knowledge and understanding to be in a position to make an informed choice of options in their final years and to have covered the background necessary to pursue these options.

The normal load in the second year is **120** CATS points. The maximum load is **150** CATS.

Candidates for Honours are required to take an appropriate number of optional modules and 108 CATS points of core modules.

Either: 72 CATS points from ***List (A),*** at least 12 CATS points from ***List (B)*** and at least 24 CATS points from ***List (C),***
Or: 84 CATS points from ***List (D)*** and at least 24 CATS points from ***List (E).***

Candidates for Pass degrees are required to take all modules in ***List (A)*** plus 12 CATS from ***Lists (B) and (C)*** combined. If candidates are allowed to increase CATS load at the end of Term 1 they must ensure they meet the regulations.

List (A)		**CATS**
EC220	Mathematical Economics IA	12
IB207	Mathematical Programming II	12
ST208	Mathematical Methods	12
ST213	Mathematics of Random Events	12
ST217	Mathematical Statistics (Part A & Part B)	24
List (B)		
MA244	Analysis III	12
ST202	Stochastic Processes	12
List (C)		
EC204	Economics 2	30
EC221	Mathematical Economics IB	12
IB211	Simulation	12
ST215	Forecasting and Control	12
List (D)		
EC220	Mathematical Economics IA	12
IB207	Mathematical Programming II	12
MA225	Differentiation	12
MA244	Analysis III	12

List (D) contd

ST213	Mathematics of Random Events	12
ST217	Mathematical Statistics (Part A & Part B)	24

List (E)		**CATS**
EC221	Mathematical Economics IB	12
IB211	Simulation	12
MA222	Metric Spaces	12
MA250	PDE	12
ST202	Stochastic Processes	12
ST215	Forecasting & Control	12

Optional Modules

Any module from Lists A-E above and for a full list of optional modules you should consult the regulations for the second year of Y602 MORSE degree at: http://www2.warwick.ac.uk/services/quality/courseregs/courseregs0910/undergrad/st/y602/

Any modules not listed (including Languages) are classed as 'Unusual Options' and permission to take these modules must be obtained by filling in an Unusual Option form available from the Undergraduate Office.

Some of the more popular options are listed below:

Popular Optional Modules		**CATS**
IB109	Foundations of Accounting and Finance	24
IB206	Introduction to Business Studies	6
IB207	Mathematical Programming II	12
IB217	Starting a Business	6
MA117	Programming for Scientists	12
MA251	Algebra I: Advanced Linear Algebra	12
PH201	History of Modern Philosophy	30
PX268	Stars	7.5
PX269	Galaxies	7.5

Full descriptions of all ***Lists (A)*** through ***(E)*** modules and some optional modules are given in the section of this handbook entitled: Module Descriptions: second year: Descriptions for other modules can be obtained from the appropriate teaching department, usually via their web pages.

10. THIRD YEAR of B.Sc. MORSE

After completing the third year of the BSc degree the students will have:

- Developed skills in formulating and solving both abstract and applied problems, and in presenting cogent and logical arguments.
- Developed a strong background in at least one specialism, thus providing a basis for further study or employment in related fields.

The normal load in the third year is **120** CATS points. The maximum load is **150** CATS.

Candidates for Honours must take at least **90** CATS from ***List (A)*** and **at most 30** CATS from ***List (B).***

At most 24 CATS of MA2** modules may be counted towards the 90 CATS ***List (A)*** requirement.

Candidates for Pass degrees are required to take modules totalling **90** CATS from ***List (A).***

List (A)		**CATS**
EC301	Mathematical Economics 2	15 or 30
EC306	Econometrics 2	30
EC307	Economic Policy in the UK	30
EC312	International Economics	30
EC314	Topics in Economic Theory	15
EC331	Research in Applied Economics	30
EC333/334	Topics in Financial Economics	15/30
IB312	Project	15
IB3A7	The Practice of Operational Research	12
IB320	Simulation	12
IB321	Forecasting	12
IB349	Operational Research in Strategic Planning	12
IB352	Mathematical Programming III	15
IB391	Decision Analysis	15
MA222	Metric Spaces`	12
MA225	Differentiation	12
MA231	Vector Analysis	12
MA250	PDE	12
MA251	Algebra I: Advanced Linear Algebra	12

All MA3** modules except MA3E5 History of Mathematics and MA397 Consolidation

List (A) *contd*		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
ST305	Designed Experiments	15
ST313	Essay or Project	15 or 30
ST318	Probability Theory	15
ST323	Multivariate Statistics	15
ST329	Topics in Statistics	15
ST332	Medical Statistics	15
ST333	Applied Stochastic Processes	15
ST337	Bayesian Forecasting and Intervention	15

List (B)		**CATS**
ST335	Finance and Financial Reporting	15
EC303	The British Economy in the Twentieth Century	30
EC310	Topics in Development Economics	30
EC313	The International Economic System since 1918	30
EC320	Economics of Public Policy	30
EC326	Industrial Economics 2	30
IB215	Principles of Finance	24 or 30
IB326	Buyer Behaviour	12
IB327	Personnel Management	24
IB333	Issues in Financial Reporting	12
IB337	Business Taxation	12
IB357	Investment Management	12
IB359	Derivatives and Financial Risk Management	12
IB361	Equality and Diversity	12
IB362	Managing Human Resources	12
IB365	Marketing Communications	12
IB368	International Business Strategy	12
IB370	Strategic Information Management	12
IB373	Cost Management Systems	12
IB375	Strategy and Accounting	12
IB377	Advanced Financial Reporting	12
IB382	Project Management	12
IB384	Supply Chain Management	12
IB385	Marketing Analysis	24
IB387	Marketing Strategy	12
IB388	International Marketing	12
IB394	International Financial Management	12
IB395	Finance in New Ventures	12

List(B) *contd*		**CATS**
IB396	Financial Statement Analysis and Security Valuation	12
IB3A5	Marketing Management	12
IB3B0	E-business and Value Chains	12
IB3D8	Corporate Strategy Part A	12
IB3D9	Corporate Strategy Part B	12
IB3E0	Comparative European Employment Relations	12
IB3E1	International and European Employment Relations	12
IB3E2	Public Finance and Policy	12
IB3E3	Advanced Issues in Strategy	12
IB3E4	Business Systems Integration	12
IB3E5	Managing IT Enterprise Architecture	12
IB3E6	Ethical Issues and Social Responsibility in Contemporary Business	12
IB3E7	Organising Consumption: Consumer Culture, Organisations and Identity	12
IB3E8	Managerial Work and Practice	12
IB3E9	Managing IT Solution Architecture	12
IB3F0	Auditing, Governance and Accountability	12
IB3F1	International Corporate Tax Planning	12
IB3F3	Managing Complexity in the Networked World	12
IB3F4	Innovation and High-Tech Enterprise	12
IB3F5	Individual Perspectives on Entrepreneurship	12
IB3F6	Macro Perspectives on Entrepreneurial Theory	12
MA3A6	Algebraic Number Theory	15
MA3B8	Complex Analysis	15
MA3D1	Fluid Dynamics	15
MA3D4	Fractal Geometry	15
MA3D5	Galois Theory	15
MA3D9	Geometry of Curves and Surfaces	15
MA3E1	Groups & Representations	15
MA3E2	Group Theory **Not running in 09/10**	15
MA3F1	Introduction to Topology	15
MA3F2	Knot Theory	15
MA3G0	Modern Control Theory	15

List(B) *contd*		**CATS**
MA3G1	Theory of Partial Differential Equations	15
MA3G2	Continuum Mechanics **(Not running 2009/10)**	15
MA3G3	Probability Theory in Bioinformatics **(Not running 2009/10)**	15
MA3G4	Computational Algebraic Geometry **(Not running 2009/10)**	15
MA3G5	Introduction to Statistical Mechanics **(Not running 2009/10)**	15
MA3G6	Commutative Algebra	15
MA3G7	Functional Analysis 1	15
MA3G8	Functional Analysis II	15
MA3H0	Numerical Analysis and PDE's	15
MA3H1	Topics in Number Theory	15
MA3H2	Markov Processes	15
MA3H3	Set Theory	15
MA359	Measure Theory	15
MA371	Qualitative Theory of Ordinary Differential Equations	15
MA372	Reading Course	15
MA377	Rings and Modules	15
MA390	Topics in Mathematical Biology	15
MA395	Essay	15
MA398	Matrix Analysis and Algorithms	15
CS301	Complexity of Algorithms	15
CS324	Computer Graphics	15
CS330	History of Computing	15
CS332	Programming Language Design & Semantics	15
IE419	Development of Mathematical Concepts	12
IE420	Problem Solving	12
PH340	Logic III: Incompleteness and Undecidability	15
PH329	Philosophy of Logic	15
PX308	Physics in Medicine	7.5
PX350	The Weather and Environment	7.5
PX366	Statistical Physics	7.5
PX370	Optoelectronics and Laser Physics	7.5
PX382	Quantum Physics of Atoms	7.5
PX384	Electrodynamics	7.5

List(B) *contd*		**CATS**
PX387	Astro Physics	15
PX389	Cosmology	7.5
PX390	Scientific Programming	7.5
PX391	Non-Linearity, Chaos and Complexity	7.5
PX392	Plasma Electrodynamics	7.5
PX436	General Relativity	15
PX439	Statistical Mechanics of Complex Systems	7.5

- No student is allowed to take courses so that more than 50% of their overall degree mark is obtained from assessed work.
- Recall the advice from 5.2: In awarding a first class BSc degree, the Examination Board expect to see good first class marks on ***List (A)*** third year papers equivalent to at least 42 CATS points in this year. A student who achieves a final credit higher than 70% but who does not satisfy this requirement will not usually be awarded a first class degree.
- Economics Modules do not run if there aren't sufficient numbers. Check with Economics Department.
- Certain third and fourth year options have prerequisites which are not in the compulsory component of previous years. It is the responsibility of each student to be in a position to understand the chosen modules.
- It is a student's responsibility to ensure that the modules they are following are permitted- either because the modules are given explicitly as options by the regulations or because permission has been sought and granted by filling in an unusual option form. **Recall: Final year students are not allowed to take first and second year modules.**
- In year 3 of the BSc MORSE degree the credit for any unusual options taken counts towards the maximum 30 CATS allowed for ***List (B)*** options.
- If you break a rule such as "at most 30 CATS credit from ***List (B)***" then the credit for each ***List (B)*** module taken will be multiplied by a scaling factor in order to reduce the total credit to 30 CATS.

11. THIRD YEAR of INTEGRATED MASTERS

The integrated Masters degree in MORSE is currently running in two variants. The difference between the two variants is in the approved title that you will be able to use. The first variant whose degree course code is Y604 is entitled MMORSE and the second variant which carries the course code G300 is entitled BSc MMORSE.

The regulations for the two variants are identical except that, as is noted below, they require different minimum levels of CATS taken at level 4. The intention of introducing G300 is to allow students to take a degree whose title makes explicit the fact that they have covered the material which leads to a Batchelor degree as well as material at Masters level.

The first two years are in common with the BSc degree in MORSE.

Students at the end of the second year **must** choose one of 4 possible streams:

- Actuarial and Financial Mathematics.
- Econometrics and Mathematical Economics.
- Operational Research and Statistics.
- Statistics with Mathematics.

Students must follow the same stream in the third and fourth year.

For all streams the normal load is **120** CATS. The maximum load is **150** CATS. **Recall: Final year students are not allowed to take first and second year modules.**

- Students registered for Y604 must take, over their third and fourth years, ***at least*** **90 CATS of level 4+ modules** given by the Departments of Economics, Mathematics, Statistics and the Warwick Business School.
- Students registered for G300 must take, over their third and fourth years, ***at least*** **120 CATS of level 4+ modules** given by the Departments of Economics, Mathematics, Statistics and Warwick Business School. At least 90 CATS of level 4 should be taken in the fourth year.
- No student is allowed to take modules so that more than 50% of their overall degree mark is obtained from assessed work ("assessed work" means anything other than a conventional University-supervised examination). If you break this rule you will get a mark of zero for assessed work in excess of the 50% maximum.
- Certain third and final year options have prerequisites which are not in the compulsory component of the second year. It is the responsibility of each student to be in a position to understand the modules chosen.
- Recall the advice from 5.3: in awarding a first class integrated Masters degree the Examination Board expect to see good first class marks on at least 75 CATS from: (a) modules from the core or ***Lists (A)*** through ***(F)*** taken in year 3 and (b) modules from core or ***Lists (A) through (E)*** taken in year 4. A student who

achieves a final credit higher than 70% but who does not satisfy this requirement will not usually be awarded a first class degree.

- It is a student's responsibility to ensure that the modules they are following are permitted - either because the modules are given explicitly as options by the regulations or because permission has been sought and granted by filling in an unusual option form.
- You will want to consider possible choices of fourth year options when choosing your third year options. You should bear in mind that the module positions (whether they are in Term 1 or 2) do vary slightly from year to year and the positions published in this book will not necessarily be the same next year.
- You are not allowed to take both the level 3 and level 4 version of the same module, eg ST323 Multivariate Statistics in Year 3 and then ST412 Multivariate Statistics with Advanced Topics in Year 4. So, again, when choosing your 3^{rd} year options it is advisable to consider your 4^{th} year options at the same time.

ACTUARIAL AND FINANCIAL MATHEMATICS STREAM

Objective: to provide students with a sound theoretical and practical basis for careers and research in financial mathematics and to prepare students for an actuarial career by covering around 7 of the 9 papers in the diploma in Actuarial Techniques of the Institute of Actuaries.

Syllabus: This comprises three interlocking strands:

- Background knowledge on financial institutions and financial instruments.
- Construction and analysis of financial models - these models are predominantly stochastic so that the key techniques are probability, time series modelling and stochastic processes.
- Analysis of financial data: the key techniques are regression and linear models, multivariate data analysis, time series & forecasting, and risk analysis.

Students must take the core modules, at least **15** CATS from ***List (A)***, at least **15** CATS from ***List (B)*** and an appropriate number of optional modules.

Core Modules		**CATS**
ST318	Probability Theory	15
ST404	Applied Statistical Modelling	15
IB215	Principles of Finance	24/30

List (A)		**CATS**
EC306	Econometrics 2	30
IB352	Mathematical Programming III	15
ST334	Actuarial Methods	15
ST335	Finance and Financial Reporting	15
ST338	Actuarial Models	15

List (B)		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
ST323	Multivariate Statistics	15
ST333	Applied Stochastic Processes	15
ST337	Bayesian Forecasting and Intervention	15
ST405	Bayesian Forecasting and Intervention with Adv Topics	15
ST406	Applied Stochastic Processes with Advanced Topics	15
ST412	Multivariate Statistics with Advanced Topics	15
ST413	Bayesian Statistics and Decision Theory with Adv Topics	15

Optional Modules

Modules available in the third year of the Y602 BSc MORSE degree and in any stream of the third and fourth year of the Y604/G300 integrated Masters degrees.

ECONOMETRICS AND MATHEMATICAL ECONOMICS STREAM

Objective: To prepare students for careers in econometrics, economic consultancy, and research in quantitative economics.

Syllabus: A combination of courses on economics, mathematical models in economics, and the analysis of economic data. The key techniques are differential equations, optimisation, probability, game theory, stochastic processes, regression, time series and forecasting, and multivariate data analysis.

Students must take the core modules, at least **45** CATS from ***List C*** and an appropriate number of optional modules.

Core Modules		**CATS**
ST318	Probability Theory	15
ST323	Multivariate Statistics **or**	15
ST412	Multivariate Statistics with Advanced Topics	15
ST404	Applied Statistical Modelling	15

List (C)		**CATS**
EC301	Mathematical Economics 2	15 or 30
EC303	The British Economy in the 20th Century	30
EC304	The Making of Economic Policy	30
EC306	Econometrics 2	30
EC307	Economic Policy in the UK	30
EC310	Topics in Development Economics	30
EC312	International Economics	30
EC314	Topics in Economic Theory	15
EC331	Research in Applied Economics	30
EC333/334	Topics in Financial Economics	15 or 30
EC208	Industrial Economics 1	30

Optional Modules

Modules available in the third year of the Y602 BSc MORSE degree and in any stream of the third and fourth year of the Y604/G300 integrated Masters degrees.

OPERATIONAL RESEARCH AND STATISTICS STREAM

Objective: To prepare students for employment as management scientists and for research in Operational Research (OR).

Syllabus: This covers mathematical techniques in OR, the design and organisation of information systems, and the analysis of production and management information. The key techniques include mathematical programming, simulation, applied probability, decision theory, regression, time series and forecasting, multivariate data analysis, and the design and analysis of experiments.

Students must take the core modules, at least **12** CATS from ***List (D)*** and an appropriate number of optional modules.

Core Modules		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
or		
ST413	Bayesian Statistics and Decision Theory with Adv Topics	15
ST323	Multivariate Statistics	15
or		
ST412	Multivariate Statistics with Advanced Topics	15
ST404	Applied Statistical Modelling	15
IB320*	Simulation	12
IB352	Mathematical Programming III	15

****If IB211 not taken in the second year***

List (D)		**CATS**
IB3A7	The Practice of Operational Research	12
IB349	Operational Research in Strategic Planning	12
IB391	Decision Analysis	15
IB408	Operational Research in SP with Advanced Topics	12
IB407	Decision Analysis with Advanced Topics	15

Optional Modules

Modules available in the third year of the Y602 BSc MORSE degree and in any stream of the third and fourth year of the Y604/G300 integrated Masters degrees.

STATISTICS WITH MATHEMATICS STREAM

Objective: To prepare students for employment as statisticians and for research into statistics.

Syllabus: All the major areas of probability modelling, stochastic processes and statistical modelling.

Students must take the core modules, at least **15** CATS from ***List (E)***, at least **15** CATS from ***List (F)*** and an appropriate number of optional modules.

Core Modules		**CATS**
MA359	Measure Theory	15
ST318	Probability Theory	15
ST323	Multivariate Statistics	15
or		
ST412	Multivariate Statistics with Advanced Topics	15
ST404	Applied Statistical Modelling	15

List (E)		**CATS**
MA222	Metric Spaces	12
MA225	Differentiation	12
MA231	Vector Analysis	12
MA3G7	Functional Analysis I	12
MA251	Algebra I: Advanced Linear Algebra	12

All MA3** modules except MA3E5 History of Mathematics and MA397 Consolidation.

List (F)		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
ST305	Designed Experiments	15
ST329	Topics in Statistics	15
ST332	Medical Statistics	15
ST333	Applied Stochastic Processes	15
ST337	Bayesian Forecasting and Intervention	15
ST405	Bayesian Statistics and Decision Theory with Adv Topics	15
ST406	Applied Stochastic Processes with Advanced Topics	15
ST409	Medical Statistics with Advanced Topics	15
ST410	Designed Experiments with Advanced Topics	15
ST413	Bayesian Statistics and Decision Theory with Adv Topics	15

Optional Modules

Modules available in the third year of the Y602 BSc MORSE degree and in any stream of the third and fourth year of the Y604/G300 integrated Masters degrees.

12. FOURTH YEAR of INTEGRATED MASTERS

The normal load is **120** CATS. The maximum load is **150** CATS. **Recall: Final year students are not allowed to take first and second year modules.**

- Students registered for Y604 must take, over their third and fourth years, ***at least* 90 CATS of level 4+ modules** given by the Departments of Economics, Mathematics, Statistics and the Warwick Business School.
- Students registered for G300 must take, over their third and fourth years, ***at least* 120 CATS of level 4+ modules** given by the Departments of Economics, Mathematics, Statistics and Warwick Business School. At least 90 CATS of level 4 should be taken in the fourth year.
- No student is allowed to take modules so that more than 50% of their overall degree mark is obtained from assessed work ("assessed work" means anything other than a conventional University-supervised examination). If you break this rule you will get a mark of zero for assessed work in excess of the 50% maximum.
- Certain third and final year options have prerequisites which are not in the compulsory component of the second year. It is the responsibility of each student to be in a position to understand the modules chosen.
- Economics modules do not run if there aren't sufficient numbers. Check with Economics Department.
- In order to award an MMORSE degree the Examination Board expects that the candidate has passed the core project module.
- Recall the advice from 5.3: in awarding a first class integrated Masters degree the Examination Board expect to see good first class marks on at least 75 CATS from: (a) modules from the core or ***Lists (A)*** through ***(F)*** taken in year 3 and (b) modules from core or ***Lists (A) through (E)*** taken in year 4. A student who achieves a final credit higher than 70% but who does not satisfy this requirement will not usually be awarded a first class degree.
- It is a student's responsibility to ensure that the modules they are following are permitted - either because the modules are given explicitly as options by the regulations or because permission has been sought and granted by filling in an unusual option form.

ACTUARIAL AND FINANCIAL MATHEMATICS STREAM

Students must take the core module, at least **57** CATS from ***List (A)*** and an appropriate number of optional modules.

Core Modules		**CATS**
ST415	Statistics Masters Dissertation, or	30
EC400	Statistics Masters Dissertation in Economics, or	30
IB403	Operational Research Dissertation	30

List (A)		**CATS**
EC306	Econometrics 2	30
EC910	Econometrics B	30
IB357	Investment Management	12/15
IB359	Derivatives and Financial Risk Management	12/15
IB407	Decision Analysis	15
ST323	Multivariate Statistics	15
ST401	Stochastic Methods in Finance	15
ST402	Risk Theory	15
ST403	Brownian Motion	18
ST405	Bayesian Forecasting and Intervention with Advanced Topics	15
ST406	Applied Stochastic Processes with Advanced Topics	15
ST409	Medical Statistics with Advanced Topics	15
ST410	Designed Experiments with Advanced Topics	15
ST411	Dynamic Stochastic Control	15
ST412	Multivariate Statistics with Advanced Topics	15
ST413	Bayesian Statistics and Decision Theory with Advanced Topics	15
ST414	Advanced Topics in Statistics	15
ST416	Advanced Topics in Biostatistics	15
ST417	Topics in Applied Probability	15
ST906	Financial Time Series	15
ST908	Probability and Stochastic Processes	15
ST909	Continuous Time Finance for Interest Rate Models	15

Optional Modules

Third year (3** and 4**) modules available in the third year of the Y604/G300 integrated Masters degrees and any modules in any stream of the fourth year of the Y604/G300 integrated Masters degrees.

ECONOMETRICS AND MATHEMATICAL ECONOMICS STREAM

Students must take the core module, at least **60** CATS from ***List (B)*** and an appropriate number of optional modules.

Core Module		**CATS**
ST415	Statistics Masters Dissertation, or	30
EC400	Statistics Masters Dissertation in Economics, or	30
IB403	Operational Research Dissertation	30

List (B)		**CATS**
EC301	Mathematical Economics 2	15 or 30
EC306	Econometrics 2	30
EC314	Topics in Economic Theory	15
EC333/334	Topics in Financial Economics	30
EC901	Economic Analysis (***subject to availability***)	24 or 48
EC910	Econometrics B (***subject to availability***)	36
EC914	The Market for Labour	15
EC920	International Monetary Economics	18
EC924	Monetary Economics	15
EC931	International Trade Theory	15
EC938	Macroeconomic Topics in Development and Transition	15
EC940	The Theory of Public Economics	15
EC941	Game Theory	15
EC943	Industrial Economic Analysis	15
EC950	Microeconometrics	15
ST908	Probability and Stochastic Processes	15
ST909	Continuous Time Finance for Interest Rate Models	15

Optional Modules
Third year (3** and 4**) modules available in the third year of the Y604/G300 integrated Masters degrees and any modules in any stream of the fourth year of the Y604/G300 integrated Masters degrees

OPERATIONAL RESEARCH AND STATISTICS STREAM

Students must take the core module, at least **24** CATS from ***List (C)***, at least **30** CATS from ***List (D)***, and an appropriate number of optional modules.

Core Modules		**CATS**
ST415	Statistics Masters Dissertation, or	30
EC400	Statistics Masters Dissertation in Economics, or	30
IB403	Operational Research Dissertation	30

List (C)		**CATS**
IB3A7	The Practice of Operational Research	12
IB407	Decision Analysis	15
IB408	Operational Research in Strategic Planning	12
IB94W0	Spreadsheet Modelling	12
IB9W1	Web Applications Development ***(Not running 2009/10)***	12
	Certain additional IB modules may be designated as List (C). Please see the online regulations for updated information.***	

List (D)		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
ST305	Designed Experiments	15
ST318	Probability Theory	15
ST329	Topics in Statistics	15
ST332	Medical Statistics	15
ST401	Stochastic Methods in Finance	15
ST402	Risk Theory	15
ST403	Brownian Motion	18
ST405	Bayesian Forecasting and Intervention with Adv Topics	15
ST406	Applied Stochastic Processes with Advanced Topics	15
ST407	Monte Carlo Methods	15
ST409	Medical Statistics with Advanced Topics	15
ST410	Designed Experiments with Advanced Topics	15
ST411	Dynamic Stochastic Control	15
ST412	Multivariate Statistics with Advanced Topics	15
ST413	Bayesian Statistics and Decision Theory with Advanced Topics	15
ST414	Advanced Topics in Statistics	15
ST906	Financial Time Series	15
ST908	Probability and Stochastic Processes	15
ST909	Continuous Time Finance for Interest Rate Models	15

Optional Modules

Third year (3** and 4**) modules available in the third year of the Y604/G300 integrated Masters degrees and any modules in any stream of the fourth year of the Y604/G300 integrated Masters degrees.

STATISTICS WITH MATHEMATICS STREAM

Students must take the core module, at least **60** CATS from ***List (E)***, and an appropriate number of optional modules.

Core Modules		**CATS**
ST415	Statistics Masters Dissertation, or	30
EC400	Statistics Masters Dissertation in Economics, or	30
IB403	Operational Research Dissertation	30

List (E)		**CATS**
ST301	Bayesian Statistics and Decision Theory	15
ST305	Designed Experiments	15
ST329	Topics in Statistics	15
ST332	Medical Statistics	15
ST401	Stochastic Methods in Finance	15
ST402	Risk Theory	15
ST403	Brownian Motion	18
ST405	Bayesian Forecasting and Intervention with Advanced Topics	15
ST406	Applied Stochastic Processes with Advanced Topics	15
ST407	Monte Carlo Methods	15
ST409	Medical Statistics with Advanced Topics	15
ST410	Designed Experiments with Advanced Topics	15
ST411	Dynamic Stochastic Control	15
ST412	Multivariate Statistics with Advanced Topics	15
ST413	Bayesian Statistics and Decision Theory with Advanced Topics	15
ST414	Advanced Topics in Statistics	15
ST416	Advanced Topics in Biostatistics	15
ST417	Topics in Applied Probability	15
ST906	Financial Time Series	15
ST908	Probability and Stochastic Processes	15
ST909	Continuous Time Finance for Interest Rate Models	15

All MA3** modules except MA3E5 History of Mathematics and MA397 Consolidation. All MA4** modules and all modules from the MSc in Mathematics.

Optional Modules
Third year (3** and 4**) modules available in the third year of the Y604/G300 integrated Masters degrees and any modules in any stream of the fourth year of the Y604/G300 integrated Masters degrees.

13. MODULE DESCRIPTIONS

The remainder of this handbook consists of detailed descriptions of all the core modules and some of the more popular optional modules. Modules are listed in year order.

Further descriptions of Optional Modules can be found on the following websites:

Mathematics:
http://www2.warwick.ac.uk/fac/sci/maths

Economics:
http://www2.warwick.ac.uk/fac/soc/economics/ug

Warwick Business School:
http://www.wbs.ac.uk/students/undergraduate

Physics
http://www2.warwick.ac.uk/fac/sci/physics/teach/syllabi/

Course Regulations
http://www2.warwick.ac.uk/services/quality/courseregs/courseregs0910/undergrad/st

Modules are listed in alphabetical order

COMPUTER SCIENCE	CS128	6 CATS
Term 3	**Further Discrete Mathematics**	

Commitment: 15 lectures ***Not Running 09/10***

Prerequisites: CS130 or MA132

Content: Topics include a review of enumeration problems and techniques including generating functions.

Aims: To develop understanding of the concepts and techniques of discrete mathematics and to explore their use in various application areas important to Computer Science.

Learning Outcome: Students will be able to apply basic enumeration and approximation techniques to estimate quantities arising in some common computations and data structures. They will be able to use the mechanism of generating functions to represent and evaluate enumeration problems.

Books: Aigner and Ziegler, *Proofs from* THE BOOK (3rd Ed.) Springer, 2003
Graham, Knuth, Patashnik, *Concrete Mathematics A Foundation for Computer Science* (2nd Ed.), Addison-Wesley, 1994
Truss, *Discrete Mathematics for Computer Scientists* (2nd Ed), Addison-Wesley, 1999
Tucker, *Applied Combinatorics* (4th Ed), John Wiley & Sons, 2000

Assessment: One and a half hour examination (100%).

Lecturer: J. Feng/Enrico Rossoni

ECONOMICS	EC106	24 CATS
Terms 1 & 2	**Introduction to Quantitative Economics**	

Module leader	Dennis Novy
Teaching format	2 lectures per week in Terms 1 and 2 plus fortnightly classes
Assessment methods	2 Hour examination in June, plus in-lecture tests
Prerequisites	This module is specifically designed for students taking mathematics-based degree programmes. All students will normally have GCE A-Level or equivalent in mathematics. Past experience has shown that approximately 40% of students taking the module have studied economics to GCE A level or equivalent. The pace of presentation and the depth of analysis aim to strike a balance between the needs of those students who have prior knowledge of economics and those who do not.
Academic aims	This module is intended as an introduction to economics for students with a relatively strong mathematical background. At the end of the year students should have a good grasp of the main theories and be ready if

they wish to embark upon more advanced economics options taught in the second year, in particular, EC220/221 Mathematical Economics 1, and EC204 Economics 2.

Syllabus

Term 1 covers microeconomics, which is concerned with the economic behaviour of individual consumers and producing firms, and their interaction in markets for goods, services and factors of production.

Term 2 covers macroeconomics, which is concerned with aggregate economic variables or the workings of the national economy as a whole: aggregate output (Gross Domestic Product or GDP), employment and unemployment, inflation, interest rates, the balance of payments, exchange rates, etc., and with government economic policies to influence these variables.

The focus is mainly on economic theory but "real world" applications of relevant theories will also be examined, subject to time limitations.

Illustrative reading

- W. Morgan, M. L. Katz and H.S. Rosen, *Microeconomics* (European edition, 2006, McGraw-Hill)
- N. Gregory Mankiw, *Macroeconomics* (6th edition, 2007, Worth Publishers)

Assessment: 2 hour examination in June plus 4 assessments in the form of term tests.

Lecturer: Sayantan Ghosal (term 1) and Dennis Novy (term 2).

BUSINESS SCHOOL	**IB104**	**12 CATS**
Term 3	**Mathematical Programming I**	**(12 or 7.5 CATS for MathStats students only)**

Commitment: 20 lectures and 5 problem classes.

Academic Rationale: This is a short intensive module on theoretical and practical aspects of linear programming including an introduction to other optimisation techniques.

Content: Formulation of linear programming models; graphical representation and solution of two variable models; simplex method; sensitivity analysis; duality; formulation and solution of transportation models; game theory. Also included in the course is a computer based project which involves the formulation of a linear programming problem and its solution using a standard computer package.

Leads to: IB207 Mathematical Programming II and IB352 Mathematical Programming III

Assessment: Open book examination (7.5 cats), written report (4.5 cats).
(**MORSE**: **12 CATS core or 7.5 CATS for MathStats Students only)**

Lecturer: Vladimir Deineko

MATHEMATICS	**MA106**	**12 CATS**
Term 2	**Linear Algebra**	

Commitment: 30 one-hour lectures.

Content: Many problems in maths and science are solved by reduction to a system of simultaneous linear equations in a number of variables. Even for problems which cannot be solved in this way, it is often possible to obtain an approximate solution by solving a system of simultaneous linear equations, giving the "best possible linear approximation".
The branch of maths treating simultaneous linear equations is called linear algebra. The module contains a theoretical algebraic core, whose main idea is that of a vector space and of a linear map from one vector space to another. It discusses the concepts of a basis in a vector space, the dimension of a vector space, the image and kernel of a linear map, the rank and nullity of a linear map, and the representation of a linear map by means of a matrix.

These theoretical ideas have many applications, which will be discussed in the module. These applications include:

- Solutions of simultaneous linear equations.
- Properties of vectors.
- Properties of matrices, such as rank, row reduction, eigenvalues and eigenvectors.
- Properties of determinants and ways of calculating them.

Aims: To provide a working understanding of matrices and vector spaces for later courses to build on and to teach students practical techniques and algorithms for fundamental matrix operations and solving linear equations.

Objectives: Students must understand the ideas of linear independent vectors, spanning sets and bases of vector spaces. They must also understand the equivalence of linear maps between vector spaces and matrices and be able to row reduce a matrix, compute its rank and solve systems of linear equations. The definition of a determinant in all dimensions will be given in detail, together with applications and techniques for calculating determinants. Students must know the definition of the eigenvalues and eigenvectors of a linear map or matrix, and know how to calculate them.

Leads to: Mainly 2nd year algebra modules, but results and techniques from linear algebra may be used in any higher year maths modules and even in some outside options.

Books: David Towers, *Guide to Linear Algebra*, Macmillan 1988. Howard Anton, *Elementary Linear Algebra*, 7th Edition, John Wiley and Sons, 1994. Paul Halmos, *Linear Algebra Problem Book*, MAA, 1995.
G Strang, *Linear Algebra and its Applications,* 3rd ed, Harcourt Brace, 1988.

Assessment: 15% from weekly assignments, 85% from a 2 hour examination.

Lecturers: Inna Korchagina/Colin Rourke

MATHEMATICS	MA113	6 CATS
Term 2	Differential Equations A	

You may not take this module as well as MA133 Differential Equations

Commitment: 15 one-hour lectures

Content: How do you reconstruct a curve given its slope at every point? Can you predict the trajectory of a tennis ball? The basic theory of ordinary differential equations (ODEs) as covered in this module is the cornerstone of all applied mathematics. Indeed, modern applied mathematics essentially began when Newton developed the calculus in order to solve (and to state precisely) the differential equations that followed from his laws of motion.
However, this theory is not only of interest to the applied mathematician: indeed, it is an integral part of any rigorous mathematical training, and is developed here in a systematic way. Just as a "pure" subject like group theory can be part of the daily armoury of the "applied" mathematician , so ideas from the theory of ODEs prove invaluable in various branches of pure mathematics, such as geometry and topology.

In this module we will cover relatively simple examples, first order equations ($dy/dx = f(x, y)$) and linear second order equations ($\ddot{x} + p(t)\dot{x} + q(t)x = g(t)$), for most of which we can find an explicit solution. However, even when we can write the solution down it is important to understand what the solution means, ie. its "qualitative" properties. This approach is invaluable for more complex equations for which we cannot find an explicit solution: here we see how to understand the behaviour of all the solutions of an equation $dx/dt=f(x)$ using a very simple method.

If we try to approximate an ordinary differential equation like $dx/dt=f(x)$ numerically, one way would be to split the time into small increments Δ and try to approximate $x(t+\Delta t)$ by, for example,

$$x(t+\Delta t) = x(t) + f(x(t))\Delta t$$

If we write x_n for $x(n\Delta \mathrm{t})$ then we have

$$x_{n+1} = x_n + f(x_n)\Delta t\,,$$

a simple example of a difference equation.

In the final part of the module we will show how the techniques we learned for second order differential equations have natural analogues that can be used to solve difference equations.

The last lecture will give some indication of the complicated behaviour that can occur even in the simplest nonlinear difference equations.

Aims: To introduce simple differential and difference equations and methods for their solution, and to illustrate the importance of a qualitative understanding of these solutions.

Objectives: You should be able to solve various simple differential equations (first order and linear second order) and to interpret their qualitative behaviour; and to do the same for simple difference equations.

Leads to: MA112 Experimental Mathematics; MA250 Partial Differential Equations; MA240 Modelling Nature's Nonlinearity; MA235 Introduction to Mathematical Biology; MA209 Variational Principles; MA371 Qualitative Theory of Differential Equations; MA394 Waves; MA3D1 Fluid Dynamics; MA235 Topics in Mathematical Physics; MA3G1 Theory of PDEs; MA458 Mathematical Recipes.
There are also links with MA131 Analysis; MA106 Linear Algebra; MA124 Mathematics by Computer; MA222 Metric Spaces; MA228 Numerical Analysis.

Books: The primary text will be:

J. C. Robinson *An Introduction to Ordinary Differential Equations*, Cambridge University Press 2003. This is a new text designed for the length and rigour of this set of courses.

Additional references are:

W. Boyce and R. Di Prima, *Elementary Differential Equations and Boundary Value Problems*, Wiley 1997
C. H. Edwards and D. E. Penney, *Differential Equations and Boundary Value Problems*, Prentice Hall 2000
K. R. Nagle, E. Saff, and D. A. Snider, *Fundamentals of Differential Equations and Boundary Value Problems*, Addison Wesley 1999

Assessment: One-hour written examination (100%)

Lecturer: Markus Kirkilionis

MATHEMATICS MA117 12 CATS
Term 2 Programming for Scientists

Commitment: 10 lectures plus lab sessions/tutorials

Prerequisite: No previous computing experience will be assumed, but students should have obtained a code to use the IT Services work area systems prior to this module. Information and assistance is available in the Student Computer Centre in the Library Road.

Content: Aspects of software specification, design, implementation and testing will be introduced in the context of the Java language. The description of basic elements of Java will include data types, expressions, assignment and compound, alternative and repetitive statements. Program structuring and object oriented development will be introduced and illustrated in terms of Java's method, class and interface. This will enable the development of software that reads data in a variety of contexts, performs computations on that data and displays results in text and graphical form. Examples of iterative and recursive algorithms will be given. The importance of Java and Java Virtual Machine in networked computing will be described. The majority of examples will be standard applications but the development of Java Applets to be delivered by web browsers will also be covered.

Aims: To provide an understanding of the process of scientific software development and an appreciation of the importance of data vetting, sound algorithms and informative presentation of results.

Objectives: To enable the student to become confident in the use of the Java language for scientific programming.

Leads to: MA228 Numerical Analysis and modules given by the Computer Science Department that are based upon the Java language, including CS223 Introduction to Software Engineering, CS236 Data Structures and Algorithms and CS237 Concurrent Programming.

Books: Books are not essential for this module as use will be made of on-line tutorial and reference material. An informative, optional text is H M Deitel/P J Deitel, *Java How to Program (2nd or 3rd Ed.)*, Prentice Hall

Assessment: Three programming assignments.

Lecturer: Zadim Visram

MATHEMATICS	**MA125**	**6 CATS**
Term 1 Weeks 6-10	**Introduction to Geometry**	

Commitment: 15 one-hour lectures

Content: This module begins with a quick tour through elementary plane Euclidean geometry. We emphasise proof, and the careful use of diagrams as an aid to understanding problems and finding proofs. Plane geometry then provides the setting for an introduction to the geometry of the sphere and of polyhedra.

Aims:
- To learn and enjoy Euclidean geometry of the plane, the sphere and of three-dimensional space.
- To learn to visualise geometrical problems, and to draw diagrams which represent them accurately.
- To learn to reason from diagrams, and use them as an aid to writing rigorous proofs.
- To learn to construct proofs, and to set them out clearly and convincingly.

Objectives: You will gain familiarity with
- Plane Euclidean geometry, isometries, congruence and similarity; theorems on triangles, circles, tangents and angles; ruler and compass constructions.
- Polyhedra: the Euler characteristic; classification and construction of regular polyhedra.
- Spherical geometry: the angle sum formula for spherical triangles; sterographic projection and its relation with inversion; conformal (angle preserving) maps.

Books: Notes for the module will be available at cost price from the departmental office. Also relevant G A Jennings, *Modern geometry with applications,* Springer-Verlag (a fine book with many challenging exercises, but useful only as a complement to the course).

Assessment: One-hour exam taken in the summer term.

Equipment: Students should come equipped with a ruler and a compass.

Lecturer: Stefan Friedl

MATHEMATICS	**MA131**	**24 CATS**
Terms 1 & 2	**Analysis**	

CAUTION: MORSE and MathStats students are taught separately from students of the Mathematics Department.

***Commitment*:** 30 lectures each term.

***Content*:** At the beginning of the nineteenth century the familiar tools of calculus, differentiation and integration, began to run into problems. Mathematicians were unsure of how to apply these tools to sums of infinitely many functions. The origins of Analysis lie in their attempt to formalize the ideas of calculus purely in the language of arithmetic and to resolve these problems.

You will study ideas of the mathematicians Cauchy, Dirichlet, Weierstrass, Bolzano, D'Alembert, Riemann and others, concerning sequences and series in term one, continuity and differentiability in term two and integration in term one of your second year.

By the end of the year you will be able to answer many interesting questions: What do we mean by `infinity'? How can you accurately compute the value of or e or ? How can you add up infinitely many numbers, or infinitely many functions? Can all functions be approximated by polynomials?

There will be considerable emphasis throughout the module on the need to argue with much greater precision and care than you had to at school. With the support of your fellow students, lecturers and other helpers, you will be encouraged to move on from the situation where the teacher shows you how to solve each kind of problem, to the point where you can develop your own methods for solving problems. You will also be expected to question the concepts underlying your solutions, and understand why a particular method is meaningful and another not so. In other words, your mathematical focus should shift from problem solving methods to concepts and clarity of thought.

***Assessment*:** First term weekly assignments and mid-term tests (7.5%); one-and-a-half-hour hour examination on the first term's work (25%) (held in the first week of the second term); weekly assignments in the second term (7.5%); three-hour end-of-year examination (60%).

Books:
D. Stirling, Mathematical Analysis and Proof, 1997.
M. Spivak, Calculus, Benjamin.
M. Hart, Guide to Analysis, Macmillan. (A good traditional text with theory and many exercises.)
G.H. Hardy, An introduction to Pure Mathematics, CUP.

***Lecturers*:** For students based in Physics, Statistics or other Departments:
Term 1 – Xue-Mei Li; Term 2 - Jon Warren

MATHEMATICS	MA132	12 CATS
Term 1	Foundations	

Commitment**:** 30 lectures , 10 weekly assignments with 5 fortnightly tests based on them.

Prerequisites: Grade A in A-level Maths or equivalent, plus an interest in how Mathematics is built up from logical foundations.

Aims: University mathematics introduces progressively more and more abstract ideas and structures, and demands more and more in the way of proof, until by the end of a mathematics degree most of the student's time is occupied with understanding proofs and creating his or her own. This is not because university mathematicians are more pedantic than schoolteachers, but because proof is how one knows things in mathematics, and it is in its proofs that the strength and richness of mathematics is to be found.

But learning to deal with abstraction and with proofs takes time. This module aims to bridge the gap between school and university mathematics, by beginning with some rather concrete techniques where the emphasis is on calculation, and gradually moving towards abstraction and proof.

Content:

1. Numbers

- Number systems: Natural numbers, integers, rationals and real numbers. Existence of irrational numbers.
- Euclidean algorithm; greatest common divisor and least common multiple.
- Prime numbers, existence and uniqueness of prime factorisation (and non-uniqueness in other ``number systems", e.g. even integers, Gaussian integers).
- Properties of commutativity, associativity and distributivity.
- Infinity of the primes.
- Summing series of integers; proofs by induction.

2. Language

- Basic set theory: $\cap$, $\cup$, Venn diagrams and de Morgan's Laws.
- Logical connectives $\wedge$, $\vee$, $\Rightarrow$ and their relation with $\cap$, $\cup$ and $\supseteq$

3. Polynomials

- Multiplication and long division of polynomials.
- Binomial theorem
- Euclidean algorithm for polynomials.
- Remainder theorem; a degree n polynomial has at most n roots.
- Rational functions and partial fractions.
- Incompleteness of the real numbers, completeness of the complex numbers (sketch).

4. Counting

- Elementary combinatorics as practice in bijections, injections and surjections.
- Cardinality of the set of subsets of a set X is greater than cardinality of X. Russell's paradox.
- Definition of Cartesian product.
- Countability of the rational numbers, uncountability of the reals.
- Transcendental numbers exist!

The second (and smaller) part of the module explores the elementary properties of a fundamental algebraic structure called a *group*. Groups arise in an extraordinary range of contexts in mathematics and beyond (for example, in elementary particle physics and in card tricks), and can be used to analyse the symmetry of geometric objects or physical systems.

1. Modular arithmetic: 3 hours

- Addition, multiplication and division in the integers modulo n.
- Some theorems of modular arithmetic.
- Equivalence relations.

2. Permutations and the symmetric group

- Multiplying (composing) permutations.
- Cycles and disjoint cycle representation.
- The sign of a permutation.

Organisation: This module is lectured in two parallel sections:

Section 1 Mathematics students (including M/Econ, M/BS, M/CS, M/Phil).

Section 2 MORSE, Maths/Stats, Maths/Phys, and any other students.

Objectives: Students will work with number systems and develop fluency with their properties; they will learn the language of sets and quantifiers, and will become familiar with various styles of proof. They will approach group theory via modular arithmetic and permutations.

Leads to: Most later pure mathematics modules; specifically MA131 Analysis, MA106 Linear Algebra and MA242 Algebra I.

Books: None of these is the course text, but each would be useful, especially the first.

A.F.Beardon, *Algebra and Geometry*, CUP, 2005.
I.N. Stewart and D.O. Tall, *Foundations of Mathematics*, OUP, 1977.
J. A. Green, *Sets and Groups; First Course in Algebra*, Chapman and Hall, 1995.

Assessment: 15% from fortnightly tests, 20% from Maths Techniques and 65% from a one-and-a-half hour written exam in the **first week of Term 2** (probably on the first day of term 2!).

Lecturers: Section 1: David Mond, Section 2: Neil O'Connell

MATHEMATICS	**MA134**	**12 CATS**
Term 2	**Geometry and Motion**	

Commitment: 30 lectures.

Content: When a particle moves in space, it traces out a curve. This is one of the simplest connections between geometry and motion. The motion contains more information than the curve traced out by the particle because the same curve can be traversed at different, possibly non-uniform, speeds (different motion). The length of the curve (a geometric property) is given by the integral (with respect to time) of the speed at which the curve is traversed. However, the length is evidently independent of the actual motion of the particle along the curve. This independence is established by means of the change of variables formula for integrals. Another connection between geometry and motion is provided by the relation between curvature and acceleration.

In high school, one learns how to integrate a function of one real variable. This course describes how to integrate vector-valued functions and functions of two and three real variables. In particular, the area of a surface and volume of a region (geometry) will be defined, as well as the circulation of a fluid around a closed curve (motion). The change of variables formula for two and three dimensional integrals will be (heuristically) derived; it involves a determinant and is somewhat more complicated than the one dimensional formula.

A section on particle mechanics will derive Kepler's Laws of planetary motion from Newton's second law of motion and the law of gravitation. The motion of the simple pendulum will also be discussed. This section introduces the notion of conserved quantities.

Aims: This module aims to indicate to students how intuitive geometric and physical concepts such as length, area, volume, curvature, mass, circulation and flux can be translated into mathematical formulas. It also aims to teach the practical calculation of these formulas and their application to elementary problems in particle and fluid dynamics. The importance of conserved quantities in mechanics is also highlighted.

Objectives: On successful completion of this module students should be able to:

- parametrise simple curves and surfaces, such as conic sections, helix, surface of revolution (including sphere, cylinder, paraboloid and torus), in cartesian and other coordinates, including polar, spherical polar and cylindrical coordinates.
- calculate lengths and curvatures of curves in 3-space and demonstrate that length is independent of parametrisation.
- understand and be able to calculate line, surface and volume integrals with respect to various coordinate systems. This includes change of variables and change of order of integration in repeated integrals. Please note that in the examination, *no formula sheets* will be provided. :-(
- to be able to determine whether a vector field is conservative and to calculate its potential when it is.
- apply all these techniques to elementary problems from fluid dynamics (mass, work, circulation and flux) and geometry (area and volume).

- understand basic notions from particle mechanics including momentum (linear and angular), force, work, energy (potential and kinetic), Newton's laws of motion, Newton's law of gravity, conservation laws. Students should also be able to apply all these principles to elementary problems from mechanics, including central force theory (including, but not restricted to, planetary motion) and the simple pendulum.

***Books*:**
G. B. Thomas et al., *Calculus and Analytic Geometry*, Addison-Wesley. The course is concerned with only the later chapters of this massive book. However, the earlier chapters are relevant to other first year courses and even contain A-Level material from a different perspective. Any edition of this book is appropriate. You may be able to buy a cheap copy through Amazon.

F. J. Flannigan and J. L. Kazdan, *Calculus Two*, Springer-Verlag. Again, the earlier chapters of this book are relevant to other first year courses.

J.E. Marsden and A.J. Tromba, *Vector Calculus*, Freeman. This book is more advanced than *Calculus Two* and is useful for the second year courses on Vector Analysis and Differentiation.

Assessment: 15% by marked homework, 85% by a three-hour exam.

***Lecturer**:* Mario Micallef

PHYSICS	**PX132**	**6 CATS**
Term 1 (6-10)	**Mechanics A**	

***Aims*:**
This module will revise the classical mechanics that should have been met in A Level courses. Extension is made to writing vector equations to describe motion in three dimensions. The module is designed to ensure that you are competent in classical mechanics for future physics modules.

***Objectives*:**
At the end of the module, you should be able to:
- Outline the place of Newtonian mechanics in the development of science and to explain the experimental basis for Newton's three Laws of Motion.
- Solve $\mathbf{F} = d\mathbf{p}/dt$ for a variety of simple cases and be familiar with the concepts of potential and kinetic energy, and of the conservation of linear momentum and of energy.
- Solve motions under the influence of a central force using conservation of angular momentum and of energy.

Syllabus:
- Forces, interactions and Newton's Laws of Motion.
- Applying Newton's Laws - equilibrium, dynamics of particles, friction and dynamics of circular motion.
- Work and kinetic energy.
- Potential energy and energy conservation.
- Conservation of momentum, elastic collisions, centre of mass.

- Rotation of rigid bodies - angular velocity and acceleration.
- Dynamics of rotational motion, conservation of angular momentum.
- Equilibrium and centre of gravity.

Assessment: 1 hour examination

***Recommended Texts*:** H D Young and R A Freedman, University Physics 11th Edition, Pearson.

***Leads from*:** A level Physics and Mathematics, PX145 Physics Foundations

Leads to: PX242 Hamiltonian Mechanics, PX244 Introduction to Fluids

Lecturer: Rudolf Roemer

STATISTICS	ST104	12 CATS
Term 1	**Statistical Laboratory**	

Prerequisite: None (but A level Mathematics is assumed).

Commitment: 2 lectures and 1 laboratory per week

Content: A first course on data collection and analysis, probability and statistical inference. The emphasis is on using and interpreting statistical methods in practice, with a clear understanding of potential pitfalls. The course provides valuable motivation for the theory presented in the second year courses on Mathematical Statistics.

Aims: To introduce and explain the important ideas in practical statistics, so that, with full access to textbooks and other resources, students will know when to apply various statistical methods, and will understand the associated problems and pitfalls.

Objectives: After completing this course, students should be able to do the following given a Practical problem:

- Suggest methods to obtain relevant data.
- Summarise low-dimensional data-sets, both graphically and numerically.
- Apply simple formal statistical techniques and interpret the results.
- Criticise the whole process and the applicability of the conclusions, in the light of the practical situation and the actual data, discussing points such as: (sampling) bias, data quality, independence, explanatory variables, distributional assumptions, outliers, prediction.
- Suggest improvements to the design and analysis.

Leads to: ST217 Mathematical Statistics A & B.

Assessment: 30% on laboratory reports and 70% on a 2-hour open-book examination held at the end of the Autumn Term (Week 10).

Lecturers: David Croydon/Adam Johansen

STATISTICS	**ST105**	**7.5 CATS**
Term 1 or 2	**Essay or Project**	

Under the supervision of a member of staff in any one of the four departments: Mathematics, Business Studies, Economics or Statistics.

If you are interested in this option discuss it first with your personal tutor in the Autumn term.

STATISTICS	**ST108**	**7.5 CATS**
Terms 2 and 3	**Applications in Algebra & Analysis**	

Prerequisites: MA131 Analysis I and MA106 Linear Algebra.

Aims: This course aims to motivate and apply results from Algebra and Analysis in the study of difference equations (often arising from models of population growth) and to develop quantitative and qualitative methods to discover their solution, meeting relevant topics such as bifurcation and chaos theory along the way.

Objectives: Its objectives are that by the end of the course students will be able to:
- recognise various types of difference equations;
- illustrate the behaviour of the system using cobwebs;
- describe the equilibrium points;
- solve simple systems of difference equations by using matrix methods and by recognising the general form of the solution.

Assessment: 50% by tests and 50% by assessed exercises.

Lecturer: Heather Humphries

STATISTICS	**ST111**	**6 CATS**
Term 2	**Probability A**	

Prerequisites: MA132 Foundations, MA131 Analysis.

Content: This course is essential to all subjects concerned with uncertainty. It lays the foundation for statistical inference, prediction, and decision making. Consequently it is vital to real world problems.

Part A (Probabilities of events): interpretations, mathematical probability, combinatorics, series of trials, limiting frequencies.

Aims: This course aims to introduce the concept of probability as quantified uncertainty, to give a critique of the frequentist interpretation of probability and to provide the basic knowledge necessary to pursue further study in probability and statistics.

Objectives:

Part A (ST111)

- understand the concept of probability as a measure of uncertainty, and how considerations of symmetry enable simple classical problems to be solved.
- understand and be able to apply, in simple settings, basic results such as the addition law and Bayes Theorem.
- understand and be able to check and apply, in simple settings, the concept of independence of events.
- Understand Means and Variancies of discrete random variables.

STATISTICS	ST112	6 CATS
Term 2	**Probability B**	

Part B (Random variables): standard distributions, expectations, independence, variance and covariance, distribution of sums, generating functions, an introduction to continuous probability.

Objectives:

Part B (ST112)

- have acquired knowledge of the definition of a random variable and have met and manipulated some standard distributions.
- be able to calculate and manipulate expectations, covariances and generating functions.
- be able to manipulate standard continuous distributions.
- be able to apply the above in various settings.

Books: S. Ross, "A First Course in Probability" (4^{th} Ed.), Prentice Hall, 1994.
J. Pitman, "Probability" Springer Texts in Statistics.

Leads to: ST217 Mathematical Statistics A, ST202 Stochastic Processes and to numerous statistical, probabilistic, operational research and econometric courses. An understanding of probability is necessary for quantitative studies in all areas ranging from management, marketing, sociology and psychology through to engineering, medicine and scientific research.

Assessment: 10% by class tests and 90% by written examination.

Lecturers: Julia Brettschneider/Vassili Kolokoltsov

STATISTICS	ST113	7.5 CATS
Term 1	**Statistical Computing**	

Prerequisites: None

Commitment: 10 lectures, plus practical sessions.

Content: This course introduces some mathematically-oriented computer software and corresponding skills that help students make the jump from school to university-level mathematics and statistics.

Aims:

- To familiarise students with the use of appropriate computer technology for mathematics;

- To demonstrate the value and importance of expressing mathematical statements precisely when communicating.

Objectives: After completing the course, students should be able to do the following:
- Use a computer algebra system such as *Mathematica* or *Maple* to attack simple mathematical problems – algebraically, numerically and/or graphically.
- Use a system such as TeX or LaTeX to typeset reports with mathematical content.
- Demonstrate simple programming skills.

Assessment: 100% by assessment. One short project (20%) and one long practical assessment (80%).

Lecturer: Ewart Shaw

STATISTICS	ST114	7.5 CATS
Term 2	**Games and Decisions**	

Commitment: 20 lectures.

Content: Throughout their history, game and decision theories have used ideas from mathematics and probability to help understand, explain and direct human behaviour. This course introduces some of the less technical results in both of these disciplines. Ideas to be presented will include:
- The quantification of subjective belief through probability.
- The EMV decision rule.
- The quantification of subjective preferences.
- The concept of a rational opponent in a two player game.

As well as providing an insight into various applications of mathematical concepts, the course will inform students how, at least in simple problems, they might ensure that their own decision-making is coherent and rational.

Aims: To give an introduction into how the use of probabilistic and mathematical ideas can enhance decision making by providing a framework in which actions can be judged as sensible or irrational. Examples will be given both of games against nature and games against other rational opponents.

Objectives:
- The student will be taught some of the arguments underpinning the use of rationality and a definition of subjective probability.
- They will be taught how to use the simpler tools of decision analysis as a framework to discover sensible decision rules which balance quantified uncertainties and payoffs.
- The course will explain and illustrate some of the issues of rationality as they apply to games and techniques will be given which will enable the student to solve some simple zero sum games.

Assessment: 1.5 hour examination.

Lecturer: Adam Johansen

Modules are listed in alphabetical order

ECONOMICS	**EC204**	**30 CATS**
Terms 1 & 2	**Economics 2**	

Commitment: A total of 45 lectures and 16 tutorial meetings in the year.

Note: **This module is only available in Year 2.**

Academic aims: The module aims to enable students to develop a deeper understanding of economic concepts introduced in first–year analysis and to introduce new concepts in both micro and macroeconomic analysis. New concepts include the treatment of risk, asymmetric information, general equilibrium, welfare economics, rational expectations and time consistency. The module aims to introduce students to the analysis of public policy issues such as privatisation, regulation and counter-inflation policy.

Learning objectives: By the end of the module, the student will be expected to be familiar with a range of tools for the analysis of both micro and macroeconomic problems. The student will have a rigorous knowledge of the theoretical models which underlie economic analysis and an understanding of both the applicability and the limitations of particular models and approaches. The student will also be expected to have an understanding of how to evaluate both competing economic theories and empirical evidence.

Learning methods: The teaching process combines lectures and small group classes. Classes focus chiefly on exercise sheet problems but also involve ? The teaching process combines lectures and small group classes. Classes focus chiefly on exercise sheet problems but also involve student presentations and group work. The macro part of the module follows a consecutive building–block approach while the micro material is based more on specific topics and allows specialisation: although a good understanding of the analytical core of each element of the module is regarded as essential.

Syllabus:
Microeconomics (c.22 lectures): The analysis of consumer demand; including a focus on markets with asymmetric information. The analysis of production, cost, supply and input demand functions, with an emphasis on markets under oligopoly. The analysis of general equilibrium and welfare economics. Consideration of the economics of public policy issues such as privatisation and regulation. Game theoretic approaches to oligopoly, entry and other strategic areas in industrial and business economics. Economics of risk and uncertainty.
Macroeconomics (c.22 lectures): The unemployment-inflation relationship. The effect of monetary policy. Expectations, financial markets and the Macroeconomy. Political business cycles. The Time inconsistency problem. The open economy.

Illustrative reading:

Microeconomics
Katz, M. and Rosen, H.S., Microeconomics, 4th edition, McGraw-Hill.
Varian, H., Intermediate Microeconomics, W W Norton 5th edn, 1999.

Macroeconomics:
Blanchard, O. Macroeconomics, Prentice Hall, 4th edn.

Assessment methods: 2 x 2000 word essays (20%) and 3–hour examination (80%)

Module leader: Andres Carvajal

ECONOMICS	EC220/221	24 CATS
Terms 1 & 2	**Mathematical Economics 1a and 1b**	

Module leaders: *TBA*

Context: Refer to degree course regulations. Prerequisites: for non-economists, EC106 Introduction to Quantitative Economics.

Teaching format: Two lectures per week, one problem class per fortnight and one tutorial per fortnight.

Assessment methods: 3-hour exam (80%) 2 x tests (20%).

Academic aims:
Mathematical Economics 1a: "Introduction to Game Theory", aims to provide a basic understanding of pure game theory and also introduce the student to a number of applications of game theory to economic problems of resource allocation. Strategic, normative and bargaining approaches to resource allocation are treated.

Mathematical Economics 1b: "Models of Static and Dynamic Optimisation" provides some basic mathematical tools of static and dynamic optimisation and presents some applications in theory of incentives and in macroeconomic growth.

Learning objectives: Both game theory and general equilibrium theory involve deep analysis of relatively simple situations conducive to the advancement of the reasoning ability of students. Students will acquire a sense of the importance of strategic considerations in economic problem solving and the normative significance of competitive markets in obtaining Pareto optimal allocations via appropriate extensions of the commodity space. Students will learn that a few simple, intuitive principles, formulated precisely, can go a long way in understanding the fundamental aspects of many economic problems. Problem solving abilities and understanding of the concepts and methods will be tested in the exam.

Learning methods: The best way to study for this course is to read the text and attend lectures in preparation to working exercises. The best preparation is solving problems. To be able to do this, it is extremely helpful to prepare in advance for lectures by reading the relevant textbook material and by working at solving the problems in the text on that material. The classes are particularly important for students having any difficulty with the material and also to ensure that one is solving the assigned problems correctly

Syllabus: **Term 1 - Mathematical Economics 1a**

(i) Games in strategic form: Nash equilibria and its applications to voting games, oligopoly, provision of public goods.
(ii) Games in extensive form: sub game perfect equilibria and its applications to voting games, repeated games.
(iii) Static games with incomplete information: Bayesian equilibria and its applications to auctions, contracts and mechanism design.
(iv) Dynamic games of incomplete information: Perfect Bayesian equilibria, Sequential equilibria and its application to signalling games.
(v) Bargaining theory: Nash bargaining, non-cooperative bargaining with alternating offers and applications to economic markets.

Illustrative reading: **Mathematical Economics 1a**

Dutta, P.K. (1999): *Strategies and Games: Theory and Practice,* MIT Press.
And, for supplementary reading for the student seeking a deeper understanding,
Fudenberg and Tirole (1996) *Game Theory.*

Term 2: Mathematical Economics 1b

Status: **List B** for Maths.

Commitment: Two lectures per week, one problem class and one tutorial per fortnight.

Prerequisites: EC220 Mathematical Economics 1A

Content: Lectures shall develop the fundamental properties of competitive equilibrium: Existence, optimality and determinacy (i) in abstract economies, (ii) in economies over time and under uncertainty, and (iii) in economies with incomplete asset markets and/or particular demographic structures (overlapping generations), and their implications for monetary and fiscal policy.

Aims: ``Models of Static and Dynamic Optimisation" provides some basic mathematical tools of static and dynamic optimisation and presents some applications in theory of incentives and in macroeconomic growth.

Books:

Principal reference:

Mas-Colell, A., Whinstone, M. D., and Green, J. R. (1995), *Microeconomic Theory*, OUP. (Chapters 3 and 15-20)

Additional useful textbooks are:

For consumer theory:

Varian, H. (1992), *Microeconomic Analysis,* W. W. Norton.

For general equilibrium:

Bewley, T. F. (2007), *General Equilibrium Overlapping Generations Models and Optimal Growth Theory*, Harvard University Press.

Assessment: 3-hour examination (80%) and tests (20%) if taking both EC220 and EC221, else a 1.5 hour examination (80%) and one test (20%).

Lecturer: Pablo Becker

BUSINESS SCHOOL	IB109	24 CATS
Terms 1 & 2	**Foundations for Accounting & Finance**	

Restriction: You cannot take IB109 and the module ST335 Finance and Financial Reporting (which may lead to an actuarial exemption).
Note: **This module is only available in Year 2.** ***IB109 will be a pre-requisite for IB215 in 2010/11. Students who are intending to register for IB215 in 2010/11 need to study IB109 in 2009/10.***

Commitment: Two 1 hour lectures (starts in week 2) plus a 1 hour seminar each week.

Objectives: The module is designed to provide students with a broad introduction to accounting and finance, with a user's or manager's perspective rather than that of an accounts preparer or specialist.

On completion of the module students will be able to:
- understand the relation between the principal financial statements
- understand the major assumptions and limitations employed in conventional financial reporting
- forecast financial statements for simple cases and adjust financial statements for transactions
- understand the interpretation of financial statements, the analysis of profitability, of solvency and gearing
- understand cost behaviour and development of product costs under competing assumptions
- understand the construction and use of budgets inside organisations
- value investments and capital projects under the certainty case
- understand the trade-offs between risk and return
- understand the principles of valuation of basic instruments of debt and equity
- identify the issues in setting a rate of return and understand how this is influenced by borrowing policy.

Content: Balance sheets, profit & loss accounts and cash flow statements. Accounting conventions and creative accounting. Forecasting financial statements. Financial statement analysis. Cost behaviour. Cost tracing (direct & indirect). Product costing. Budgeting. Elements of finance.

Leads to: IB215 Principles of Finance.

Books: McLaney and Atrill, *Accounting: An Introduction*

Assessment: 1 x 2 hour exam (80%) 1 x 1 hour test (20%)

Lecturer: Simona Scarparo

BUSINESS SCHOOL	IB206	6 CATS
Term 3	**Introduction to Business Studies**	

Academic Rationale: Please ensure that you register for this module with the WBS Undergraduate Office as well as on OMR. If you are not registered correctly, you will not have access to all of the necessary web-based materials needed for the module. **This module is only available to 2nd year students**

Objectives: This module is intended as a general introduction to key disciplines in business and management.

Syllabus:
There are four main subject topics:-
- Marketing
- Human Resources
- Accounting & Finance
- Operations Management

Bibliography
There is no required text though students are advised to study a recommended text such as "Introduction to Management", Richard Pettinger, or "Mastering Basic Management, E C Eyre, MacMillan Master series. Additional materials, and some cases and exercises will be given out during the module. These will form the basis of the module for revision and assessment purposes.

Teaching
3 x 1-hour lectures per week for five weeks in Term 3.

Assessment: 2 hour Examination (100%) by multiple choice question paper.

Lecturer: Terni Abimbola

BUSINESS SCHOOL	IB207	12 CATS
Term 1	**Mathematical Programming II**	

Prerequisite: IB104 Mathematical Programming I

Commitment: 2 x 1 hour lectures per week/1 x 1 hour seminar per week..

Content: This module includes coverage of theoretical and practical aspects of mathematical programming. In particular it covers linear programming problems with integer variables; the branch and bound algorithm; dynamic programming; network optimisation including project management problems; stochastic linear programming; convex sets and functions and their role in optimisation; simple optimality conditions for non-linear programming problems; the use of spreadsheets for the solution of optimisation problems.

Objectives: On successful completion of this module, you will be able to:
- Identify the business problems that can be modelled using optimisation techniques and formulate them in a suitable mathematical form
- Apply optimisation techniques to the solution of the problems using spreadsheets and other appropriate software
- Report on the meaning of the optimal solution in a manner suited to a business context.

Leads to: IB352 Mathematical Programming III

Assessment: 2 hour open book exam + 15 minutes reading time (70%), assessed (30%).

Lecturer: Victor Podinovski

BUSINESS SCHOOL	IB211	12 CATS
Term 2	**Simulation**	

Restriction: **Students taking this module may not later take the third year course IB320 Simulation.**

Prerequisite: ST111/2 Probability & ST217 Mathematical Statistics A

Commitment: 8 x 2 hour lectures and 1 tutorial hour per week for students for 7 weeks.

Objectives: Simulation is one of the most commonly used operational research methods for analysing complex operational/ industrial problems. This course will focus on discrete event simulation. Students will learn the theoretical underpinnings of the methods and the range of applications for which they are useful. They will gain practical experience in problem solving using commercial simulation software.

The course assumes the student has covered some introductory courses in computer programming and statistics.

***Contents**:* Topics covered will be: introduction to simulation methods, the discrete-event simulation method, software for discrete-event simulation (with use of a specific package e.g. Simul8 or Witness), performing a simulation study (conceptual modelling, data collection and analysis, experimentation and verification and validation).

The tutorials provide the opportunity for supervised exercises and help students develop their own computer based simulation programmes.

***Books**:* Robinson, S. (2003), Simulation: The Practice of Model Development and Use, Wiley

***Assessment*:** Assessed 100%.

Lecturer: Ruth Davies

BUSINESS SCHOOL	IB3A7	12 CATS
Term 2	**The Practice of Operational Research**	

Note: Students can take IB3A7 The Practice of Operational Research in their second or third years.

***Commitment**:* 9x1 lectures. 9x1 seminars/tutorials

***Academic Rationale*:** The module covers the theoretical frameworks and craft processes associated with the conduction of operational research (OR) studies in organisations. While other OR modules generally provide specific technical capabilities, this module supplies the general approaches and skills necessary to use these techniques effectively in organizational interventions.

***Objectives**:* On successful completion of the module, students will be able to:
- Understand the nature of OR studies and the practical issues involved in developing OR models
- Recognise the importance of the problem structuring skills required in conducting OR studies.
- Formulate, test and validate OR models.
- Conduct interviews using problem structuring methods.
- Appreciate a range of modelling approaches and the circumstances in which they might be applied.

***Contents**:*
- The nature and methods of operational research (OR).
- Models and modelling in OR studies.
- Issues in problem structuring and data collection.
- OR model validation and verification.

Books: Daellenbach, H.G. and McNickle D.C. (2005). Management Science: decision making through systems thinking, Basingstoke: Palgrave MacMillan; Mitchell, G. (1993) The Practice of Operational Research, Chichester: Wiley; Pidd, M. (2003) Tools for Thinking: modelling in Management Science (2nd ed.), Chichester: Wiley; Rivett, B.H.P. (1994) The Craft of Decision Modelling, Chichester: Wiley; Rosenhead, J. and Mingers, J. (2001) Rational Analysis for a Problematic World Revisited: problem structuring methods for complexity, uncertainty and conflict (2nd ed.), Chichester: Wiley.

A reading pack will be provided.

Assessment: A 3-hour, open book, partly seen, examination comprising:
Part A: 40 marks based on a modelling case study given out two weeks before the examination date.
Part B: 60 marks based on the material covered during the lectures and seminars.

Lecturer: Giles Hindle

MATHEMATICS	MA209	6 CATS
Term 3	Variational Principles	

Commitment: 15 lectures

Prerequisite: MA131 Analysis, MA225 Differentiation is also helpful and a module on differential equations.

Aims: To introduce the calculus of variations and to see how central it is to the formulation and understanding of physical laws.

Objectives: To show you how to set up and solve minimisation problems with and without constraints, to derive Euler-Lagrange equations and to have you appreciate how the laws of mechanics fit in this framework.

Content: This module consists of a study of the mathematical techniques of variational methods, with applications to problems in physics and geometry. Critical point theory for functionals in finite dimensions is developed and extended to variational problems. The basic problem in the calculus of variations for continuous systems is to minimise the integral

$$I(y)=\int_a^b f(x,y,y_x)\,dx$$

on a suitable set of differentiable functions $y:[a,b]\to \mathbf{R}$. The Euler-Lagrange theory for this problem is developed and applied to dynamical systems (Hamiltonian mechanics and the least action principle), shortest time (path of light rays and Fermat's principle), shortest length and smallest area problems in geometry. The theory is extended to constrained variational problems using Lagrange multipliers.

Books: A useful introduction is: R Weinstock, *Calculus of Variations with Applications to Physics and Engineering*, Dover, 1974.
Other useful texts are: F Hildebrand, *Methods of Applied Mathematics* (2^{nd} ed), Prentice Hall, 1965. IM Gelfand & SV Fomin. *Calculations of Variations*, Prentice Hall, 1963.
The module will not, however, follow the syllabus of any book.
Assessment: One-hour examination.

Lecturer: John Rawnsley

MATHEMATICS	**MA222**	**12 CATS**
Term 2	**Metric Spaces**	

Commitment: Read the set book: W A Sutherland*, Introduction to Metric and Topological Spaces*, OUP (chs 1-9); 10 support lectures; homework exercises.

Prerequisite: MA132 Foundations, MA131 Analysis and MA244 Analysis III.

Content: Roughly speaking, a metric space is any set provided with a sensible notion of the "distance" between points. The ways in which distance is measured and the sets involved may be very diverse. For example, the set could be the sphere, and we could measure distance either along great circles or along straight lines through the globe; or the set could be New York and we could measure distance "as the crow flies" or by counting blocks. Or the set might be the set of real valued continuous functions on the unit interval, in which case we could take as a measure of the distance between two functions either the maximum of their difference, or alternatively its "root mean square".

This module examines how the important concepts introduced in first year analysis, such as convergence of sequences, continuity of functions, completeness, etc, can be extended to general metric spaces. Applying these ideas we will be able to prove some powerful and important results, used in many parts of mathematics. For example, a continuous real-valued function on a **compact** metric space must be bounded. And such a function on a **connected** metric space cannot take both positive and negative values without also taking the value zero. Continuity is readily described in terms of open subsets, which leads us naturally to study the above concepts also in the more general context of a topological space, where, instead of a distance, it is declared which subsets are open.

Aim: To introduce the theory of metric and topological spaces; to show how the theory and concepts grow naturally from problems and examples.

Objectives: To be able to give examples which show that metric spaces are more general than Euclidean spaces, and that topological spaces are yet more general than metric spaces. To be able to work with continuous functions, and to recognise whether spaces are connected, compact or complete. To know the definition of the quotient topology and to be able to work with it in simple cases like projective space.

Leads to: The module is a vital prerequisite for most later (especially Pure) Mathematics modules, including MA3F1 Introduction to Topology, MA3D9 Geometry of Curves and Surfaces, MA3F4 Linear Analysis, MA359 Measure Theory, MA3B8 Complex Analysis, MA371 Qualitative Theory of ODEs, MA3G1 Theory of PDEs, MA424 Dynamical Systems, MA475 Riemann Surfaces, MA4E0 Lie Groups.

Books: The set text is W A Sutherland, *Introduction to Metric and Topological Spaces*, OUP. You will need your own copy (or a half share in one) from day 1.
Other books worth consulting:
E T Copson, *Metric Spaces*, CUP.; W Rudin, *Principles of Mathematical Analysis*, McGraw Hill;. G W Simmons, *Introduction to Topology and Modern Analysis*, McGraw Hill. (More advanced, although it starts at the beginning; helpful for several third year and MMath modules in analysis). A M Gleason, *Fundamentals of Abstract Analysis*, Jones and Bartlett. D Epstein, Metric Spaces Lecture Notes, 1999--2000, Mathstuff.

Assessment: Examination 85%, assignments and class tests 15%.

Lecturer: David Preiss

MATHEMATICS	**MA225**	**12 CATS**
Term 2	**Differentiation**	

Commitment: Three one-hour lectures per week.

Prerequisites: MA131 Analysis I, MA244 Analysis III.

Content: There are many situations in maths where one has to consider the continuity and differentiability of a function $f:R^m \rightarrow R^n$ (e.g., the determinant of an *n x n* matrix as a function of its entries, or the wind velocity as a function of space and time). The derivative is interpreted as a linear transformation, or matrix, and basic properties which generalise those of ordinary calculus are established, including finding maxima and minima and Taylor expansions. The inverse and implicit function theorems are proved---these have many applications in both geometry and the study of solutions of nonlinear equations.

We will also study norms on infinite dimensional vector spaces and some applications.

Aims :
- To extend the results on differentiation of functions of 1-variable to functions between higher dimensional linear spaces.
- To develop the theory of the derivative as a linear map and study its relationship with partial derivatives.
- To introduce the basic theory of normed vector spaces as needed for this theory and to provide a basis for later modules.
- To show how different branches of mathematics, in this instance linear algebra and analysis, combine to give an aesthetically satisfying and powerful theory.
- To encourage self-motivated study of mathematics.

Objectives: At the end of this module the student should have a basic working knowledge of higher dimensional calculus. The student should understand this is in the context of normed spaces and appreciate the role this level of abstraction plays in the theory. They should understand basic linear analysis to the extent of being able to follow it up in the relevant third year modules. They should also be in a position to make use of more advanced textbooks if they wish to go further into these theories.

Books*:* J Marsden and A Tromba, *Vector Calculus*, McGraw Hill. T Apostol, *Mathematical Analysis*, Addison-Wesley
W Rudin, *Principles of Mathematical Analysis*, McGraw Hill M Spivak, *Calculus on manifolds,* Benjamin Cummings

Assessment*:* Two-hour examination.

Lecturer: Vassili Gelfreich

MATHEMATICS	**MA228**	**6 CATS**
Term 2 (weeks 1-5)	**Numerical Analysis**	

Commitment: 15 lectures and 3 or 4 computing exercises.

Prerequisite*:* Calculus; Linear Algebra; Familiarity with C++ or Java

Updated information on this course is given at
http://www.maths.warwick.ac.uk/~mak/Lecture0304_NET.html

Content: This module focuses on basic numerical methods for problems arising in mathematics and the physical sciences. Through selected examples such as multi-dimensional zero-finding and the solution of ordinary differential equations, the important concepts of iteration, convergence, cost, accuracy and stability will be covered.

Aims: To introduce the numerical methods used in tackling mathematical equations which do not yield to exact forms of analysis.

Objectives:
- To learn how computers represent numbers and what kind of errors this representation can involve.
- To understand iterative methods through the techniques for finding roots of nonlinear equations.
- To understand convergence through techniques for solving ordinary differential equations.
- To be able to write a computer program to implement the methods covered in the module.

Books: The lectures will follow relatively closely the book by Burden & Faires (see below) and cover material from chapters 1-5.

WH Press, BP Flanney, SA Teukolsky & WT Vetterling, *Numerical Recipes*, CUP.
KE Atkinson, *Introduction to Numerical Analysis*, Wiley.
RL Burden & JD Faires, *Numerical Analysis*, Wadsworth.

Assessment: By reports from computing exercises.

Lecturer: Xinyu He

MATHEMATICS	**MA231**	**12 CATS**
Term 1	**Vector Analysis**	

Commitment: 30 one-hour lectures

Prerequisite: MA134 Geometry and Motion or PX129 (Maths/Physics) Worksheets

Contents: The first part of the module provides an introduction to vector calculus which is an essential toolkit for differential geometry and for mathematical modelling. After a brief review of line and surface integrals, div, grad and curl are introduced and followed by the two main results, namely, Gauss' Divergence Theorem and Stokes' Theorem. These theorems will be proved only in simple cases; complete proofs are best deferred until one has learned about manifolds and differential forms. The usefulness of these results in applications to flow problems and to the representation of vector fields with special properties by means of potentials will be emphasised. This leads to Laplace's and Poisson's equations which will be discussed briefly. The solution of these equations are discussed more fully in modules on partial differential equations. Cartesian co-ordinates are in many cases not well suited to a particular problem: for example, polar co-ordinates yield simpler equations for the flow of water in a cylindrical pipe. We will show how to represent div, grad and curl in general curvilinear co-ordinates, paying particular attention to spherical and cylindrical geometries.

The second part of the module introduces the rudiments of complex analysis leading up to the calculus of residues. The link with the first part of the module is achieved by considering a complex valued function of one complex variable as a vector field in the plane. This idea is particularly useful in the study of two-dimensional fluid flow. Complex differentiability leads to the Cauchy-Riemann equations which are interpreted as conditions for the vector field to have both zero divergence and zero curl. Cauchy's theorem for complex differentiable functions is then established by means of the main integral theorems of vector calculus. Cauchy's integral formula which expresses the value of a complex differentiable function at a point as a line integral of the function on a contour surrounding the point is the key result from which the stunning properties of complex differentiable functions follow.

Aim: This module aims to:
- Teach a practical ability to work with functions of two or three variables and vector fields;
- Present the theorems of Gauss and Stokes as generalisations of the fundamental theorem of calculus to higher dimensions;
- Establish Cauchy's theorem in complex analysis as a consequence of the Cauchy-Riemann equations and the divergence theorems;
- Teach those rudiments of complex analysis which follow from Cauchy's theorem, namely, the Cauchy integral formula, Taylor expansions and residue calculus.

Objectives: On successful completion of this module, a student should:
- Be able to calculate line, surface and volume integrals in general curvilinear coordinates;
- Be familiar with and use in a variety of contexts the fundamental results of vector calculus, namely, the divergence theorem and Stokes' theorem;
- Understand the relation between the existence of a scalar or vector potential of a vector field and the vanishing of the curl or divergence of that vector field and be able to calculate the potential when it exists,
- Be able to establish the Cauchy-Riemann equations for a complex differentiable function and establish Cauchy's theorem from the integral theorems of vector calculus;
- Be able to prove Cauchy's integral formula from Cauchy's theorem, and to use the integral formula to establish differentiability and series properties of complex differentiable functions;
- Be able to calculate Taylor expansions, residues and use them in the evaluation of definite integrals and summation of series.

Leads to:
- MA3D1 Fluid Dynamics,
- MA3G1 Theory of PDEs,
- MA3D9 Geometry of Curves and Surfaces,
- MA3B8 Complex Analysis
- MA390 Topics in Mathematical Biology,
- Various 400 level courses.

Books: There are a huge number of books that cover Vector and Complex Analysis at roughly the right level for this course. Comments on a selection of books that are useful for this module will be distributed at the first lecture and posted on the http://www.warwick.ac.uk/MathStuff/2ndyear/MA231/>}Mathstuff\html website for this module.

Assessment: 2-hour examination (90%) and coursework (10%)

Lecturer: Bas Lemmens

MATHEMATICS	**MA240**	**12 CATS**
Term 1 - 2	**Modelling Nature's Nonlinearity**	
(6-10 & 1-5)		

***Commitment*:** 30 one-hour lectures.

***Prerequisites*:** This module leads on directly from MA132 Differential Equations. For those students who took only MA113 Differential Equations A in their first year, you should still be able to follow the module but are *strongly* encouraged to do some background reading. I will assume at least a rudimentary memory of coupled linear differential equations and competence with linear second order differential equations. A good book is James Robinson's ``*An Introduction to Ordinary Differential Equations*''.

***Content*:** This module is designed to be a gentle introduction to the area of non-linear dynamical systems by way of its application to the ``Natural World''. Some quite deep ideas are introduced to help explain or describe natural phenomena such as evolutionary theory, species diversity, weather forecasting, animal locomotion and epidemics. The mathematics considered will cover the full spectrum of nonlinear dynamical systems theory including game theory, nonlinear oscillations, symmetry, sensitive dependence upon initial conditions (chaos) and (if time permits) fractals. In many cases these ideas are introduced outside of a rigorous setting so that the beauty and power of the techniques can be explored. There will be occasional reference to numerical solutions of some problems, and some of the assessed work may require use of a computer, but no previous experience (or love) of computing will be assumed.

***Aims*:** To provide a general introduction to the many aspects of dynamical systems theory through its application to the ``Natural World''.

***Objectives*:** At the end of the module you should be familiar with the ideas of stable/unstable equilibria and periodic orbits, strange attractors, Poincaré maps, bifurcations, catastrophes, nonlinear oscillations, chaos and fractals.

Leads to: Although not leading directly onto another course, this module should provide a useful introduction/motivation/complement to MA235 Introduction to Mathematical Biology.

***Books*:** There is no one textbook which adequately covers the whole module, but J.D. Murray, Mathematical Biology is recommended for many aspects. Other suggestions will be made during the course.

***Lecture Notes*:** Printed lecture notes for the module will be available, but these should be seen to complement the lectures rather than replace them since there will be additional material (including examples) covered during lectures. This additional material will almost certainly form the basis of a significant amount of the assessments.

***Assessment*:** The module is 100% assessed, through two assessments and what has on many previous years proved to be a popular mini project. Expect the assessments to be quite demanding, and make sure that you understand the university rules on plagiarism. In previous years there have been some harsh penalties imposed for breach of these regulations. Ignorance is not an excuse.

***Lecturer*:** Dave Wood.

MATHEMATICS	**MA243**	**12 CATS**
Term 1	**Geometry**	

Commitment: 30 lectures plus weekly worksheets

Prerequisite: None, but an understanding of MA125 Introduction to Geometry will be helpful.

Content: Geometry is the attempt to understand and describe the world around us and all that is in it; it is the central activity in many branches of math and physics, and offers a whole range of views on the nature and meaning of the universe.

Klein's Erlangen program describes geometry as the study of properties invariant under a group of transformations. Affine and projective geometries consider properties such as collinearity of points, and the typical group is the full *n x n* square matrix group. Metric geometries, such as Euclidean geometry and hyperbolic geometry (the non-Euclidean geometry of Gauss, Lobachevsky and Bolyai) include the property of distance between two points, and the typical group is the group of rigid motions (isometries or congruencies) of 3-space. The study of the group of motions throws light on the chosen model of the world.

The module includes a diversity of topics, such as the rules of life and self-consistency of the non-Euclidean world, symmetries of bodies both Euclidean and otherwise, tilings of Escher and the regular solids, and the geometric rules of perspective in photography and art.

Aims: To introduce students to various interesting geometries via explicit examples; to emphasise the importance of the algebraic concept of group in the geometric framework; to illustrate the historical development of a mathematical subject by the discussion of parallelism.

Objectives: Students at the end of the module should be able to give a full analysis of Euclidean geometry; discuss the geometry of the sphere and the hyperbolic plane; compare the different geometries in terms of their metric properties, trigonometry and parallels; concentrate on the abstract properties of lines and their incidence relation, leading to the idea of affine and projective geometry.

Leads to: MA3D9 Geometry of Curves and Surfaces, MA4E0 Lie Groups, MA473 Reflection Groups.

Books: M. Reid, *Geometry and Topology*, chapters of forthcoming textbook, available from General
Office. E G Rees, *Notes on Geometry*, Springer. HSM Coxeter, *Introduction to Geometry*, John Wiley & Sons.

Assessment: The weekly worksheets carry 15% assessed credit; the remaining 85% credit by 2-hour examination.

Lecturer: Diane Maclagan

MATHEMATICS	MA244	12 CATS
Term 1	**Analysis III**	

This module will be examined in the first week of Term 3

***Commitment*:** 30 lectures.

***Prerequisites*:** MA131 Analysis, MA106 Linear Algebra.

***Content*:** This covers three topics: (1) integration, (2) convergence of sequences and series of functions, (3) Norms.

The idea behind integration is to compute the area under a curve. The fundamental theorem of calculus gives the precise relation between integration and differentiation. However, integration involves taking a limit, and the deeper properties of integration require a precise and careful analysis of this limiting process. This module proves that every continuous function can be integrated, and proves the fundamental theorem of calculus. It also discusses how integration can be applied to define some of the basic functions of analysis and to establish their fundamental properties.

Many functions can be written as limits of sequences of simpler functions (or as sums of series): thus a power series is a limit of polynomials. The second part of the module develops methods for deciding when a function defined as the limit of a sequence of other functions is continuous, differentiable, integrable, and for differentiating and integrating this limit. Norms are used at several stages and finally applied to show that a Differential Equation has a solution.

***Aims*:**
- To develop a good working knowledge of the construction of the integral of regulated functions;
- to study the continuity, differentiability and integral of the limit of a uniformly convergent sequence of functions;
- to use the concept of norm in a vector space to discuss convergence and continuity there.

***Objectives*:**
- Understand the need for a rigorous theory of integration, and that this can be developed for regulated functions by approximating the area under the graph by rectangles;
- understand uniform and pointwise convergence of functions together with properties of the limit function;
- be able to prove the main results of integration: any continuous function can be integrated on a bounded interval and the Fundamental Theorem of Calculus;
- prove and apply the Contraction Mapping Theorem.

Leads to: MA222 Metric Spaces, MA225 Differentiation, MA359 Measure Theory, MA3F4 Linear Analysis and MA3G1 Theory of PDE's.

***Books*:** No book covers the module although the MathSoc Revision Guide is recommended. A list of books to consult is given on Mathstuff.

***Assessment*:** Two-hour examination (85%)( ), assignments (15%).

***Lecturer*:** Anthony Manning

MATHEMATICS	**MA246**	**6 CATS**
Term 3	**Number Theory**	

Status: **Students may take this module in Years 1 and 2 only. *It is NOT available as an unusual option in Years 3 and 4.***

Commitment: There are five workbooks for this course. Each contains notes, examples and questions. Solutions to the questions are available on Mathstuff. You are expected to study the workbooks on your own, or with the help of friends. The workbooks are self-contained, but you may also wish to refer to the recommended texts. There will be a single organisational lecture at the start of Term 3 (the only lecture for this module). Workbooks 1 - 4 will each be examined by a 50-minute test held once a week in the first half of term 3. Arrangements for these tests and details of a support forum will be announced at the lecture.

Prerequisites: MA132 Foundations, MA106 Linear Algebra; second year Algebra courses are also useful in understanding the material. First-year students should be able to tackle the module if they are prepared to do a little reading around some of the topics (and if they are convinced it will not interfere unduly with their revision for other examinations).

Content:

Workbook 1 The arithmetic of congruence classes, solving linear congruences, the multiplicative structure of $\mathbb{Z}_n$(Euler's Theorem and Fermat's Little Theorem).

Workbook 2 Primitive roots and finite logarithms, Euler's phi-function, decimal representation of rational numbers.

Workbook 3 The greatest integer function, de Polignac's formula, standard multiplicative functions, perfect numbers and Mersenne primes, Möbius's function and inversion formula.

Workbook 4 Finite continued fractions and Euclid's algorithm, infinite continued fractions for irrational numbers.

Workbook 5 Periodic continued fractions, Pell's equation.

Aims:

- To introduce students to the delights of elementary number theory.
- To encourage independent study through using specially-prepared workbooks which develop abstract theory through sequences of concrete exercises, problems, and calculations.

Objectives:

- To give students an easy facility with modular arithmetic, continued fractions, and the elementary functions of number theory; in particular, to develop their ability to do serious calculations with these objects.
- To stress the role of problem-solving in developing mathematical understanding.
- To stimulate the use of pocket calculators in investigative mathematics (but note that calculators will not be needed and will not be allowed in the examination).
- To provide an incentive for cooperative study.

Leads to: MA3D5 Galois Theory, MA426 Elliptic Curves.

Books:

Prices are from amazon.co.uk (2006) where available.

First Choice: Harry Davenport, *The Higher Arithmetic*, 7th Edn. (CUP, 1999), ISBN 0521634466, £20.69.

A Problems-Based Approach R.P. Burn, *A Pathway into Number Theory* (CUP, 2nd edition, 1997), ISBN 0521575400, £23.99.

Also Recommended: Joseph Silverman, *A Friendly Introduction to Number Theory* (Prentice-Hall, 2nd edition, 2001), ISBN 0130309540, £40.99.

Also Recommended: James J. Tattersall, *Elementary Number Theory in Nine Chapters* (CUP, 1999), ISBN 0521585317, £5.99 + postage.

The Classic: G.H.Hardy & E.M.Wright, *An Introduction to the Theory of Numbers* (OUP, 1980), ISBN 0198531710, £30.40.

A Number Theorist's World View: G.H.Hardy, *A Mathematician's Apology* (CUP, 1992), ISBN 0521427061, £11.99.

Assessment: Four weekly tests plus a 90-minute final examination. Your combined score for the tests, which will be calculated from your best 3 results out of 4, contributes 25% to your module mark. The final examination makes up the remaining 75% of the module credit.

Lecturer: Trevor Hawkes

MATHEMATICS	MA249	12 CATS
Term 2	Algebra II: Groups and Rings	

Commitment: 30 lectures.

Prerequisite: First year MA132 Foundations, MA106 Linear Algebra, and MA242 Algebra I

Content: This is an introductory abstract algebra module. Abstract algebra is a bit like solfeggio. The latter is an abstract language that is served to preserve and communicate beautiful music. The former is an abstract language to preserve and communicate beautiful mathematics. And both require an essential mental effort to learn.

As the title suggests, the two main objects of the study are groups and rings. You already know that a group is a set with one binary operation. But you have also seen examples of rings which are sets with two binary operations. The most notable example is the set of integers with addition and multiplication. We will develop the theories of groups and rings. Theorems discussed include the Orbit-Stabiliser Theorem, the Chinese Remainder Theorem, and Gauss' theorem on unique factorisation in polynomial rings. We will also enjoy some beautiful mathematics by seeing examples and applications such as RSA, game 15 and, maybe, the discrete Fourier transform.

Aims: To study abstract algebraic, their examples and applications.

Objectives: By the end of the module the student should know several results about groups and rings as well as be able to manipulate with them.

***Leads to*:** The results of this module are used in several modules including: MA377 Rings and Modules, MA453 Lie Algebras, MA362 Non-commutative Rings, MA3D5 Galois Theory, MA3E1 Group and Representations and MA3G0 Modern Control Theory

***Books*:** This is a new module, so a printed study guide will be available from the general office toward the end of the Spring term.

The study guide will be updated during the term and will be available online at

www.maths.warwick.ac.uk/~rumynin

The only recommended book is:
Niels Lauritzen, *Concrete Abstract Algebra*, Cambridge University Press.
You should seriously consider buying it for a number of reasons including:

- it is relatively cheap: £22 for the paperback on Amazon or £6 on the Amazon marketplace;
- it will be the only book I will use to prepare lectures (disclaimer: I can use my head, so not everything in the course will be in the book);
- it will be used as a source of exercises.

***Assessment*:** Three example sheets will be assessed and are worth 5% each. Optional support classes are available. The two-hour examination in June is worth 85%.

***Lecturer*:** Dmitriy Rumynin.

MATHEMATICS	**MA250**	**12 CATS**
Term 2	**PDE**	

***Commitment*:** 30 lectures.

***Prerequisites*:** MA131 Analysis, MA244 Analysis III, MA113 Differential Equations, , , MA231 Vector Analysis.

***Content*:** The theory of partial differential equations (PDE) is important both in pure and applied mathematics. On the one hand they are used to mathematically formulate many phenomena from the natural sciences (electromagnetism, Maxwell's equations) or social sciences (financial markets, Black-Scholes model). On the other hand since the pioneering works on surfaces and manifolds by Gauss and Riemann partial differential equations have been at the centre of many important mathematical developments (geometry, Poincaré-conjecture).

In this module I will classify the most important equations and discuss the qualitative behaviour of the solutions. I will develop several approaches to construct solutions: Method of characteristics, Green's functions and Fourier series to solve the classical equations

1. Laplace equation (elliptic),
2. Heat equation (parabolic),
3. Wave equation (hyperbolic).

The module will build upon the Analysis courses, Vector Analysis and Differential Equations. In particular different notions of convergence of a sequence of functions will be discussed, and an introduction to the theory of Fourier-series will be given.

Aims: To introduce the basic phenomenology of partial differential equations and their solutions. To construct solutions using classical methods.

Objectives: At the end of the course you will be able to classify partial differential equations and know which types of boundary conditions can be used. You will understand that the solutions of PDEs depend in a very sensitive way on the type of the equation and you will be able to solve the most important equations.

Leads to: MA3G1 Theory of Partial Differential Equations, MA4A2 Advanced PDEs, MA4A7 Quantum Mechanics of Atoms and Molecules, MA433 Fourier Analysis and MA592 Topics in PDE.

Books: W. Strauss *Partial Differential Equations. An introduction.* John Wiley (1992).
M. Renardy and R.C. Rogers, *An introduction to partial differential equations*, Springer TAM 13 (2004).

Assessment: 2 hour exam.

Lecturer: Jose Luis Rodrigo

MATHEMATICS	**MA251**	**12 CATS**
Term 1	**Algebra 1: Advanced Linear Algebra**	

Commitment*:* 30 one-hour lectures plus six assignments

Prerequisite: MA132 Foundations and MA106 Linear Algebra.

This module will be examined in the first week of Term 3.

Content: This module is a continuation of First Year Linear Algebra. In that course we studied conditions under which a matrix is similar to a diagonal matrix, but we did not develop methods for testing whether two general matrices are similar. Our first aim is to fill this gap for matrices over **C**. Not all matrices are similar to a diagonal matrix, but they are all similar to one in *Jordan canonical form*; that is, to a matrix which is almost diagonal, but may have some entries equal to 1 on the superdiagonal.

We next study quadratic forms. A *quadratic form* is a homogeneous quadratic expression $\Sigma a_y x_i x_j$ in several variables. Quadratic forms occur in geometry as the equation of a quadratic cone, or as the leading term of the equation of a plane conic or a quadric hypersurface. By a change of coordinates, we can always write *q(x)* in the *diagonal form* $\Sigma a_i x_i^2$. For a quadratic form over **R**, the number of positive or negative diagonal coefficients a_i is an invariant of the quadratic form which is very important in applications.

Finally, we study matrices over the integers **Z**, and investigate what happens when we restrict methods of linear algebra, such as elementary row and column operations, to operations over **Z**. This leads, perhaps unexpectedly, to a complete classification of finitely generated abelian groups.

Aims: To develop further and to continue the study of linear algebra, which was begun in Year 1.

To point out and briefly discuss applications of the techniques developed to other branches of mathematics, physics, etc.

Objectives**:** By the end of the module students should be familiar with: the theory and computation of the Jordan canonical form of matrices and linear maps; bilinear forms, quadratic forms, and choosing canonical bases for these; the theory and computation of the Smith normal form for matrices over the integers, and its application to finitely generated abelian groups.

Leads to**:** third year algebra modules, such as MA3D5 Galois Theory, MA377 Rings and modules. Some of the theory is also needed in MA371 Qualitative Theory of ODEs.

Books**:** P M Cohn, Algebra, Vol. 1, Wiley.

I N Herstein, Topics in Algebra, Wiley.

Neither is essential, but are a good idea if you are intending to study further algebra modules.

Assessment**:** Assignments 15%, two-hour examination 85% (**usually first week April**).

Lecturer**:** Derek Holt

STATISTICS	ST202	12 CATS
Term 1	**Stochastic Processes**	

Prerequisite: ST111 Probability A & B and MA131 Analysis

Content: Loosely speaking, a stochastic or random process is something which develops randomly in time. Only the simplest models will be considered in this course, namely those where the process moves by a sequence of jumps in discrete time steps. We will discuss: Markov chains, which use the idea of conditional probability to provide a flexible and widely applicable family of random processes; random walks, which serve as fundamental building blocks for constructing other processes as well as being important in their own right; and renewal theory, which studies processes which occasionally "begin all over again." Such processes are common tools in economics, biology, psychology and operations research, so they are very useful as well as attractive and interesting theories.
Aims: To introduce the idea of a stochastic process, and to show how simple probability and matrix theory can be used to build this notion into a beautiful and useful piece of applied mathematics.

Objectives: At the end of the course students will:
- understand the notion of a Markov chain, and how simple ideas of conditional probability and matrices can be used to give a thorough and effective account of discrete-time Markov chains;
- understand notions of long-time behaviour including transience, recurrence, and equilibrium;
- be able to apply these ideas to answer basic questions in several applied situations including genetics, branching processes and random walks.

Leads to**:** ST333 Applied Stochastic Processes.

Assessment*:* 95% by examination, 5% by coursework.

Lecturer: Larbi Alili

STATISTICS	ST204	6 or 12 CATS
Term	**Statistics Essay/Project**	

Under this course title, you may study a topic in Probability or Statistics which interests you. It might involve reading articles and/or books on a topic and then writing your own version of what you have learnt (essay). Or it may consist of doing some practical statistical analysis and writing up your findings (project). Your work will be done in conjunction with a member of staff who acts as your supervisor. If you are interested in this kind of option you should first discuss it with your Personal Tutor in the Autumn Term.

STATISTICS	ST208	12 CATS
Term 1	**Mathematical Methods**	

Prerequisites: MA106 Linear Algebra, MA131 Analysis, ST108 Applications of Algebra and Analysis

Aims: This is a course of techniques which are in everyday use in probability and statistics, and which are essential to a proper understanding of any second or third year course in these subjects. It will provide the mathematical background for optimization, convergence, regression and best approximation and to develop mathematical thinking.

Objectives: At the end of the course students will be familiar with and be able to apply the following concepts and techniques:

a) multivariate calculus; multiple integration, calculation of volumes, under surfaces; change of variable formule and Fubinis Theorem; partial derivatives, critical points and extrema; constrained optimization;
b) eigenvalues/eigenvectors; diagonalisation and Jordan normal form; characteristic polynormals; constant co-efficient differential equations; orthogonal bases and orthonormalisation; generalised Fourier co-efficients; quadratic forms; projections; Spectral Decomposition Theorem ;
c) metrics; open, closed and compact sets; convergence and continuity in metric spaces.

Books: Anton & Rorres, "Elementary linear Algebra", Sutherland, "An Introduction to Metric Spaces, Finney and Thomas, "Calculus".

Assessment: 80% by examination, 20% by coursework.

Lecturer: Heather Humphries

STATISTICS	ST213	12 CATS
Term 2	**Mathematics of Random Events**	

Imagine picking a real number *x* between 0 and 1 "at random" and with perfect accuracy, so that the probability that this number belongs to any interval within [0,1] is equal to the length of the interval. Can we compute the probability of x belonging to any subset to [0,1]?

To answer this question rigorously we need to develop a mathematical framework in which we can model the notion of picking a real number "at random". The mathematics we need, called measure theory, permeates through much of modern mathematics, probability and statistics. The aim of the module is to provide an introduction to this theory, concentrating on examples and applications.

Objectives: By the end of the course students will be able to:

- Use and understand the language of measure theory and probability.
- Compute the probabilities of complicated events using countable additivity.
- Understand the proper formulation of the notion of statistical independence.
- Understand the basic theory of integration, particularly as applied to expectation of random variables, and be able to compute expectations from first principles in simple cases.
- Understand and identify convergence in probability and almost sure convergence of sequences of random variables, and use and justify convergence in the computation of integrals and expectations.

Prerequisite: ST111 Probability A and MA131 Analysis.

Leads to**:** ST318 Probability Theory, MA359 Measure Theory.

Books: Williams, Probability with Martingales, C.U.P.
Pfeiffer, Concepts of Probability theory
Jacod and Protter, Probability Essentials

Assessment: 100% by 2 hour examination.

Lecturer: Sigurd Assing

STATISTICS	ST215	12 CATS
Term 2	**Forecasting and Control**	

Prerequisite: ST217 Mathematical Statistics, ST113 Statistical Computing.

Only available to students in the Department of Statistics.

Commitment: 3 lectures per week supplemented by practical classes.

Content: An introduction to the theory and application of linear regression. Introduction to time series forecasting: moving averages and exponentially weighted regression.

Aims: To introduce the ideas of linear regression, model diagnostics, model building and time series forecasting.

Objectives: At the end of the course, students will be familiar with:
- the use of SPLUS to do a simple regression;
- the idea of interactively building a statistical model by using graphs and model diagnostics;
- the ideas of trend and seasonality in time series.

***Leads to*:** ST404 Applied Statistical Modelling. Nearly all project work in the statistics department (apart from theoretical projects) will require the use of SPLUS. Knowledge of SPLUS is required for the third year of MMORSE.
Assessment: 100% by course work. There will be two assessments. The first deadline will be near the end of the Spring Term. The second deadline will allow time for students to complete the assessment during the first 2-3 weeks of the summer term.

Lecturer: Robin Reed

STATISTICS	ST217	12 CATS
Term 1	**Mathematical Statistics A**	**(of a 24 CATS module)**

Prerequisite: ST111 Probability A and ST112 Probability B.

Commitment: 3 lectures/week; 1 tutorial per fortnight will be offered. It is essential for students to prepare for and attend these tutorials as they form an important part of the learning process.
Students who do not make full use of the tutorials do not perform as well in the exam.

Content: ST217 is a key course for all students wishing to study statistics beyond the introductory level, and a prerequisite for all further statistics and econometrics courses.

The course develops the main ideas of mathematical statistics, with an emphasis on probabilistic inference and the basic concept of likelihood. Topics include empirical probability models, random variables and expectations, the Central Limit Theorem and applications, parametric statistical models and graphical methods, likelihood functions, estimation and asymptotic distributions, hypothesis testing and confidence intervals.

ST217A is strongly recommended also to students wishing to take operational research courses, quantitative business courses and any courses involving uncertainty, whether concerned with data analysis, forecasting, finance, system modelling, marketing, quality management or decision making. It is essential for students who wish to become actuaries and highly recommended to those who wish to gain exemption from professional accountancy statistical examinations.

Aims: To introduce the main ideas of mathematical statistics and how they are used in practical applications.

Objectives: To understand the concept of a statistical model. To understand, use and interpret the statistical methods discussed in the course.

***Leads to*:** ST217 Mathematical Statistics B, ST215 Forecasting and Control, ST301 Bayesian Statistics and Decision Theory, ST304 Time Series and Forecasting, ST305 Designed Experiments, ST323 Multivariate Statistics, ST404 Applied Statistical Modelling, ST329 Topics in Statistics, ST332 Medical Statistics, ST337 Bayesian Forecasting and intervention, ST405 Bayesian Forecasting and Intervention with Advanced Topics, ST414 Advanced Topics in Statistics, and all ST3** and ST4** modules which cover the actuarial syllabus. IB320 Simulation, IB321 Forecasting, EC3xx Econometrics courses, Post graduate MSc in Financial Mathematics, Institute of Actuaries paper CT3 (see Introduction).

Books: For both ST217A and B: G. Casella & R.L. Berger, "Statistical Inference", 2nd Ed. Duxbury. Also useful: D.S. Moore & G.P. McCabe, "Introduction to the Practice of Statistics", 4th Ed., 2002, Palgrave. M.H.DeGroot, M.J.Schervish, "Probability and Statistics", 3rd Ed., 2002, Addison-Wesley.

Assessment: 100% by examination **in January (Week 1 of Term 2).**

Lecturer: Jon Warren

STATISTICS	**ST217**	**12 CATS**
Term 2	**Mathematical Statistics B**	**(of a 24 CAT module)**

Prerequisite: ST217 Mathematical Statistics A .

Commitment: 3 lectures/week; 1 tutorial per fortnight will be offered. It is essential for students to attend these tutorials as they form an important part of the learning process. **Students who do not attend the tutorials do not perform as well in the exam.**

Content: This course builds on Mathematical Statistics A to study the interrelationships between unknown quantities, enabling better predictions and decisions. The main topics covered are: Bivariate and multivariate distributions, conditional expectations, the multivariate normal distribution, statistical concepts and techniques for multi-parameter models, the linear statistical model, inference for model parameters, residuals and the analysis of variance.

Aims: To review, expand and apply the ideas from ST217A (Mathematical Statistics A). In particular to analyse interrelationships between unknowns such as random variables, rather than just one unknown at a time.

Objectives: After completing this course, students should be able to do the following:

- Quote and prove important simple results such as properties of conditional expectations and variances, least squares estimates, and others related to the syllabus
- Know and understand more advanced results such as asymptotic properties of likelihood ratios, and some simple formulae appearing in multiple regression and analysis of variance
- Apply their knowledge to derive estimators, hypothesis tests etc. in unfamiliar situations
- Apply theoretical results when analysing data, and discuss the results obtained.

Books: G. Casella & R.L. Berger, "Statistical Inference", 2nd Ed., Duxbury. M.H.DeGroot, M.J.Schervish, "Probability and Statistics", 3rd Ed., 2002, Addison-Wesley. D.S. Moore & G.P. McCabe, "Introduction to the Practice of Statistics", 2nd Ed., W.H. Freeman.

Leads to: ST305 Designed Experiments, ST323 Multivariate Statistics, ST404 Applied Statistical Modelling, ST329 Topics in Statistics, ST332 Medical Statistics, ST337 Bayesian Forecasting and intervention, ST405 Bayesian Forecasting and Intervention with Advanced Topics, ST414 Advanced Topics in Statistics and all ST3** and ST4** modules which cover the actuarial syllabus. IB320 Simulation, IB321 Forecasting, EC306 Econometrics 2, other Econometrics courses, and Institute of Actuaries paper CT3 (see Introduction).

Assessment: 100% by examination in June

Lecturer: Barbel Finkenstadt

Students should be aware that ST217A & B can lead to an actuarial exemption if a combined mark of 60 is obtained.

Modules are listed in alphabetical order

ECONOMICS Terms 1 & 2	EC301 Mathematical Economics 2	15 or 30 CATS

Module leader:	Pablo Becker
Commitment:	2 × 50–minute lectures per week for first 7 weeks of each term 2 × 50–minute seminars per week for final 3 weeks of each term
Assessment:	30 CATS: Two assessed essays (22.5% each) AND 2 hour final exam (50%) 15 CATS: One assessed essay (45%) AND 1 hour final exam (50%) 5% seminar weighting.
Academic aims:	The module aims to introduce advanced topics in mathematical economics and applied game theory. The treatment builds on the foundation established in EC220. Topics covered vary from year to year with staff availability and student interest. They are likely to include some or all of variants and refinements of Nash equilibrium (Bayesian, sequential, correlated, perfect, etc equilibria); reputations; auction theory; mechanism design; principal-agent theory; games on networks; evolutionary game theory; and cooperative game theory (core and Shapley values). A major objective of this module is advancement of the logical reasoning abilities of the students through learning to recognise strategic aspects of economic problems, formulating appropriately simplified game-theoretic models, and solving these models using appropriate techniques. In the mechanism design and auction portions of the module, students will learn how to design games to overcome information and incentive obstacles to desirable outcomes and how to interpret constructively the nature and evolution of social and economic institutions. During the seminar portion, students will be expected to read and critically discuss basic papers relating to the chosen topic.
Learning objectives:	By the end of the module students will have an appreciation of the use and limitations of formal mathematical approaches to economic theory and applications and be familiar with the main results and open questions in the chosen areas. The seminar portion will strengthen skills in team working, the absorption and analysis of peer reviewed literature, conveying and interpreting this material to a critical audience and leading discussions around a technical topic. The project (for those students completing it) will teach them how to select a research area, review the relevant literature, design a research or review question and carry out and write up the results in a way that meets academic standards of style, scholarship, clarity and rigour.
Learning methods:	The module proceeds through lecturer–based overviews of theoretical material, backed up by student reading. Active in–class discussion is encouraged. The best way to prepare is to read the text *in advance* attend lectures (and *ask questions*) in addition to working exercises. During the seminars, groups of students present material based on suggested readings. These presentations can be synthetic (summarising the literature as regards a specific issue) or critical (developing a critical analysis of a seminal paper in light of subsequent research or a recent paper in light of

related or prior work). Presenters are expected to lead a discussion rather than deliver a lecture. Success in the module consists in being able to interpret economic problems in game–theoretic terms, solve specific non–cooperative games of incomplete information using appropriate solution concepts and design games to solve specific implementation problems. The best preparation is solving problems.

Students will be assessed by a combination of examination and coursework that requires them to demonstrate understanding of the mathematical models and analytic techniques, the applied issues (where relevant), and the contribution theory can make to practical problems.

Seminar participation is mandatory and counts for 5% of the overall mark. For students taking both halves of the module the assessed essay (project) can comprise two 2000-word essays (one for each part of the module) or a single 5000-word project (by agreement with the instructors). Topics must be approved in advance.

For students taking one half of the module the assessed essay (project) component comprises a 2000-word essay.

The coursework component consists of mandatory seminar participation (5%) and either a problem set or an original. A problem set can be substituted for either of the 2000 word essays.

Syllabus: The topics covered change from year to year. The academic year 2005/2006 topics were:

Term 1:

- Topics on incomplete information games (Refinements of Bayesian equilibrium: sequential, perfect Bayesian, intuitive and divine equilibria– especially in signalling and agency games).
- Auction theory and practice
- Cooperative games (Bargaining, core and Shapley value, applications)
- Seminar presentations (Auctions, Evolutionary games; Intellectual property rights, Network economics, Political games, Trust)

Term 2:

- Normal Form (Static Games) and Extensive Form games and Nash equilibria: Recap.
- Weaker (than Nash) Solution Concepts : Iterated Elimination of strictly/weakly dominated strategies, Rationalisability, Correlated Equilibria.
- Refinements of Nash equilibrium: Subgame Perfect Equilibria, Trembling hand perfection, proper equilibria.
- Critique of Equilibrium Theory – and Evolutionary Game Theory.
- Links with Nash equilibria and refinements.
- Dynamic Games.
- Markov Perfect Equilibrium.
- Adverse Selection and Moral Hazard: Incentives Theory.
- Seminar presentations

Illustrative reading:

Introductory:

R. Gibbons, *A Primer in Game Theory*, Prentice Hall
A. Mas-Collell, M. Whinston and J. Green, *Microeconomic Theory*, OUP
K. Binmore, *Fun and Games*, Houghton Mifflin
G. Romp, *Game Theory*
C. D. Aliprantis, S. K. Chakrabarti, *Games and Decision Making*, OUP, 2000
M. Osborne, *An Introduction to Game Theory*, OUP

Advanced:

D. Fudenberg and J. Tirole, *Game Theory*, MIT Press 1994
M. Osborne and A. Rubinstein, *A Course in Game Theory*, MIT Press
R. Myerson, Game Theory, Harvard Press

ECONOMICS	**EC306**	**30 CATS**
Terms 1 & 2	**Econometrics 2**	

Module leader Gianna Boero

Teaching format Two 1–hour lectures per week for 20 weeks, and 3 exercise classes a term.

Assessment methods Two assessments (20%) AND 3–hour examination (80%).

Academic aims The module will equip the student with the ability to undertake, understand, and critically assess empirical work in economics, with a view to enabling the student to use econometrics to catalogue and describe empirical regularities and test various propositions.

Learning objectives By the end of the module students will have learnt how to carry out empirical analyses using different types of economics data (panel, limited dependent variable, time series); how to interpret the results of such analyses; and will have acquired an ability to critically assess empirical papers.

Learning methods The first term teaches students how to analyze models for discrete, censored and truncated dependent variables where the range of the dependent variable is restricted in some way. The last part of the term focuses on the use of panel data. Matrix notation will be used for models where necessary. The second term focuses on techniques for the econometric analysis of economic and financial time series, covering issues related to non-stationarity, cointegration and time varying conditional volatility.

Understanding the material is of paramount importance, and the best way of doing that is by attempting the class exercises before the classes take place. You should follow the reading associated with each lecture to remain on top of the material, and to deepen and widen your knowledge.

Students will be assessed by a combination of examination and coursework in which they will be required to demonstrate understanding of the key concepts and acquired analytical skills, and the ability to comment critically on empirical regression results.

Syllabus	The first term of the course covers Maximum Likelihood estimation and specification tests, models with limited dependent variable models, and models based on panel data. The second term focuses on some issues and recent developments in the area of time series econometrics. This part of the module deals with issues related to non-stationarity and testing for unit roots; cointegration in single equations and in multivariate systems; error-correction models; vector autoregressive models (VARs); modelling and forecasting financial time series; ARCH and GARCH models. Knowledge of the contents of Econometrics I (EC226) or an equivalent module is assumed.
Illustrative reading	Verbeek, M., A *Guide to Modern Econometrics*, Wiley, 2000. Johnston, J and DiNardo, J (1997), *Econometric Methods*, 4th edn. An additional useful reference for term 2 is: Harris, R. D. and Sollis R., Applied time series modelling and forecasting, Wiley, 2003.

ECONOMICS	**EC312**	**30 CATS**
Terms 1 & 2	**International Economics**	

Module leader	Natalie Chen
Teaching format	50 lectures/classes in the first two terms
Assessment methods	One 2 assessed essays (20%) and 3-hour examination (80%)
Syllabus	The first term covers international macroeconomic theory and recent policy issues. The module examines national income accounting in an open economy and in particular the balance of payments, models of the inter-temporal approach to the current account, the foreign exchange market and the interaction between price levels and exchange rates in the long-run. Models of exchange rate determination with flexible prices (Monetary Model), fixed prices (Mundell-Fleming Model) and sticky prices (Overshooting Model) are also developed. We also examine in more detail the empirical literature on Purchasing Power Parity and on the analysis of trade flows (using the gravity equation framework) at the macroeconomic level. The second term focuses on the theory of international trade and trade policy. After a brief overview of world trade and its phenomenal growth in recent decades, we develop the classic models of trade theory and use them to address policy issues. The Ricardian theory of comparative advantage shows how a country may gain from trade. The Heckscher-Ohlin model allows us to understand the effect of international trade on income distribution. More recent trade models incorporate economies of scale, imperfect competition and product differentiation. We also consider the economic rationale behind labour migration and foreign direct investment by multinational corporations. Then the module turns to issues

of trade policy. We analyse the economic effects of tarrifs, antidumping duties and import quotas, combining the discussion with case studies, for example the Common Agricultural Policy of the European Union. We also examine why globalisation has been so controversial and how environmental and labour standards enter the debate. Finally, we try to explain why countries join international trade agreements and how the World Trade Organisation (WTO) settles international trade disputes.

Illustrative Reading

Copeland, L.S. (2008), *Exchange Rates and International Finance*, 5th edition, Pearson Education.

Krugman, P.R. and Obstfeld, M. (2008), *International Economics: Theory and Policy*, 8th edition, Addison-Wesley.

Feenstra, R.C. (2004), *Advanced International Trade: Theory and Evidence*, Princeton University Press

ECONOMICS — EC314 — 15 CATS
Term 1 — Topics in Economic Theory

Module leader Sushama Murty

Teaching format Two lectures per week for 10 weeks.

Assessment methods One 2000–word essay relating to that term's material (20%) AND 1.5–Hour final exam (80%).

Academic aims The module aims to introduce students to several related areas of active application of economic theory. The topics covered vary from year to year, but in recent years have concentrated on social choice and mechanism design, with the ultimate aim of bringing economic theory to bear on social problems and economic and policy mechanisms to address them.

Learning objectives The objective of the course is to give you an appreciation of the use, but also the limitations, of economic theory and its methods in understanding the chosen topics and analysing important social and economic problems.

Learning methods The course proceeds through lecturer–based overviews of theoretical material backed by student reading. Active in–class discussion and input to topic choice is encouraged. Students will be assessed by a combination of examination and coursework that requires them to demonstrate understanding of theoretical constructs, real–world issues and the contribution each can make to the other.

Syllabus:

Topic 1: Welfare Economics, Social Choice and Cost-Benefit Analysis

Positive economics tries to understand how the economy functions; what will happen if policy A is employed as opposed to policy B. Supposing that we understand what our choices are as well as their consequences, society needs to choose among its many options. This is the role of *normative economics*---to guide our thinking about how and why to make such choices. For example, there is some probability that the green-house effect will impact disastrously future generations. How much should current generations give up for certain to limit the possible damage to future ones? Given a certain amount of foreign aid to a developing region how much should be used for current consumption and how much for population control so that there will be fewer people to feed in the future with possibly better lives. How much should be invested in highway safety to save just one more life? More mundanely, was the policy that the brewers sell off large numbers of managed and/or owned pubs a good one? Traditional welfare economics takes the possible states of the economy as given and asks how one is to choose among them. Many possibilities will be considered beginning with the rejection of utilitarianism in the 30s and the various compensation tests that were proposed to replace it, most importantly the Boadway paradox. The failure of these compensation tests leads naturally to the study of Bergson-Samuelson social welfare functions to make choices among the many alternatives available. This part of the course entails understanding the first and second theorems of welfare economics and more generally the notion of Pareto efficiency. What is the origin of these social welfare functions? That is the question that is central to social choice theory. Here we study Arrow's impossibility theorem and the possibilities that arise when intra-personal comparisons of utility are permitted. This part of the course requires the understanding of a limited amount of symbolic logic which will be presented in the lectures. Although social choice theory may tell us how to make choices, for the most part, economists rely upon the tools of cost-benefit analysis. We will study these tools in order understand the ethics that are implicit in their use. More specifically we will show that when cost-benefit studies are internally consistent they are simply implementing a specific social welfare function without having explicitly admitted such an ethical choice.

Topic 2: Law and Economics

This part of the module discusses the economic approach to law. There are various topics covered under this heading, as the standard texts by Shavell, Katz and Cooter & Ulen discuss. The treatment here will be much less comprehensive and will develop three points of view. The first is the idea of *mechanism design* - in this view, legal structures constitute the 'rules of the game' for economic (or other rational) agents in society. The second is the *game theoretic* perspective, according to which the analysis of behaviour within legal and economic institutions can be understood by considering individuals' strategic interactions, taking account of their motivations (payoffs or incentives), powers of action (strategies) and information. The third is *contractarian* and considers the creation of legal institutions as a conscious activity of individuals. In this view, one can consider contract, civil and criminal law as follows: contract refers to the 'private law' created between contracting parties, civil law refers to the implicit social contract that binds people not to injure each other and criminal law refers to the explicit contract to which all citizens are bound. The lectures will not deal with criminal law.

Topic 3: Duality Theory in Microeconomics and some Applications

This part of the module covers modern duality theory in microeconomics and some of its numerous applications. In conventional microeconomic theory, the primitives of economic agents (such as the consumers' preferences or the producers' technologies) are defined over the primal space of the quantities of commodities. Economic agents are assumed to possess optimising natures (*e.g.,* consumers are assumed to maximise utility or minimise expenditure and producers are often assumed to maximise profits or minimise production costs). An axiomatic approach is then adopted to derive certain regular features about the behaviour of economic agents (*e.g.,* the law of demand in the theory of the consumer and the upward sloping supply curve in the theory of the firm). However, conducting these analyses in the primal space of quantities is computationally very demanding and tedious. Also, it may be less tractable for empirical purposes.

The basic premise of modern duality theory is the optimising behaviour of economic agents. Under certain conditions, this behaviour induces a nexus between the primal variables (such as the quantities demanded by the consumers and the quantities supplied by the firms) and the dual variables (such as the prices of commodities and consumer incomes.) This makes possible an equivalent representation of the primitives of economic agents (*e.g.,* the consumers' preferences and the producers' technologies) in the space of the dual variables. This proves to be extremely convenient when we exploit a very powerful result called the *envelope theorem.* By applying this result, we can derive effortlessly (by simply taking a few derivatives of appropriate functions) (i) many economic variables of interests (*e.g.,* the consumer demands, the producer supplies, indicators of consumer welfare, *etc.*) and (ii) the laws governing the way they respond to changes in other economic variables (*e.g.,* changes in prices, consumer incomes, government's tax policies, *etc.*)

Because of its simplicity, elegance, and intuitive appeal, modern duality theory has become a powerful tool of analyses in both theoretical and empirical works. It has widespread applications in all fields of economics. The applications that we will study may include those in (i) public economics (such as the theory of optimal taxation in second best worlds), (ii) the index number theory, (iii) the measurement of technical efficiency, growth, and productivity of firms, (iv) defining and deriving the correct notion of the elasticity of substitution in production*, etc.*

Illustrative reading In view of the eclectic nature of the course and the heavy emphasis on student–led learning, there are no set texts or reading for this course. Lecturers will supply lists of suggested reading to accompany their material.

ECONOMICS	EC333/EC334	15/30 CATS
Terms 1 and 2	**Topics in Financial Economics**	

Module leader Lei Zhang/Jonathan Cave

Context **Restrictions: Students who have taken IB215 are not permitted to take EC333, but can take EC334. You can only take EC334 if you have previously taken EC333 or IB215.**

Teaching format 2 lectures a week during the first two terms.

Assessment methods 2 assignments (20%) and one 3 hour exam (80%)

Academic aims The module aims to develop the general intellectual abilities in understanding the roles of capital markets, corporate policy and governance, and the causes for the financial crises. It also introduces the subject specific technical skills in finance and financial policy for firms.

Learning objectives By the end of the module students will have acquired basic understanding of the roles of the capital markets, corporate financial policy and corporate governance, how financial crises arise. They are also expected to demonstrate subject–specific technical skills in asset valuation and some simple game-theoretical models.

Learning methods It is important to possess the textbook, attend lectures regularly from the start, prepare for them as your tutor recommends, and follow the reading which is associated with each lecture and topic. Provided that you have already worked hard and acquired the module's necessary analytical core, there is some scope for selecting topics and specialising according to your personal interests. Students will be assessed by a combination of examination and coursework in which they will be required to demonstrate acquired analytical skills and historical and institutional knowledge.

Syllabus

Term 1 EC333
Introduction to Finance
International Finance

Term 2 EC334
Financial Theory and Corporate Financial Policy
Corporate Governance (including executive compensation) and corporate control (including takeovers).

Illustrative reading

Allen, F. and Gale, D. (1994) Financial Innovation ad Risk Sharing, MIT Press: London.
Allen, F. and Gale, D. (2000) Comparing Financial Systems, MIT Press: London.
Brealey, R.A., Myers, S.C. and Marcus, A.J. (1995) Fundamentals of Corporate Finance, New York: McGraw-Hill.
Copeland, T.E. and J. Fred Weston (1998), Financial Theory and Corporate Policy, 3rd edn. Reading MA: Addison-Wesley.
Cuthbertson, K. (1996) Quantitative Financial Economics, Stocks Bonds and Foreign Exchange, Chichester: Wiley.
Obstfelt, M. and Rogoff, K (1996) Foundations of International Macroeconomics, MIT Press: London.

BUSINESS SCHOOL	IB215	24/30 CATS
Term 1 & 2	**Principles of Finance**	

This module is no longer available to 2nd Year students. Students who are intending to register for IB215 in 2010/11 will need to study IB109 in 2009/10.

Commitment: Two 1-hour lectures plus one 1-hour seminar per week.

Objectives: The aim of this module is to teach the core theoretical ideas of Corporate Finance, and their applications to real-world corporate decision problems. On successful completion of this module, you will:

* Have been introduced to the workings of the financial markets.
* Be equipped with the skills and understanding to use quantitative tools for pricing stocks, bonds and derivatives, and for measuring risk and return.
* Be aware of key empirical tests of models for valuing financial instruments, and their implications.
* Have had structured opportunities to practise using the key tools and techniques of Financial Markets theory.
* Be critically aware of the key financial decisions taken by firms.
* Have developed a sound understanding of the main theories and models of Corporate Finance.
* Be aware of key empirical tests of models of Corporate Finance, and their implications.
* Have had structured opportunities to practise using the key tools and techniques of Corporate Finance.
* Be prepared for advanced undergraduate and postgraduate studies in Finance.

The topics covered in this module include:-

* Market Efficiency: Theory and empirical tests of Efficient Markets Hypothesis.
* Asset Valuation: Stocks, Bonds, Discounted Cash Flow techniques.
* Investor Preferences: Risk aversion, Expected utility.
* Portfolio Theory: Diversification and optimal asset allocation.
* Risk vs. Return: Capital Asset Pricing Model.
* Term Structure of interested rates: Spot rates, forward rates, expected future spot rates, Pure Expectations and Liquidity Preference hypotheses.
* Financial derivatives: Arbitrage-free futures pricing, binomial option pricing
* Cost of Capital: Weighted average of cost of equity and cost of debt in the presence of taxes.
* Risky debt: Valuation of risky debt using binomial option pricing. Effects of volatility.
* Capital Structure: Irrelevance propositions, taxes, costs of financial distress, agency costs, signalling.
* Payout Policy: Irrelevance proposition, taxes, transactions costs, signalling, agency effects. Share buy-backs as an alternative to dividends.
* Company valuation: Discounted cash-flow techniques, dividend growth models, P/E and other methods, growth opportunities.

* Mergers / Acquisitions: Vertical vs. horizontal mergers, motives for mergers, methods of financing mergers, merger process.
* Initial Public Offerings: IPO process, under-pricing, under-performance

***Books**:* Core Textbook: Ross S A, R W Westerfield, and J Jaffe Corporate Finance, Irwin McGraw-Hill, (7th Ed, 2005)
Recommended Textbook: TE Copeland, JF Weston, and Shastri Financial Theory and Corporate Policy, International Editiion, Addison-Wesley, (4th ed. 2005).
R.A. Brealey, S.C. Myers and F. Allen. Corporate Finance, 8th ed., McGraw-Hill (2006).

***Assessment**:* 1 x 3 hour Examination (80%) 2 x 1 hour Class Tests (20%) (To be held in, or near, first week of the Spring & Summer terms)

Lecturer: Peter Corvi

BUSINESS SCHOOL	IB312	15 CATS
Terms 1 & 2	**Project/Essay**	

This module is an option for MORSE and MMORSE students only. MathStats and MMathStats students may take this module as an unusual option.

***Commitment**:* 120 - 150 hours – 5,000 words (15 CATS)

Projects may be in Mathematical Programming or any other area of Operational Research or Information Systems by individual arrangement with OR/Systems staff. The student will prepare a brief statement of the work he or she wishes to undertake. This will be presented to the supervisor for discussion, amendment and approval. A detailed proposal from the student which has been approved by the supervisor should be submitted for approval via the project coordinator, to a sub-committee of the Undergraduate Committee, by the end of the second week of the final year. However, students who are taking half weight projects will be allowed to submit their proposals by the ninth week of the Autumn term of the final year. Normally projects should be handed in to the supervisor by the Friday at the end of the second week of the Spring or Summer term as appropriate to the start date. Students interested should contact the staff member below.

Tutor Responsible: P Walley

BUSINESS SCHOOL	IB3A7	12 CATS
Term 2	**The Practice of Operational Research**	

Note: Students can take IB3A7 The Practice of Operational Research in their second or third years.

***Commitment**:* 9x1 lectures. 9x1 seminars/tutorials

Academic Rationale: The module covers the theoretical frameworks and craft processes associated with the conduction of operational research (OR) studies in organisations. While other OR modules generally provide specific technical capabilities, this module supplies the general approaches and skills necessary to use these techniques effectively in organizational interventions.

Objectives: On successful completion of the module, students will be able to:

- Understand the nature of OR studies and the practical issues involved in developing OR models
- Recognise the importance of the problem structuring skills required in conducting OR studies.
- Formulate, test and validate OR models.
- Conduct interviews using problem structuring methods.
- Appreciate a range of modelling approaches and the circumstances in which they might be applied.

Contents:

- The nature and methods of operational research (OR).
- Models and modelling in OR studies.
- Issues in problem structuring and data collection.
- OR model validation and verification.
- Multi-methodology.

Books: Daellenbach, H.G. and McNickle D.C. (2005). Management Science: decision making through systems thinking, Basingstoke: Palgrave MacMillan; Mitchell, G. (1993) The Practice of Operational Research, Chichester: Wiley; Pidd, M. (2003) Tools for Thinking: modelling in Management Science (2nd ed.), Chichester: Wiley; Rivett, B.H.P. (1994) The Craft of Decision Modelling, Chichester: Wiley; Rosenhead, J. and Mingers, J. (2001) Rational Analysis for a Problematic World Revisited: problem structuring methods for complexity, uncertainty and conflict (2nd ed.), Chichester: Wiley.

A reading pack will be provided.

Assessment: A 3-hour, open book, partly seen, examination comprising:
Part A: 40 marks based on a modelling case study given out two weeks before the examination date.
Part B: 60 marks based on the material covered during the lectures and seminars.

Lecturer: Giles Hindle

BUSINESS SCHOOL	IB320	12 CATS
Term 2	**Simulation**	

Note: Students who took IB211 Simulation are not eligible for IB320.

Objectives: Simulation is one of the most commonly used operational research methods for analysing complex operational/ industrial problems. This course will focus on discrete event simulation. Students will learn the theoretical underpinnings of the methods and the range of applications for which they are useful. They will gain practical experience in problem solving using commercial simulation software.

The course assumes the student has covered some introductory courses in computer programming and statistics.

Content: Topics covered will be: introduction to simulation methods, the discrete-event simulation method, software for discrete-event simulation (with use of a specific package e.g.

Simul8 or Witness), performing a simulation study (conceptual modelling, data collection and analysis, experimentation and verification and validation).

The tutorials provide the opportunity for supervised exercises and help students develop their own computer based simulation programmes.

Books: Robinson, S. (2003), Simulation: The Practice of Model Development and Use, Wiley

Commitment: 8 x 2 hour lectures and 1 tutorial hour per week for students for 7 weeks.

Assessment: 100% Assessed.

Lecturer: Ruth Davies

BUSINESS SCHOOL	IB321	12 CATS
Term 2	**Forecasting**	

Note: ***The Business School has placed a restriction which makes this module unavailable to students who have already taken ST215, Forecasting and Control, in their second year.***

Commitment: Two 1-hour lectures per week plus one 1-hour seminar per week.

Prerequisites: Some basic ideas of statistics and probability (eg estimation and prediction intervals for simple linear regression), and a familiarity with multiple regression analysis and University computing facilities will be assumed.

Aims: This module aims to provide an introduction to current forecasting methods and develop practical competence in their use, and concentrates on the models for short term forecasting as these illustrate all the basic principles of analysing, comparing and extrapolating different models.

Content: Topics covered include:
- Curve fitting using regression.
- Sequential estimation and local models.
- Longer Term Forecasting.
- Error measurement and monitoring.

Objectives: On successful completion of the module, you will:
- Have acquired a firm understanding of the ideas and principles underlying the most commonly used forecasting models.
- Have applied several methods on real data sets.
- Understand the importance of the measurement of the errors associated with a forecasting system, and how they are used to monitor the forecasting system.
- Understand the relevant issues and measures available to select the most suitable system.
- Have produced short, structured reports investigating two real data series.

Books: P. E. Gaynor and R. C. Kirkpatrick, "Introduction to Time-Series Modelling & Forecasting"; S. Makridakis et.al., "Forecasting, Methods and Applications".
Hanke, Wickern & Reitsch, Business Forecasting, 7th ed.
These may change in light of newer texts.

***Examination**:* (examined at the end of Term 1) (60%).

Assessment: (practical exercise in preparing and reporting a forecast) (40%).

Lecturer: Estelle Shale

BUSINESS SCHOOL	IB349	12 CATS
Term 1	**Operational Research for Strategic Planning**	

This module can be taken in the third year (IB349) or fourth year with advanced topics (IB408). You must notify the Lecturer concerned which variant you wish to take. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS and BSc.MMORSE students at least 120 CATS of level 4+ modules over their 3rd & 4th years.

***Commitment**:* Mixture of lectures, group exercises and case studies averaging approx. 2.5-hours per week.

***Aim**:* To develop a framework for the practical application of a selection of modelling and analytical techniques which can be used to support strategic planning process.

Students from a range of academic backgrounds may be interest in the module; those from a scientific background will discover the application area of strategic planning within which techniques can usefully be employed and those from a business background will discover the use of structured methods relevant to the practice of strategic planning.

***Objectives**:* On successful completion of the module you will:

- Have an appreciation of the framework for the strategic planning/strategic development process.
- Have an understanding of the methods and models available and their role in the strategic planning process.
- Have developed skills in applying a selection of methods.

***Content**:* A conceptual model of the strategic planning process is introduced which identifies a set of essential elements. The module then focuses on a number of the elements including strategy formulation, a system model, assessment of uncertainty and evaluation and selection. Methods and models to support the planning process include:

- Corporate modelling/System Dynamics.
- Scenario planning.
- Risk Analysis.
- Strategy evaluation.
- Balanced Scorecard.
- Visioning.

Particular attention will be paid to system dynamics modelling for strategy support and scenario development for describing and assessing uncertainty. The teaching style emphasises the practical application of techniques for strategy support through the use of case studies and group exercises.

***Books**:* R.G. Dyson and F.A. O'Brien, *Supporting Strategy: Methods & Models*, Wiley (2007).

***Assessment**:* 100% assessed.
System Dynamics - Group Assessment (2000 words including computer model output) - 40%
Scenario Planning - Individual Assessment (2000 words) - 60%.

Lecturer: Frances O'Brien

BUSINESS SCHOOL	IB352	15 CATS
Term 2	**Mathematical Programming III**	

***Prerequisites**:* IB207 Mathematical Programming II.

***Commitment**:* 2 x 1 hour lecture and one 1-hour problem class per week, plus assessed work.

***Content**:* Unconstrained and constrained optimisations, quadratic programming, search methods for constrained optimisation problems, combinatoral optimisation, approximation algorithms and modern heuristic techniques for combinatoral optimisation problems.

***Assessment**:* 2- hour open book examination (80%) and assessed exercise (20%).

Lecturer: Nalan Gulpinar

BUSINESS SCHOOL	IB357	12 CATS
Term 2	**Investment Management**	

For **WBS students**, this module builds upon IB114 *Financial Management* and IB235 *Finance 1*, which are prerequisites.

For **non-WBS students**, this module builds upon IB215 *Principles of Finance*, which is a prerequisite.

This module complements the third-year electives IB359 *Derivatives and Financial Risk Management* and IB394 *International Financial Management*.

By the end of the module you should be able to:

- Explain the principles of portfolio construction.
- Evaluate the use of, and empirical evidence for, different models of asset pricing.
- Define and compute different measures of portfolio performance.
- Discuss the role of bonds in portfolio diversification and the measurement of interest-rate risk.
- Assess the use of derivatives in portfolio management.
- Describe various methods of active portfolio management.
- Translate investor preferences and market information into viable investment strategies.
- Understand how to interpret quantitative data to inform investment decisions.

- Apply statistical concepts with confidence.
- Understand the implications of prices being set by the actions of numerous interacting economic agents.
- Determine the characteristics of the optimum portfolio.
- Explain how to manage interest-rate risk and market risk.
- Assess the performance of a portfolio.

The syllabus is taught as follows:

1 x 2 hour lecture per week; 1 x 1 hour seminar per week

- Portfolio construction.
- Asset pricing models.
- Testing and use of pricing models.
- Performance measurement.
- Bond and interest-rate markets.
- Interest-rate risk management.
- Use of forwards and swap markets.
- Use of options and non-linear claims.
- Dynamic investment strategies.

This module is worth 12 Credit Accumulation and Transfer Scheme (CATS) points.

The reading list for the 2008-2009 academic year includes:

Recommended text:; Bodie, Z, Kane A and Marcus AJ, *Investments* (7th ed.), McGraw-Hill 2008.

Other texts:; Elton EJ, Gruber MJ, Brown SJ and Goetzmann WN, *Modern Portfolio Theory and Investment Analysis* (7th ed.), Wiley 2007.; Chew D and Stern J, *The Revolution in Corporate Finance* (4th ed.), Blackwell 2003.; Shiller R, *Irrational Exuberance* (2nd ed.), Princeton 2005.; Swensen D, *Pioneering Portfolio Management: An Unconventional Approach to Institutional Investment* (2nd ed.), Free Press 2008.

Lecturer: Anthony Neuberger

BUSINESS SCHOOL	IB359	12 CATS
Term 1	**Derivatives and Financial Risk Management**	

For **WBS students**, this module builds upon IB114 *Financial Management* and IB235 *Finance 1*, which are prerequisites.

For **non-WBS students**, this module builds upon IB215 *Principles of Finance*, which is a prerequisite.

This module complements the third-year electives IB357 *Investment Management* and IB394 *International Financial Management*.

The module aims to extend your knowledge and understanding of the quantitative theory of financial risk, and how that risk can be managed by means of hedging; to develop your critical reasoning skills in the context of financial derivatives and financial risk management; and to equip you with the practical skills which you will need to apply financial derivatives to hedging and risk management.

By the end of this module you should be able to:

- Describe the key characteristics of vanilla and exotic derivative products.
- Explain the use of these products as risk management tools.
- Discuss the means used to hedge the exposure that such products create for the banks that issue them.
- Price vanilla and exotic derivative products using simple lattice methods and simulation techniques.
- Design hedging and risk management strategies for
    1. corporate consumers of derivative products.
    2. banks that supply derivative products.
- Assess risk profiles arising from the use of derivatives and associated hedging activity.
- Communicate effectively the results of risk analysis to non-quantitative people
- Interpret quantitative data from the viewpoint of risk and uncertainty.
- Apply statistical tools to both time-series and cross-sectional data to derive meaningful risk management metrics.
- Understand the implications of hedging via risk-neutral replication.
- Construct hedge portfolios, with both unconstrained and restricted choices of hedging instrument.
- Price and hedge a range of non-vanilla products using simple lattice methods and simulation techniques.

The syllabus is taught as follows:

1 x 2 hour lecture per week for 9 weeks; 1 x 1 hour seminar per week for 9 weeks

1. Introduction to hedging and risk management.

2. Hedging with (FX and index) futures.
3. Fixed-income instruments and hedging (duration, convexity, immunisation).
4. Vanilla options - hedging and absence of arbitrage, valuation using (binomial) lattices and sand-box simulation.
5. Exotic options - valuation and hedging issues.
6. Valuation and hedging - extending the Black-Scholes model.
7. Credit risk and credit instruments.
8. Risk management in practice.

This module is worth 12 Credit Accumulation and Transfer Scheme (CATS) points.

The reading list for the 2008-2009 academic year includes:

Recommended text:; Hull J, *Options, Futures and Other Derivatives (6th ed.)*, Pearson 2006.

Other texts:; Hull J, *Fundamentals of Futures and Options Markets (6th ed.)*, Pearson 2008.; Hull J, *Risk Management and Financial Institutions*

Lecturer: Alex Stremme

BUSINESS SCHOOL	IB391	15 CATS
Term 2	**Decision Analysis**	

This module can be taken in the third year (IB391) or fourth year with advanced topics (IB407). You must notify the Lecturer concerned which variant you wish to take. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS, and BSc.MMORSE students at least 120 CATS, of level 4+ modules over their 3rd & 4th years.

Prerequisite: IB104 Mathematical Programming I and IB207 Mathematical Programming II.

Commitment: 2 x 1 hour lecture per week and 1 x 1 hour seminar per week.

Content: This course builds upon the foundation of the two courses: 'Mathematical Programming I' and 'Mathematical Programming II', which are the prerequisites. The course consists of two closely related but nevertheless distinct parts: decision analysis and efficiency assessment. The former is represented by multiple criteria problems in which a number of objectives have to be achieved, for example, the maximisation of profit or market share whilst simultaneously minimising environmental impact. The mathematical models and optimisation techniques for the solution of such problems are considered.

The second part of the course deals with the use of optimisation based techniques for the assessment of the relative efficiency of organisational units, such as bank branches, pubs, hospitals, schools, etc. For each inefficient unit the models provide a range of diagnostic output. This includes identifying the target performance levels that the inefficient unit should achieve to become efficient and which of the other units operate in a similar manner but achieve efficiency. The latter enables benchmarking and the dissemination of best practice.

The methodologies developed in the course have numerous applications in the private and public sectors. The course is supported by the use of specialised software and spreadsheets.

Objectives: By the end of the course, students should be able to:

- Understand mathematical models and methods used in decision analysis and performance measurement.
- Formulate business-related decision problems in a structured form suited to solution by the use of mathematical techniques.
- Apply these techniques to the solution of the problems using appropriate software.
- Assess the efficiency of organisational units under various assumptions about the operational environment.
- Interpret the results of their analysis and report on their findings in a manner suited to a business context.
- Be able to critically assess the relevance and limitations of the methods
- Use linear programming for modelling decision making processes.

Syllabus: Multiple criteria decision analysis, multi-objective optimisation, linear programming models of efficiency assessment (data envelopment analysis), benchmarking techniques

Books: E. Thanassoulis. Introduction to the Theory and Application of Data Envelopment Analysis. Kluwer: Dordrecht, 2001 W.W. Cooper, L.M. Seiford, K. Tone. Data Envelopment Analysis. Kluwer: Dordrecht, 2000 W.L. Winston. Operations Research, 3d edition. Duxbury Press, 1994

Assessment: 1 x Assessment,1 x Exam. **NB: IB391 will be examined in the first week of Summer Term.**

Lecturer: Estelle Shale

BUSINESS SCHOOL	IB403	30 CATS
	Operational Research Dissertation	

Availability: **This module is available to final year (4) MMORSE students only**.

A list of titles of potential titles will be available to students at the beginning of the academic year. Other titles are possible by individual arrangements.

BUSINESS SCHOOL	IB407	15 CATS
Term 2	**Decision Analysis**	

Availability: **Not available to students who have taken IB391.**

Content: This is a 4th year variant of the existing module IB391 Decision Analysis. This course builds upon the foundation of the two courses: ‘Mathematical Programming I’ and ‘Mathematical Programming II’, which are the prerequisites.

In comparison with the existing 3rd year IB391, the proposed module has an extended bibliography, would require significantly more reading and the assignment will be marked to a higher standard. The course consists of two closely related but nevertheless distinct parts:

decision analysis and efficiency assessment. The former is represented by multiple criteria problems in which a number of objectives have to be achieved, for example, the maximisation of profit or market share whilst simultaneously minimising environmental impact. The mathematical models and optimisation techniques for the solution of such problems are considered.

The second part of the course deals with the use of optimisation based techniques for the assessment of the relative efficiency of organisational units, such as bank branches, pubs, hospitals, schools, etc. For each inefficient unit the models provide a range of diagnostic output. This includes identifying the target performance levels that the inefficient unit should achieve to become efficient and which of the other units operate in a similar manner but achieve efficiency. The latter enables benchmarking and the dissemination of best practice.

The methodologies developed in the course have numerous applications in the private and public sectors. The course is supported by the use of specialised software and spreadsheets.

Objectives: On successful completion of the module you will:

- Understand mathematical models and methods used in decision analysis and performance measurement
- Formulate business-related decision problems in a structured form suited to solution by the use of mathematical techniques.
- Apply these techniques to the solution of the problems using appropriate software.
- Assess the efficiency of organisational units under various assumptions about the operational environment.
- Interpret the results of their analysis and report on their findings in a manner suited to a business context.
- Be able to critically assess the relevance and limitations of the methods
- Use linear programming for modelling decision making processes.

Syllabus: Multiple criteria decision analysis, multi-objective optimisation, linear programming models of efficiency assessment (data envelopment analysis), benchmarking techniques.

Books:
E. Thanassoulis. Introduction to the Theory and Application of Data Envelopment Analysis. Kluwer: Dordrecht, 2001
W.W. Cooper, L.M. Seiford, K. Tone. Data Envelopment Analysis. Kluwer: Dordrecht, 2000
W.L. Winston. Operations Research, 3d edition. Duxbury Press, 1994

Commitment: 2x1 hour lectures and 1x1 hour seminar per week.

Assessment: 1 x 2 hour examination – 70% 1 x assessment – 30%.
Lecturer: Estelle Shale

BUSINESS SCHOOL	IB408	12 CATS
Term 1	**Operational Research for Strategic Planning with Advanced Topics**	

Availability: **Not available to students who have taken IB349.**

Commitment: Mixture of lectures, group exercises and case studies averaging approx. 2.5-hours per week. **Additional material will be given on the evaluation of Scenario Planning which involves additional contact time (lecture and discussion) and an additional component to an assessment.**

Aim: To develop a framework for the practical application of a selection of modelling and analytical techniques which can be used to support strategic planning process.

Students from a range of academic backgrounds may be interest in the module; those from a scientific background will discover the application area of strategic planning within which techniques can usefully be employed and those from a business background will discover the use of structured methods relevant to the practice of strategic planning.

Objectives: On successful completion of the module you will:

- Have an appreciation of the framework for the strategic planning/strategic development process.
- Have an understanding of the methods and models available and their role in the strategic planning process.
- Have developed skills in applying a selection of methods.

Content: A conceptual model of the strategic planning process is introduced which identifies a set of essential elements. The module then focuses on a number of the elements including strategy formulation, a system model, assessment of uncertainty and evaluation and selection. Methods and models to support the planning process include:

- Corporate modelling/System Dynamics.
- Scenario planning.
- Risk Analysis.
- Strategy evaluation.
- Balanced Scorecard.
- Visioning.

Particular attention will be paid to system dynamics modelling for strategy support and scenario development for describing and assessing uncertainty. The teaching style emphasises the practical application of techniques for strategy support through the use of case studies and group exercises.

Books: R.G. Dyson and F.A. O'Brien, *Supporting Strategy: Methods & Models*, Wiley (2007).

Assessment: 100% assessed.
System Dynamics - Group Assessment (2000 words including computer model output) - 40%
Scenario Planning - Individual Assessment (2000 words) - 60%

Lecturer: Frances O'Brien

BUSINESS SCHOOL	**IB94W0**	**12 CATS**
Term 1	**Spreadsheet Modelling**	

***Academic Rationale*:** This module recognises the essential role that computing plays in Operational Research, and the need for the students to develop hands on experience, good modelling and design skills and an understanding of the role of popular business computing tools. It includes both a top-down conceptual modelling/design and a bottom-up skills based course. The module demonstrates and develops both conceptual and practical understanding of the fundamental computing tool of spreadsheets and the problems they can address. There is an emphasis on OR applications such as simulation, stochastic and data management processes. The module aims to promote good analysis and design skills so that the student can build or specify applications that both meet the requirements and are usable and well documented. To this end the focus includes both methodological rigour and practical problem-solving techniques, and computer programming for control and usability of custom applications.

Objectives:

- Understand the capabilities and contribution that computer-based spreadsheets can offer in business and operational research.
- Design a functional, well structured, documented and usable spreadsheet application.
- Implement a functional, well structured, documented and usable spreadsheet application.
- Work collaboratively towards application design.
- Design and write simple computer programs.
- Know how to develop and use a spreadsheet for investigating a problem situation.

Syllabus: The module covers conceptual modelling, design and implementation. This includes basic model building and formatting, data validation, data analysis and simulation techniques, charts and special functions. Then it presents a gradual but progressive introduction to the capability of computer programming within the package including basic syntax and structure of programming, conditional and repeated routines, interacting with the user. All these are treated within the context of operational research oriented problems.

Books:

- Edwards, J.S. and Finlay, P. (1997). *Decision Making with Computers*. Pitman.
- Harvey, G. (2003). *Excel 2003 for Dummies*. Hungry Minds.
- Harvey, G. (2006). *Excel 2007 for Dummies*. Hungry Minds.
- Walkenbach, J. (2004). *Excel VBA Programming for Dummies*. Wiley.
- Walkenbach, J. and Pieterse JK (2007). *Excel 2007 VBA Programming for Dummies*. Hungry Minds.
- Walkenbach, J. (2004). Excel 2003 Power Programming with VBA. Hungry Minds.
- Walkenbach, J. (2007). Excel 2007 Power Programming with VBA. Wiley.

Assessment Method: Individual (75%) and group(25%) coursework.

Lecturer: Andrew Martin

MATHEMATICS

Only the third year analysis courses are listed below. For others in algebra and topology, see the Mathematics PYDC booklet. Each course carries a commitment of 3 lectures per week, and unless stated otherwise is assessed solely by examination.

MATHEMATICS	MA359	15 CATS
Term 1	**Measure Theory**	

Commitment: 30 hours.

Prerequisites: MA132 Foundations, MA222 Metric Spaces, MA244 Analysis III.

Content: A *measure m* is a law which assigns a number *m(A)* to certain subsets *A* of a given space. Measures are indispensable tools in various fields of mathematics: in geometry, measures are used to quantify areas and volumes; in probability theory, measures are used to quantify the probability of events; in dynamics, measures are used to quantify the fraction of time a chaotic system spends in a given state.

Given a measure *m*, one can define the *integral* of suitable real valued functions with respect to *m*. *Lebesgue's integral* is what you get when you integrate with respect to *Lebesgue's measure*, which is the measure on the real line which assigns to intervals their lengths. Although Lebesgue's integral coincides with the regulated integral for regulated functions, it is much more comfortable to use. This is because the class of Lebesgue integrable functions is significantly larger than that of regulated functions, and since the Lebesgue integral is more adapted to limit procedures than the regulated integral. Indeed, very often the pointwise limit of a sequence of regulated functions looses its regularity, but retains its Lebesgue integrability. It is therefore not surprising that Modern Analysis is based on the Lebesgue integral and its generalizations, and not on the regulated integral.

The Module will cover the following topics: Definition of a measurable space and σ-additive measures, Construction of Lebesgue's measure and Carathéodory's extension procedure, Lebesgue measurability, Construction of a non-measurable set, Regularity of Lebesgue measurable sets, Measurable Functions, Lusin's Theorem, Egoroff's Theorem, Integral with respect to a measure and approximation by measurable step functions, Fatou's Lemma, Monotone Convergence Theorem, Dominated Convergence Theorem, Product Measures and Fubini's Theorem.

Aim: To introduce the concepts of *measure* and *integral with respect to a measure* and to discuss their basic properties, so as to provide a basis for further studies in Analysis, Probability, and Dynamical Systems.

Objective: To construct Lebesgue's measure on the real line; to construct the integral and discuss its basic properties; to explain the basic properties of measurable functions with emphasis on proofs by approximation; to define product measures.

Leads to: ST318 Probability Theory, MA3D4 Fractal Geometry, MA482 Stochastic Analysis, MA496 Signal Processing, Fourier Analysis and Wavelets, MA3F4 Linear Analysis.

Books: Stein, E. M. and Shakarchi, R. *Real Analysis - measure theory, integration and Hilbert spaces*. (Princeton Lectures in Analyis III) Princeton University Press (2005). Royden, H. L.: *Real Analysis*, Third Edition, Macmillan Publishing Company (1988).Rudin, W.: *Real and Complex Analysis*, Third Edition, McGraw-Hill Book Company (1987). Halmos, P. R.: *Measure Theory*, D. Van Nostrand Company Inc., Princeton, N.J. (1950).

Assessment: 3-hour examination (85%) plus assessed work (15%)

Lecturer: Jose Rodrigo

MATHEMATICS	MA3G7	15 CATS
Term 1	**Functional Analysis I**	

Prerequisites: You should revise the material from MA225 Differentiation and MA244 Analysis III; MA222 Metric Spaces would be useful but not essential; MA359 Measure Theory would be a natural course to take in parallel.

Commitment: 30 lectures.

Content: This is essentially a module about infinite-dimensional Hilbert spaces, which arise naturally in many areas of applied mathematics. The ideas presented here allow for a rigorous understanding of Fourier series and more generally the theory of Sturm-Liouville boundary value problems. They also form the cornerstone of the modern theory of partial differential equations.

Hilbert spaces retain many of the familiar properties of finite-dimensional Euclidean spaces (R^n) - in particular the inner product and the derived notions of length and distance - while requiring an infinite number of basis elements. The fact that the spaces are infinite-dimensional introduces new possibilities, and much of the theory is devoted to reasserting control over these under suitable conditions.

The module falls, roughly, into three parts. In the first we will introduce Hilbert spaces via a number of canonical examples, and investigate the geometric parallels with Euclidean spaces (inner product, expansion in terms of basis elements, etc). We will then consider various different notions of convergence in a Hilbert space, which although equivalent in finite-dimensional spaces differ in this context. Finally we consider properties of linear operators between Hilbert spaces (corresponding to the theory of matrices between finite-dimensional spaces), in particular recovering for a special class of such operators (compact self-adjoint operators) very similar results to those available in the finite-dimensional setting.

Throughout the abstract theory will be motivated and illustrated by more concrete examples.

Books: Printed lecture notes will be provided, which will contain all the material in the module. A useful book to use as an accompanying reference is:

BP Rynne & MA Youngson, Linear Functional Analysis, Springer-Verlag, London, 2000.
Leads to: MA3F4 Functional Analysis II, MA3G1 Theory of PDEs, MA433 Fourier Analysis, MA482 Stochastic Analysis, MA4A2 Advanced PDES, MA4G6 Calculus of Variations, MA4G8 Computational PDE

Assessment: 15% by assessed work, 85% by two-hour examination.

Lecturer: James Robinson

MATHEMATICS	MA3G8	15 CATS
Term 2	Functional Analysis II	

Commitment: 30 lectures.

Prerequisites: MA3G8 Functional Analysis I

Content: Many problems in Mathematics lead to linear problems on infinite-dimensional spaces. In this course we shall mainly study infinite-dimensional normed linear spaces and continuous linear transformations between such spaces. We will study Banach spaces and prove the main theorems of this subject (Hahn-Banach, open mapping, uniform boundedness). The last part of the course will be devoted to bounded and unbounded operators with specific mention of differential operators in L^2 spaces.

Books: E. Kreyszig, *Introductory Functional Analysis with Applications*, Wiley, 1989.
W. Rudin, *Functional Analysis*, McGraw-Hill, 1973.
G. B. Folland, *Real Analysis*, Wiley, 1999.
J. K. Hunter and B. Nachtergaele, *Applied Analysis*, World Scientific, 2001.

Leads to: MA4A2 Advanced PDEs, MA433 Fourier Analysis.

Assessment: 3-hour examination

Lecturer: Stefan Adams

STATISTICS	ST300	30 CATS
	Third Year MMathStat Project	

Only available to MMathStats students.

A list of titles of topics in Probability and Statistics will be available at the beginning of the academic year. Other titles are possible by individual arrangements.

Students are advised to refer to the introduction to this booklet for the rules regarding missed deadlines and unacknowledged copying.

5% of the credit is awarded for giving a short oral presentation in the last week of term 1.

The deadline for submission of the project is the end of week 3 of the third term.

STATISTICS	**ST301**	**15 CATS**
Term 1	**Bayesian Statistics & Decision Theory**	

Important: If you decide to take ST301 you cannot then take ST413. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS of level 4+.

***Prerequisites**:* ST217 Mathematical Statistics A.

***Content**:* Bayesian statistics is one of the fastest growing areas in statistics. With the advance of computer technology it is now a highly practical methodology for addressing many important high dimensional decision problems as well as being underpinned by a sound mathematical foundation. It is especially useful when some of the components of uncertainty have only sparsely collected data associated with them, so that expert judgements need to be incorporated. The course first introduces the central concepts of Bayesian decision analysis through a selection of simple examples. Various methodologies are then presented for:

- Structuring a decision problem – for example by decision trees and influence diagrams.
- Eliciting probability distributions over many variables – using the concepts of irrelevance and the Belief net.
- Eliciting the objectives and preferences of the client – developing the ideas of m.u.i.a. and value independence and the use of the decision conference.

The formal methodologies are illustrated through a wide range of examples for health, the environment, finance and public sector administration. Some of the examples build on the practical experience of the lecturer as an active Bayesian decision analyst.

Aims:

- To demonstrate how to build statistical models of non-trivial problems when data is sparse and expert judgements need to be incorporated.
- To give ways to represent the pertinent features of a decision problem.
- To give practical algorithms for finding decision rules which the client can expect will best satisfy pre-specified objectives.
- To train the student in the rudiments of decision analysis.

Objectives:

- The student will gain an appreciation of the importance of conditional independence in subjective (Bayesian) statistical modelling and be introduced to the DAG as an efficient representation of collections of conditional independence statements as they arise in practice.
- The student will be provided with techniques for eliciting subjective probability distributions over many variables.
- The student will be provided with techniques for eliciting quantitative preference structures from a client which may involve competing objectives.
- The student will obtain an appreciation of the foundational arguments that justify expected utility maximisation as a paradigm for rational action.
- The student will obtain practice in implementing these techniques.
- The student will learn the bases of fast algorithms for the calculation of probabilities needed in such maximisation.

Assessment**:* 100% by 2-hour examination. ***Lecturer: Jim Smith

STATISTICS	**ST305**	**15 CATS**
Term 1	**Designed Experiments**	

Important: If you decide to take ST305 you cannot then take ST410. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS of level 4+.

Prerequisite: ST217 Mathematical Statistics A & B.

Commitment: 30 one-hour lectures.

Background: Designed experiments are used in industry, agriculture, medicine and many other areas of activity to test hypotheses, to learn about processes and to predict future responses. The purpose of experimentation is to determine the relationship between a response variable and the settings of a number of experimental variables which are presumed to affect it. Experimental design is the discipline of determining the number and order (spatial or temporal) of experimental runs, and the setting of the experimental variables.

Content: The theory of experimental design is quite mathematical while the practice involves important eliciting and communication skills. In this course we will look at both these aspects. Classical experimental design is based on the linear model, and the course will start with a review of linear model theory and some simple models; we shall then examine the principles of experimental design and analysis in design theory, in which we consider both qualitative and quantitative factors; a significant part of the course will be spent developing aspects of factorial design theory including confounding and fractional designs, other important topics to be included will be response surface designs and incomplete block designs; finally, we shall discuss optimal design in which the focus is on maximising the information available to the experimenter whatever the experimental constraints. Further topics such as repeated measures and non-linear design will conclude the module.

Aims: This course aims to give students a sound understanding of experimental design, both theoretical and practical. The course will explore the method of analysis of variance and show how it is structurally linked to particular types of design. The combinatoric properties of designs will be explored, and the impact of computers on classical design considered. Examples from many different application areas will be given throughout.

Objectives: By the end of the course students will be able to:

- Describe the basic principles behind designed experiments
- Construct the design matrix for simple experiments and estimate their parameters
- Perform an analysis of variance on standard experimental designs
- Distinguish between different designs and recognise their efficiency / utility
- Show the relationship between designing experiments and analysing the resulting data
- Perform diagnostic tests on the results from a designed experiment.
- Take a practical design problem and determine an optimal or robust solution

Books: G Clarke & R Kempson, *Introduction to the Design and Analysis of Experiments*, Arnold, 1996. DR Cox & N Reid, *The Theory of the Design of Experiments*, Chapman & Hall / CRC, 2000. AC Atkinson & AN Doney, *Optimal Experimental Designs*, Oxford, 1992. DC Montgomery, Design and Analysis of Experiments, Wiley, 2001, 2005

Assessment: 20% by coursework and 80% by 2-hour examination. There will be two major pieces of coursework, one at the half-way point and one at the end of the course. Other exercises will be provided and discussed during the lectures.

Lecturer: John Fenlon

STATISTICS	**ST313**	**15 or 30 CATS**
	Third Year Essay/Project	

This involves undertaking an individual project under the supervision of a member of staff, which will be assessed by means of a substantial written report.

Usually students must develop their own proposal for a project, which they should discuss with their personnel tutor before approaching a member of staff to supervise it. There is no guarantee that a supervisor will be available. '

Students are advised to refer to the introduction to this booklet for the rules regarding missed deadlines and unacknowledged copying.

The deadline for submission of the project is Wednesday of the second week of the third term.

STATISTICS	**ST318**	**15 CATS**
Term 2	**Probability Theory**	

Prerequisites: ST213 Mathematics of Random Events or MA359 Measure Theory (3rd year).

Content: Independence and conditioning, probability measures on metric spaces, types of probabilistic convergence, an introduction to martingales.

Aims: This course aims to give the student a rigorous presentation of some fundamental results in measure theoretic probability and an introduction to the theory of discrete time martingales. In so doing it aims to provide a firm basis for advanced work on probability and its applications.

Objectives: The objectives of the course are as follows: at the end of the course the student will:

- Understand the ideas relating to independence and zero-one laws and be able to apply these ideas in simple contexts.
- Understand the different modes of convergence for sequences of random variables (more generally random elements) and the relationship between these different modes.
- Be able to state and prove the Central Limit Theorem and understand how this result can be applied.
- Understand some basic results on discrete time martingales and how this theory can be used to prove Kolmogorov's Strong Law of Large Numbers.

Assessment: 5% by class tests and 95% by 2-hour examination.

Prerequisite Material: The first two main sections of the online lecture notes survey prerequisite material on probability models and random variables and are now available online. You are strongly advised to ensure that you are familiar with this material: if not then you should fill this deficit for example by working through these two sections in the vacation before the module commences.

Lecturer: Wilfrid Kendall

STATISTICS	ST323	15 CATS
Term 1	Multivariate Statistics	

Important: If you decide to take ST323 you cannot then take ST412. Bear this in mind when planning your module selection.

Prerequisites: ST208 Mathematical Methods or equivalent, ST217 Mathematical Statistics A and B.

Aims: Multivariate data arises whenever several interdependent variables are measured simultaneously. This occurs frequently in many areas: in medicine, in the social and environmental sciences and in economics. The analysis of such multidimensional data often presents an exciting challenge that requires new statistical techniques which are usually implemented using computer packages. This module aims to give you a good understanding of the geometric and algebraic ideas that these techniques are based on, before giving you any chance to try them out on some real data sets.

Objectives: By the end of the course students will be able to:

- Carry out a principal components analysis and use it to summarise high dimensional data.
- Use linear discriminant analysis to solve simple classification problems.
- Understand the theory of the multivariate normal distribution.
- Perform multivariate hypothesis tests and construct confidence regions.

Book: Krzanowski, W.J., *Principles of Multivariate Analysis : a user's perspective*, Oxford: Clarendon 2000

Assessment: 20% by coursework, 80% by 2-hour examination.

Lecturer: Ewart Shaw

STATISTICS	ST329	15 CATS
Term 1	Topics in Statistics	

Prerequisites: ST217 Mathematical Statistics A and B.

Content: Three self-contained sets of ten lectures given.

<u>Introduction to Mathematical Finance</u> (Dario Spanò):

Aims:

This short course introduces and studies the procedure of hedging in simple tree models of a financial market. Following the fundamental work of Black and Scholes hedging is used to find the value of derivative contracts.

Objectives:
By the end of the course students will be able to:

- Calculate fair prices for simple derivatives.
- Check whether or not a market is arbitrage-free and complete by investigating the existence and uniqueness of pricing mechanisms.

Bayesian Methods in Practice (Fabio Rigat):

Aims: This component of the course offers a practical introduction to Bayesian statistical procedures, a rapidly developing area of statistics. Key Bayesian themes such as choice of prior distribution, the use of hierarchical models and computational techniques will be discussed.

Objectives*:* By the end of the course students should be able to:

1. Understand the role of the prior distribution in Bayesian methods.
2. Fit simple models using MCMC in WinBUGS.
3. Recognize good and bad behaviour of MCMC methods.

Graphical Models (P. Thwaites):

Aims: The aim of this short course is to present a modern statistical methodology which uses graphical structures to model high-dimensional problems, and to convey the advantages of such an approach in the analysis of large data sets. Topics include Markov properties on undirected graphs, maximum likelihood estimation, and hypothesis testing for multinomial graphical models.

Objectives*:* After completing the course students should be able to:

1. specify the conditional independence assumptions and the probabilistic structure implied by a graphical model;
2. compute maximum likelihood estimates of the probabilities that parameterise a graphical model;
3. apply graphical modelling techniques to the analysis of contingency tables, and test the conditional independence hypotheses implied by such models.

Assessment*:* 100% by 2-hour examination.

STATISTICS	**ST332**	**15 CATS**
Term 2	**Medical Statistics**	

Important: If you decide to take ST332 you cannot then take ST409. Bear this in mind when planning your module selection.

Commitment*:* 3 lectures/week

Prerequisites*:* ST217 Mathematical Statistics A and B.

Content*:* Modern applications of statistics to medicine are highly developed. A look at almost any medical journal reveals that a substantial proportion of medical research papers employ statistical techniques. Large numbers of statisticians are employed in medical research establishments, particularly in the pharmaceutical companies and the medical schools, and medical statistics continues to be the most buoyant area for statistical recruitment. Although the course will cover some topics of a specifically medical nature, much of the work will be discussing basic statistical techniques as applied to medical data, but which could equally well be applied to data arising in other applications. Thus, whilst medicine provides the focus of the course, it could also be viewed as a more general applied statistics course. The course will explain why and how statistics is used in medicine, and study some of the statistical methods commonly used in medical research. Examples and case studies in areas such as cancer, heart disease and psychiatry will be discussed.

- *Generalised linear models:* linear models as an extension of linear regression; analysis of binary data by logistic regression; analysis of counts and proportions. Two by two tables.
- S*tudy designs:* cohort, case-control and survey designs; randomised clinical trials; sample size and power; conditioning and covariance adjustment.
- *Analysis of censored survival data:* life tables; hazard and survival functions; Kaplan-Meier survival curves; parametric survival models, the proportional hazards regression model.

Aims: To introduce applications of statistics in medicine, and some of the statistical methods commonly used in medical research.

Objectives:
- To appreciate the role of statistics in medical research.
- To understand some of the statistical principles of good practice in medical investigations.
- To understand how to use and interpret some of the statistical techniques used in medical data analysis.

Books: A.J.Dobson, "An introduction to generalised linear models"; D.G.Altman, "Practical statistics for medical research"; D.Collett, "Modelling survival data in medical research". (All Chapman & Hall)

Assessment: 20% by coursework, 80% by 2-hour examination.

Lecturers: Geraldine Clarke/Heather Turner

STATISTICS	**ST333**	**15 CATS**
Term 1	**Applied Stochastic Processes**	

Important: If you decide to take ST333 you cannot then take ST406. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS of level 4+.

Prerequisites: ST202 Stochastic Processes.

Aims: To provide an introduction to concepts and techniques which are fundamental in modern applied probability theory and operations research, and which also encroach on statistics:
- Models for queues, point processes, and epidemics.
- Notions of equilibrium, threshold behaviour, and description of structure.
- Techniques of process specification, coupling, and simulation.

These ideas have a vast range of applications, for example routing algorithms in telecommunications (queues), assessment of apparent spatial order in astronomical data (stochastic geometry), description of outbreaks of disease (epidemics). We will only be able to introduce each area - indeed each area could easily be the subject of a course on its own! But the introduction will provide you with a good base to follow up where and when required. (For example: a MORSE student graduating in 1996 found the next year their firm was asking them to address problems in queuing theory, for which ST333 provided the basis.) We will discuss these and other applications and show how the ideas of stochastic process theory help in formulating and solving relevant questions.

Objectives: At the end of the course students will:
- Be able to formulate continuous-time Markov chain models for applied problems.
- Be able to use basic theory to gain quick answers to important questions (for example, what is the equilibrium distribution for a specific reversible Markov chain?).
- Will know in principle how to use simulation techniques to get answers to harder questions.

Assessment: 20% by coursework, 80% by examination.

Lecturer: David Hobson

STATISTICS	ST334	15 CATS
Term 1	**Actuarial Methods**	

Important: ***This module is only available to students on four year degrees in the Department of Statistics (MMORSE and MMathStat).***

Prerequisites: ST217 Mathematical Statistics A & B.

Commitment: This will be a reading course based on handouts; there will be a one hour session every week.

Content:
- Interest rates and discount rates.
- Equations of value and compound interest calculations.
- Discounted cash flow.
- Types of investment.
- Concept of arbitrage.
- Introduction to the term structure of interest rates.
- Stochastic interest rate models.

Aims: To cover the syllabus for Actuarial CT1

Objectives: At the end of the course, students will:
- be familiar with basic financial terminology and be able to understand the financial press.
- be able to carry out basic financial calculations.

Leads to: Knowledge of basic financial terminology necessary for several other modules.

***Assessment**:* 3 one-hour class tests (each 15%) with 2-hour examination **in January** (55%).

Lecturer: Robin Reed

STATISTICS	ST335	15 CATS
Term 1	**Finance and Financial Reporting**	

***Important**: This module is only available to students in the Department of Statistics*.

***Prerequisites**:* None.

Students may not take this module and IB109 Foundations of Accounting and Finance.

***Commitment**:* 3 lectures per week.

Content:
- Structure of a joint stock company and the different methods by which it may be financed.
- Basic principles of personal and corporate taxation.
- Principal forms of financial instruments.
- Factors to be considered by a company when deciding on its capital structure and dividend policy.
- Company's cost of capital and how its cost of capital interacts with the nature of investment projects.
- The major forms of financial institution.
- Role and principal features of the accounts of a company.
- Construction of simple balance sheets, profit and loss accounts and cash flow statements.
- Interpretation of financial statements.

***Aims**:* To cover the syllabus for Actuarial CT2.

***Objectives**:* At the end of the course students will:
- Be familiar with the structure of a joint stock company and how it can be financed.
- Be familiar with the different types of financial instruments.
- Be able to construct simple balance sheets, profit and loss accounts and cash flow statements.
- Be able to interpret financial statements.

***Assessment**:* Two hour examination (80%) and two one-hour class tests (10% each).

Lecturers: John Panther/Graham Sara

STATISTICS	**ST337**	**15 CATS**
Term 2	**Bayesian Forecasting and Intervention**	

Important: If you decide to take ST337 you cannot then take ST405. Bear this in mind when planning your module selection. Recall: an MMORSE student must take at least 90 CATS of level 4+.

***Prerequisites**:* ST217 Mathematical Statistics A & B.

***Rationale**:* Forecasting is a vital prerequisite to decision making. This course is concerned with the theory and practice of short-term forecasting, using both data and subjective information. The course focuses on Dynamic Linear Models (DLM). DLM's are a class of Bayesian Forecasting Models which generalise linear regression models and static statistical linear models. The course offers a very powerful fundamental probabilistic approach to forecasting, controlling and learning about uncertain commercial, financial, economic, production, environmental and medical dynamic systems.

Contents:

- State space modelling
- Bayesian updating of beliefs
- Specifying Dynamic Linear Models
- Updating Dynamic Linear Models, forecasting
- Building Dynamic Linear Models, accommodating external information
- ARIMA models, stationarity

The theory will be illustrated by real examples from industry, marketing, finance, government, agriculture etc.

***Books**:* Printed course notes will be available. Mike West & Jeff Harrison, "Bayesian Forecasting and Dynamic Models", 1997 (2nd edn.) Springer - Verlag. Andy Pole, Mike West & Jeff Harrison, "Applied Bayesian Forecasting and Time Series Analysis", 1994 Chapman and Hall.

Assessment: 100% by 2-hour examination.

Lecturer: Mark Steel

STATISTICS	ST338	15 CATS
Term 2	**Actuarial Models**	

***Important**: This module replaces ST336 Life Tables. This module is only available to students on four year degrees in the Department of Statistics (MMORSE and MMathStat.)*

***Prerequisites**:* ST334 Actuarial Methods, ST217 Mathematical Statistics A & B.

***Commitment**:* 3 lectures per week.

Content:

- Principles of actuarial modelling
- Principles of stochastic processes
- Markov chains and Markov processes
- Survival models: lifetimes, curtate future lifetime, expected value and variance.
- Estimation procedures for lifetime distributions: Kaplan–Meier estimate, Cox model
- Multi-state Markov models.
- Maximum likelihood estimators for transition intensities in multi-state models.
- Binomial model of mortality.
- Estimating mortality rates by age: exact methods, census approximations
- Process of graduation.
- Statistical tests for life tables.

***Aims**:* To cover the syllabus for Institute of Actuaries exam CT4.

***Objectives**:* At the end of the course, students will be familiar with calculations involving life tables and survival analysis.

***Assessment**:* Two-hour examination (80%) and two one-hour class tests (10% each).

***Lecturer**:* A Batchelor

STATISTICS	ST401	15 CATS
Term 1	**Stochastic Methods in Finance**	

Important: This module is only available to final year (4) integrated Masters students.

Commitment: 3 x 1-hour lectures per week, 1 tutorial class per week.

Prerequisites: ST217 Mathematical Statistics A & B; ST318 Probability Theory; IB215 Principles of Finance. This module leads onto ST905 Stochastic Methods II.

Content: This module will cover the actuarial syllabus for examination CT8. It will cover material of use in financial mathematics such as Brownian motion, portfolio theory, models of asset returns, stochastic models of security prices, term structure of interest rates.

Aims: To enable students to study more deeply in the stream of Actuarial and Financial Mathematics.

Objectives: Students who have successfully completed this module will:
- Know how probability models are used in financial mathematics
- Understand the concept of Brownian Motion.

Books: M. Baxter and A. Rennie, "Financial Calculus". J.C. Hull, "Futures and Other Derivatives".

Assessment: 2 class tests (each 10%).1 x 2 hour examination (80%) **in April** (Week 1 Term 3)

Lecturer: Jon Warren

STATISTICS	ST402	15 CATS
Term 2	**Risk Theory**	

Important: This module is only available to final year (4) integrated Masters students.

Commitment: 3 x 1-hour lectures per week, 1 tutorial class per week.

Prerequisites: ST217 Mathematical Statistics A & B; ST318 Probability Theory.

Content: This module will cover the actuarial syllabus for examination CT6. It will introduce material of use in general insurance such as loss distributions, ruin, and credibility theory.

Aims: To enable students to study more deeply in the stream of Actuarial and Financial Mathematics.

Objectives: Students who have successfully completed this module will:
- Know how probability models are used in general insurance
- Understand the concept of methods of re-insurance to hedge against risk.

Books: C.D. Daykin, T. Pentikainen & M. Pesonon, "Practical Risk Theory for Actuaries". S.A. Klugman, "Loss Models".

Assessment: 1 x 2 hour examination (80%); 2 class tests (each 10%).

Lecturer: Larbi Alili

STATISTICS	ST403	18 CATS
Term 1	**Brownian Motion**	

Also offered by Maths as MA4F7

WHAT IS IT?
Brownian motion was originally the description given in physics for the random erratic movement of molecules. In 1905 Einstein made a detailed study in which he postulated certain properties should hold. In 1923 mathematical Brownian motion was born when a famous mathematician, Norbert Wiener, showed how to construct a random function $W(t)$ giving the molecules "position" at time t which had Einstein's properties.

WHY IS IT INTERESTING?
- It is a beautiful mathematical object worth studying both for its own sake and because of the deep links it has with other areas of mathematics, particularly in analysis.
- Brownian motion is a fundamental tool for modelling processes which evolve randomly in time. It is used widely in many areas of applied maths and in the last few decades it has become essential to the study of financial maths as a model of stock prices.

WHAT WILL WE LEARN?
- **Construction.** According to Einstein
  - the function $t \to W(t)$ must be continuous – the molecule never jumps
  - the displacement between times s and t, that is $W(t) - W(s)$, should be independent of the past motion and its distribution should be Gaussian with mean zero and variance $t - s$.

We will investigate methods of constructing such random functions. It turns out the Gaussian distribution is essential – it is impossible to do with any other distribution.

- **Properties of the paths.** The path $t \to W(t)$ cannot be smooth. Look at www.stat.umn.edu/~charlie/Stoch/brown.html to see a simulation. The applet at this web site allows you to zoom in on a simulated path – notice it seems to look the same no matter how much it is magnified: Brownian motion is the ultimate fractal!
- **The stochastic calculus.** Ordinary calculus is a powerful method of doing calculations with smooth functions. As we have just seen Brownian paths are not smooth, but miraculously there is a "stochastic calculus" which was developed by a Japanese mathematician Ito in the 1940s and which allows us to do computations with Brownian motion.
- **Differential equations.** Differential equations are essential to modelling deterministic phenomena in applied maths and physics. Arguably the most famous equation of all is

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} = 0$$

  Laplace's equation:

Somewhat surprisingly this can be solved probabilistically using Brownian motion – a fact that lies at the heart of the links between probability theory and analysis, and which is still today yielding new discoveries.

***Prerequisites*:**
AT LEAST ONE OF: ST318 Probability Theory, MA359 Measure Theory.

***Assessment*:** 100% by 2 hour examination.

Lecturer: Vassili Kolokoltsov

STATISTICS	**ST404**	**15 CATS**
Term 2	**Applied Statistical Modelling**	

Important: ***This module is only available to students on four year degrees in the Department of Statistics (MMORSE and MMathStat).***

Prerequisites*:* ST217 Mathematical Statistics A & B, ST215 Forecasting and Control. Students who did not take ST215 can attend the classes for ST215 in order to obtain practice in using SPLUS.

Content*:* Regression is the most widely used tool in statistics. This course will start with a look at multiple regression including variable selection and transformations. The second half of the course will consist of topics chosen from: logistic regression, Poisson regression, robust regression, non-linear regression, time series and simulation.

Aims: To introduce the art of statistical model-building, and to demonstrate that statistical problems do not have precise clear-cut solutions. To give practice in writing a report on a statistical investigation.

Objectives: At the end of the course, students will:
- Appreciate that real problems do not have precise clear-cut solutions
- Understand the need to critically assess the quality of a statistical model by the use of diagnostic measures.

Assessment: 100% by coursework (five questions each worth 20%, all involving the use of SPLUS).

Lecturer: Robin Reed

STATISTICS	**ST405**	**15 CATS**
Term 2	**Bayesian Forecasting and Intervention with Advanced Topics**	

Prerequisites: ST217 Mathematical Statistics A & B.

Availability: **Only available to students who have not taken ST337**

Rationale: Forecasting is a vital prerequiste to decision making. This course is concerned with the theory and practice of short-term forecasting, using both data and subjective information. The course focuses on Dynamic Linear Models (DLM). DLM's are a class of Bayesian Forecasting Models which generalise linear regression models and static statistical linear models. The course offers a very powerful fundamental probabilistic approach to forecasting, controlling and learning about uncertain commercial, financial, economic, production, environmental and medical dynamic systems.

Contents:

- State space modelling
- Bayesian updating of beliefs
- Specifying Dynamic Linear Models
- Updating Dynamic Linear Models, forecasting
- Building Dynamic Linear Models, accommodating external information
- ARIMA models, stationarity

The theory will be illustrated by real examples from industry, marketing, finance, government, agriculture etc.

Students will be given selected advanced research material for independent study and examination.

Books: Printed course notes will be available. Mike West & Jeff Harrison, "Bayesian Forecasting and Dynamic Models", 1997 (2nd edn.) Springer - Verlag. Andy Pole, Mike West & Jeff Harrison, "Applied Bayesian Forecasting and Time Series Analysis", 1994 Chapman and Hall.

Research material on some advanced topics will be made available.

Assessment: 100% by 2-hour examination.

Lecturer: Mark Steel

STATISTICS	**ST406**	**15 CATS**
Term 1	**Applied Stochastic Processes with Advanced Topics**	

Prerequisites: ST202 Stochastic Processes.

Availability: **Only available to students who have not taken ST333**

Aims: To provide an introduction to concepts and techniques which are fundamental in modern applied probability theory and operations research, and which also encroach on statistics:

- Models for queues, point processes, and epidemics.
- Notions of equilibrium, threshold behaviour, and description of structure.
- Techniques of process specification, coupling, and simulation.

These ideas have a vast range of applications, for example routing algorithms in telecommunications (queues), assessment of apparent spatial order in astronomical data (stochastic geometry), description of outbreaks of disease (epidemics). We will only be able to introduce each area - indeed each area could easily be the subject of a course on its own! But the introduction will provide you with a good base to follow up where and when required. (For example: a MORSE student graduating in 1996 found the next year their firm was asking them to address problems in queuing theory, for which ST333 provided the basis.) We will discuss these and other applications and show how the ideas of stochastic process theory help in formulating and solving relevant questions.

Objectives: At the end of the course students will:

- Be able to formulate continuous-time Markov chain models for applied problems.
- Be able to use basic theory to gain quick answers to important questions (for example, what is the equilibrium distribution for a specific reversible Markov chain?).
- Will know in principle how to use simulation techniques to get answers to harder questions.

Students will be given selected research material on advanced topics for independent study and examination.

Assessment: 20% by coursework, 80% by examination.

Lecturer: David Hobson

STATISTICS	ST407	15 CATS
Term 1	**Monte Carlo Methods**	

Aims*:* This module will provide students with the tools for advanced statistical modelling and associated estimation procedures based on computer-intensive methods known as Monte Carlo techniques.

Content*:* When modelling real world phenomena statisticians are often confronted with the following dilemma: should we choose a standard model that is easy to compute with or use a more realistic model that is not amenable to analytic computations such as determining means and p-values. We are faced with such choice in a vast variety of application areas, some of which we will encounter in this module. These include financial models, genetics, polymer simulation, target tracking, statistical image analysis and missing data problems. With the advent of modern computer technology we are no longer restricted to standard models as we can use simulation-based inference. Essentially we replace analytic computation with sampling of probability models and statistical estimation. In this module we discuss a variety of such methods, their advantages, disadvantages, strengths and pitfalls.

Learning Outcomes:
- Knowledge of a collection of simulation methods including Markov chain Monte Carlo (MCMC); understanding of Monte Carlo procedures.
- Ability to develop and implement (in BUGS) an MCMC algorithm for a given probability distribution
- Ability to evaluate a stochastic simulation algorithm with respect to both its efficiency and the validity of the inference results produced by it.
- Ability to use Monte Carlo methods for scientific applications.

Prerequisites*:*
- A basic knowledge of the statistical programming language R or SPLUS (as taught in ST215 Forecasting and Control).
- Probability A & B or equivalent.
- ST217 Mathematical Statistics A & B or equivalent.

Commitment*:* 30 hourly lectures and 5 2-hourly practicals.

Assessment*:* 20% by coursework and 80% by **exam in April**.

Syllabus*:*
1. **Introduction and Examples:** The need for Monte Carlo Techniques; History; Example applications.
2. **Basic Simulation Principles:** Rejection method; variance reduction; importance sampling.
3. **Markov chain theory:** convergence of Markov chains; detailed balance; limit theorems.
4. **Basic MCMC algorithms:** Metropolis-Hastings algorithm; Gibbs sampling.
5. **Implementational issues:** Burn In; Convergence diagnostics, Monte Carlo error.
6. **More advanced algorithms:** Auxiliary variable methods; simulated and parallel tempering; simulated annealing; reversible jump MCMC.

Books:

- W. Gilks et al., Markov chain Monte Carlo in practice, Chapman & Hall, 1996.
- J.S. Liu, Monte Carlo Strategies in Scientific Computing, Springer, 2001.

Lecturer: Elke Thonnes

STATISTICS	ST409	15 CATS
Term 2	Medical Statistics with Advanced Topics	

Availability: **Only available to students who have NOT taken ST332.**

Commitment: 3 lectures/week

Prerequisites: ST217 Mathematical Statistics A and B.

Content: Modern applications of statistics to medicine are highly developed. A look at almost any medical journal reveals that a substantial proportion of medical research papers employ statistical techniques. Large numbers of statisticians are employed in medical research establishments, particularly in the pharmaceutical companies and the medical schools, and medical statistics continues to be the most buoyant area for statistical recruitment. Although the course will cover some topics of a specifically medical nature, much of the work will be discussing basic statistical techniques as applied to medical data, but which could equally well be applied to data arising in other applications. Thus, whilst medicine provides the focus of the course, it could also be viewed as a more general applied statistics course. The course will explain why and how statistics is used in medicine, and study some of the statistical methods commonly used in medical research. Examples and case studies in areas such as cancer, heart disease and psychiatry will be discussed.

- *Generalised linear models:* linear models as an extension of linear regression; analysis of binary data by logistic regression; analysis of counts and proportions. Two by two tables.
- S*tudy designs:* cohort, case-control and survey designs; randomised clinical trials; sample size and power; conditioning and covariance adjustment.
- *Analysis of censored survival data:* life tables; hazard and survival functions; Kaplan-Meier survival curves; parametric survival models, the proportional hazards regression model.

Aims: To introduce applications of statistics in medicine, and some of the statistical methods commonly used in medical research.

Objectives:

- To appreciate the role of statistics in medical research.
- To understand some of the statistical principles of good practice in medical investigations.
- To understand how to use and interpret some of the statistical techniques used in medical data analysis.

Books: A.J. Dobson, "An introduction to generalised linear models"; D.G. Altman, "Practical statistics for medical research"; D. Collett, "Modelling survival data in medical research". (All Chapman & Hall)

Students will be given selected advanced material for further study and examination.

Assessment*:* 20% by coursework, 80% by 2-hour examination.

Lecturers: Geraldine Clarke/Heather Turner

STATISTICS	ST410	15 CATS
Term 1	Designed Experiments with Advanced Topics	

Availability: **Only available to students who have NOT taken ST305**

Prerequisite: ST217 Mathematical Statistics A & B.

Commitment: 30 one-hour lectures.

Background: Designed experiments are used in industry, agriculture, medicine and many other areas of activity to test hypotheses, to learn about processes and to predict future responses. The purpose of experimentation is to determine the relationship between a response variable and the settings of a number of experimental variables which are presumed to affect it. Experimental design is the discipline of determining the number and order (spatial or temporal) of experimental runs, and the setting of the experimental variables.

Content: The theory of experimental design is quite mathematical while the practice involves important eliciting and communication skills. In this course we will look at both these aspects. Classical experimental design is based on the linear model, and the course will start with a review of linear model theory and some simple models; we shall then examine the principles of experimental design and analysis in design theory, in which we consider both qualitative and quantitative factors; a significant part of the course will be spent developing aspects of factorial design theory including confounding and fractional designs, other important topics to be included will be response surface designs and incomplete block designs; finally, we shall discuss optimal design in which the focus is on maximising the information available to the experimenter whatever the experimental constraints. Further topics such as repeated measures and non-linear design will conclude the module.

Aims: This course aims to give students a sound understanding of experimental design, both theoretical and practical. The course will explore the method of analysis of variance and show how it is structurally linked to particular types of design. The combinatoric properties of designs will be explored, and the impact of computers on classical design considered. Examples from many different application areas will be given throughout.

Objectives: By the end of the course students will be able to:

- Describe the basic principles behind designed experiments
- Construct the design matrix for simple experiments and estimate their parameters
- Perform an analysis of variance on standard experimental designs
- Distinguish between different designs and recognise their efficiency / utility
- Show the relationship between designing experiments and analysing the resulting data
- Perform diagnostic tests on the results from a designed experiment.
- Take a practical design problem and determine an optimal or robust solution

Books: G Clarke & R Kempson, *Introduction to the Design and Analysis of Experiments*, Arnold, 1996. DR Cox & N Reid, *The Theory of the Design of Experiments*, Chapman & Hall / CRC, 2000. AC Atkinson & AN Doney, *Optimal Experimental Designs*, Oxford, 1992. DC Montgomery, Design and Analysis of Experiments, Wiley, 2001, 2005
Students will be given selected advanced material for further study and examination.

Assessment: 20% by coursework and 80% by 2-hour examination. There will be two major pieces of coursework, one at the half-way point and one at the end of the course. Other exercises will be provided and discussed during the lectures.

Lecturer: John Fenlon

STATISTICS **Term 1**	**ST411** **Dynamic Stochastic Control**	**15 CATS**

Commitment: 3 x 1-hour lectures per week, 4 examples classes in the term.

Prerequisites: ST318 Probability Theory; ST333 Applied Stochastic Processes.

An example of a stochastic control problem is the 'Red and Black' problem. Essentially, this asks what the best betting strategy is if you want to maximise your chance of winning £1000 playing roulette.

Syllabus: This module will cover:
- Recapitulation of the theory of stochastic processes.
- Introduction to finite horizon control problems and optimal stopping.
- The Hamilton-Jacobi-Bellman equation.
- Infinite horizon discounted problems.
- Applications to finance, clinical trials, planning production processes and insurance, *and, time permitting*
- Discussion of long-run average problems.

Aims: This module is designed to cover the important area of stochastic control within applied probability. The taught material will prepare students for careers in business, industry or government and will also lead up to the boundaries of research.

Learning Outcomes: Students who have successfully completed this module will be able to:
- Identify and deal with stochastic control and optimal stopping problems.
- Solve simple Hamilton-Jacobi-Bellman equations.
- Apply the above techniques to finance, to clinical trials and to the planning of production processes.

Books: Ross, S.M., *Introduction to Stochastic Dynamic Programming*, 1983, Academic Press

Assessment: 1 x 2 hour examination.

Lecturer: Saul Jacka

STATISTICS	**ST412**	**15 CATS**
Term 1	**Multivariate Statistics with Advanced Topics**	

Availability: **Only available to students who have NOT taken ST323**

Prerequisites: ST208 Mathematical Methods, ST217 Mathematical Statistics A and B.

Aims: Multivariate data arises whenever several interdependent variables are measured simultaneously. This occurs frequently in many areas: in medicine, in the social and environmental sciences and in economics. The analysis of such multidimensional data often presents an exciting challenge that requires new statistical techniques which are usually implemented using computer packages. This module aims to give you a good understanding of the geometric and algebraic ideas that these techniques are based on, before giving you any chance to try them out on some real data sets.

Objectives: By the end of the course students will be able to:

- Carry out a principal components analysis and use it to summarise high dimensional data.
- Use linear discriminant analysis to solve simple classification problems.
- Understand the theory of the multivariate normal distribution.
- Perform multivariate hypothesis tests and construct confidence regions.

Book: Krzanowski, W.J., *Prinicples of Multivariate Analysis : a user's perspective*, Oxford: Clarendon 2000

Students will be given selected advanced material for further study and examination.

Assessment: 20% by coursework, 80% by 2-hour examination.

Lecturer: Ewart Shaw

STATISTICS	**ST413**	**15 CATS**
Term 2	**Bayesian Statistics & Decision Theory With Advanced Topics**	

Availability: **Only available to students who have NOT taken ST301**

Prerequisites: ST217 Mathematical Statistics A.

Content: Bayesian statistics is one of the fastest growing areas in statistics. With the advance of computer technology it is now a highly practical methodology for addressing many important high dimensional decision problems as well as being underpinned by a sound mathematical foundation. It is especially useful when some of the components of uncertainty have only sparsely collected data associated with them, so that expert judgements need to be incorporated. The course first introduces the central concepts of Bayesian decision analysis through a selection of simple examples. Various methodologies are then presented for:

- Structuring a decision problem – for example by decision trees and influence diagrams.
- Eliciting probability distributions over many variables – using the concepts of irrelevance and the Belief net.
- Eliciting the objectives and preferences of the client – developing the ideas of m.u.i.a. and value independence and the use of the decision conference.

The formal methodologies are illustrated through a wide range of examples for health, the environment, finance and public sector administration. Some of the examples build on the practical experience of the lecturer as an active Bayesian decision analyst.

Aims:
- To demonstrate how to build statistical models of non-trivial problems when data is sparse and expert judgements need to be incorporated.
- To give ways to represent the pertinent features of a decision problem.
- To give practical algorithms for finding decision rules which the client can expect will best satisfy pre-specified objectives.
- To train the student in the rudiments of decision analysis.

Objectives:
- The student will gain an appreciation of the importance of conditional independence in subjective (Bayesian) statistical modelling and be introduced to the DAG as an efficient representation of collections of conditional independence statements as they arise in practice.
- The student will be provided with techniques for eliciting subjective probability distributions over many variables.
- The student will be provided with techniques for eliciting quantitative preference structures from a client which may involve competing objectives.
- The student will obtain an appreciation of the foundational arguments that justify expected utility maximisation as a paradigm for rational action.
- The student will obtain practice in implementing these techniques.
- The student will learn the bases of fast algorithms for the calculation of probabilities needed in such maximisation.

Students will be given selected advanced material for further study and examination.

Assessment: 100% by 2-hour examination. ***Lecturer***: Jim Smith

STATISTICS	ST414	15 CATS
Term 1	Advanced Topics in Statistics	

Prerequisites: ST217 Mathematical Statistics A & B.

Content: Three self-contained sets of ten lectures.

Asymptotic Statistics (Ioannis Kosmidis)

Aims: The aim of this 10 lectures' topics course is to introduce students to basic asymptotic methods that are used in Statistics and to highlight their importance. Special attention will be paid to likelihood based asymptotics for parametric models, focusing on the asymptotic properties of the maximum likelihood estimator.

It is intended to combine the exposition of some important tools that are used for asymptotic derivations, with parallel presentation of specific applications regarding well-used results in Statistics (such as, for example, the derivation of the asymptotic distribution of the log likelihood-ratio statistic, the $1/2$ adjustment to the binomial counts for bias reduction in log-odds estimation etc.).

Advantages and shortcomings of different asymptotic methods will be explored using computer simulation.

Objectives: By the end of the course students will be able to:

* Understand the derivation of some well-used asymptotic results.
* Use basic asymptotic tools in applications.
* Assess the efficacy of asymptotic approximations by using computer simulation.

Hidden Markov Models (John Aston)

Hidden Markov models (HMMs) provide a rich modelling structure for non-linear time series and sequence analysis. The aim of this course is to familiarise students with the fundamental ideas of HMMs including their setup, estimation and uses. In particular the following will be covered:

- The Viterbi Algorithm which is used to find the most likely underlying state sequence

- The Forwards-Backwards and Baum-Welsh Algorithms for parameter estimation

The course will be motivated by examples from many applications including engineering, economics and biological sciences.

<u>Stein-Chen Method</u> (David Croydon):

Aims: The Stein-Chen method is a powerful modern technique which extends the Poisson 'law of small numbers' (given n independent events each of small probability p, the total number of event which occur is approximately Poisson of distribution np). There are many applications, for example in bioinformatics, insurance, and the study of extreme phenomena.

Objectives: By the end of the course students will be able to:

- Describe the principles of the Stein-Chen method;
- Apply it in a couple of central examples.

STATISTICS	**ST415**	**30 CATS**
	Statistics Masters Dissertation	

Only available to year 4 integrated Masters students.

A list of titles of topics in Probability and Statistics will be available at the beginning of the academic year. This will include both individual titles and group projects (where students work together on a related theme). Other titles are possible by individual arrangements.

Students are advised to refer to the introduction to this booklet for the rules regarding missed deadlines and unacknowledged copying.

5% of the credit is awarded for giving a short oral presentation in the last week of term 1.

The deadline for submission of the project is the end of week 3 of the third term.

STATISTICS	**ST416**	**15 CATS**
Term 2	**Advanced Topics In Biostatistics**	

Prerequisites:
1) Calculus
2) Probability calculus
3) Basic computer literacy (R, Matlab ...)

Commitment: 9 hours

Assessment: 100% by 2 hour examination

This module comprises 3 self-contained sets of 10 lectures on the following topics:-

Title: Statistical Modelling of Biological Processes

Content:
Lecture 1 - Introduction to the Statistical Methodology
Lecture 2 - Survival Analysis
Lecture 3 - Clinical Trials
Lectures 4-5 - Gene Expression Modelling
Lectures 6-7 Analysis of Neural Data

Lectures 8-9 - Pharmaco-kinetic Models

Lecturer: Fabio Rigat

Title: **Missing Data In Statistical Analysis**

Aims: This course offers an introduction to methods for handling missing data in statistics. Almost all applied applications in statistics encounter issues of missing data on some or all variables. Key procedures include single or multiple imputation, weighting methods and likelihood based inferences.

Objectives*:* By the end of the course students should be able to:

1) Understand the key concepts of data being missing completely at random, missing at random and ignorability and their effect on model efficiency and bias.
2) Follow and apply the various methods for missing data problems, with an understanding of their limitations.
3) Make inferences for simple data problems in which information on some variables are missing.

Lecturer: Chiara Mazzetta

Title: **Statistical Population Genetics**

Aims*:* This course aims to introduce the stochastic models used in population genetics, and illustrate their value in analysing genetic data. The Wright-Fisher model and the Moran model will be described. The diffusion approach will be briefly outlined. Coalescent theory will constitute the core of the course, its use will be illustrated by a number of applications in molecular genetics.

Objectives*:* By the end of the course students should be able to:

- Describe the Wright-Fisher and Moran models
- Derive the coalescent theory in simple applications
- Use coalescent theory in simple applications

Lecturer: Xavier Didelot

STATISTICS	**ST417**	**15 CATS**
Term 2	**Topics in Applied Probability**	

Important: This module is only available to final year (4) integrated Masters students.

Prerequisites: ST318, ST333

Aims: This module will cover several topics chosen from modern applied probability. The topics will be selected to demonstrate how probability theory can be used to study various phenomena in the real world. Examples might include random graphs, spatial point processes, branching processes, interacting particle systems, random polymers etc.

Commitment: 3 lectures/week

***Content*:** General concepts and methods of importance in applied probability that will be covered in the module include: scaling laws and critical phenomena in random systems; distributional recursions and distributional fixed points; weak convergence; large deviations, concentration; properties of d-dimensional random walks; random environments quenched and annealed properties; size biasing and Palm measures.

The use of the methods will be introduced and studied through specific topics of approximately 6 lectures length each. These topics will change from year to year but typically might include: random polymers and randomly growing surfaces, random graphs and networks with application in social networks and epidemiology; advanced branching process theory, Galton-Watson trees and applications to genetics; mixing properties of Markov chains and applications to the performance of algorithms; interacting particle systems, voter model, contact processes and exclusion processes; spatial point processes applications to communications networks. For the coursework, students will be asked to read and critically assess in a short report a recent research article in applied probability.

Objectives: By the end of the course, the student will:
- Understand and be able to use key methods and concepts of applied probability.
- Understand and be aware of examples of current research involving the application of probability.
- Be able to critically evaluate a recent research article in applied probability.

Books: There will not be a single book that will contain all the material for this course. Examples of books containing some of the topics that will be discussed include:

Aldous, D., Probability approximations via the Poisson clumping heuristic, Springer-Verlag, New York, 1989
Bremaud, P, Markon Cahins, Gibbs Fields, MOnte Carlo Simulations and Queues, Springer, 1999
Den Hollander, F., Large Deviations, Fields Institute Monographs, 2000
Kingman, J. F. C., Poisson processes, Oxford University Press, New York, 1993.
Liggett, T. M., Interacting particle systems, Springer-Verlag, New York, 1985.
Sznitman, A-S, Brownian Motion, Obstacles and Random Media, Springer, 1998

Assessment: 10% by coursework and 90% by 2hr exam.

Lecturers: David Croydon/Nikolaos Zygouras

STATISTICS	**ST906**	**15 CATS**
Term 2	**Financial Time Series**	

Important: This module is only available to final year (4) integrated Masters students.

***Summary*:**
Most financial data is available in time series form and therefore the statistics and modelling of time series data are essential components underpinning mathematical finance. The module aims to provide the relevant statistical theory and experience in financial time series statistics. One-third of the course covers exploratory and descriptive techniques for various features,

such as long term level, fluctuation, distribution, linear and non-linear dependence, short and long memory dependence, directionality and volatility. Both linear and non-linear models are equally developed. Linear autoregressive moving average and nonlinear locally non-constant variance models are covered, as applicable to volatile financial returns, interest, exchange rates and futures. Ways of fitting these models to time series data, methods of their statistical validation and their use in such financial areas as forecasting, systematic trading models, fund manager evaluation, hedging, option evaluation and simulation are covered. The course aims to give practical experience in the use of specialized time series software for class examples and projects. .

***Aims*:**

The Module aims to provide the student with background and skills

(a) to be able to model and analyze financial time series data, and to extend and develop methodology as required

(b) to understand and be able to critically evaluate times series developments and research results in the finance area

Learning Outcomes:

By the end of the module the student should have:

- a good theoretical understanding of the standard techniques of time series analysis as applied in the finance area
- an ability to carry out exploratory and descriptive analysis of time series data, particularly with reference to financial applications
- mathematical ability in deriving the statistical properties of linear and nonlinear time series models
- a general appreciation of nonlinearity in time series modelling, and in particular with respect to modelling volatile financial series
- an ability to undertake modelling studies of time series involving forecasting and simulation, with appropriate software, and covering model choice, fitting and validation

***Content*:**

Examples, exploration and description of time series data: long term and local level, fluctuation, distribution, short and long term memory dependence, directionality and volatility. Use of statistical time series software. Linear modelling of time series: meaning of linearity, autoregressive and moving average models and their statistical properties, likelihood estimation and residual analysis, forecasting and simulation. Illustrative financial applications. Nonlinear modelling of financial time series: meaning of non-linearity, various non-constant conditional variance models for volatility, their statistical properties, their use in financial time series data analysis and systematic trading models, and example applications in finance. Presentation by practitioner from the finance industry showing use of time series methodology.

Organisation:

There will be one 2-hour lecture and one 1-hour seminar or problem class per week.

***Texts*:**

Franke J, Hardle W and Hafner C, (2004) *Statistics of Financial Markets*, Springer
Cizek P, Hardle W and Weron R, (2005) *Statistics for Finance and Insurance*, Springer
Tsay RS, (2005) *Analysis of Financial Time Series,* (Second Edition), Wiley.
T L Lai & H Xing, (2008) *Statistical Models and Methods for Financial Markets*

Brockwell PJ and Davis RA, (2002) *Introduction to Time Series and Forecasting,* (Second Edition), Springer

***Assessment*:**
Financial Time Series is examined by a single 90-minute paper **at the beginning of Term 3**. There is also assessed coursework in the form of three mini-projects which is weighted at 20%.

Lecturer: Tony Lawrance

STATISTICS	**ST907**	**15 CATS**
Term 1	**Statistics for Finance**	

Pre-Requisites: ST908 (Weeks 1-5) Probability and Stochastic Processes

Commitment: There will be one 2-hour lecture and one 1-hour tutorial or problem class per week. (Weeks 6 – 10).

Aims: This course presents introductory statistics in a quantitative finance context. It takes introductory probability from the first half of ST908 as its theoretical base and presents relevant aspects of statistical methodology together with their underlying theory, computational and graphical aspects, and financial applications. The course deals with statistical data, both as distributions of single variables and in modelling relationships between variables. Statistical estimation and formal assessment of uncertainty are covered. Experience in handling and analyzing financial data with statistical software is a practical aspect of the course. Students attending this course should be able to understand the mathematical basis of the methodology as presented, be able to analyze financial data with standard statistical analysis techniques and be able to critically understand presentations of statistical data in financial contexts

Contents:
1. The population-sample paradigm of statistics, inductive/deductive aspects, relationship to probability theory. Random variables as models of data. Graphical aspects of data distributions, such as probability plots.

2. Probability distributions, such as Normal, logNormal, high kurtosis distributions and fat tail distributions for extreme behaviour. Mathematical calculation of distributional properties, and their particular financial applicabilities.

3. Matching distributions to data, need for parameter estimation. Idea of likelihood and its use in estimating parameters.

4. Statistical relationships between variables by regression. Ideas of residuals to explore inadequacies and improve analysis.

5. Formal assessment of uncertainty in statistics, confidence intervals, tests of significance.

Learning Outcomes: Demonstrate a good understanding of basic statistical ideas, as applied in the finance area. Have the ability to carry out statistical analysis of financial data, both for single variables and for relationships between variables. An ability to efficiently and critically use statistical software to carry out and graphically present statistical-based conclusions

Texts:
Rupert D, (2004) *Statistics and Finance - An Introduction*, Springer Verlag

Franke J, Hardle W and Hafner C, (2004) *Statistics of Financial Markets*

SpringerMcNeil AJ, Frey R and Embrechts P (2005) *Quantitative Risk Management*, Princeton University Press

Assessment: Assessment consists of an examination giving 90% of the final mark, taken as a one-hour paper in January, and assessed course work giving 10% of the final mark.

Lecturer: Nikolaos Zygouras

STATISTICS	**ST908**	**15 CATS**
Term 1	**Probability and Stochastic Processes**	

Commitment: 1 x 2 hour lectures + 1 seminar per week

***Content*:**

1. Sample spaces, events and probabilities. Conditional probability. Independence. Discrete random variables including geometric, Poisson. Expectation.

2. Continuous random variables, including Gaussian, exponential, gamma. Distributions of functions of functions of random variables. Sums of random variables. Conditional distributions.

3. Borel-Cantelli Lemmas, Convergence of random variables. Convergence of expectations.Fatou's Lemma.

4. Weak law, strong law. Connections with Monte-Carlo simulation. Central limit theorem.

5. Filtrations, information conditional expectation. Martingales in discrete and continuous time. Stopping times.

6. Stochastic processes. Markov property. Simple random walks. Ruin probabilities. Poisson process.

7. Brownian motion. Quadratic variation, volatility. Hitting times for linear boundaries. Simple models for bankruptcy.

8. Ito’s formula. Stochastic integrals. Gains from trade processes. Stochastic differential equations.

9. Diffusions, exponential Brownian motion. Samuelson model for stock prices. Scale functions.

10. Brownian martingale representation theorem, Girsanov change of measure. Black-Scholes formula for call options.

***Texts*:**

Grimmett G. and Stirzacker D., (2001), *Probability and Random Processes*, 3rd edition, Oxford: OUP.

Oksendal B., (2003), *Stochastic Differential Equations: An Introduction with Applications*, 6th edition, Berlin and Heidelberg: Springer-Verlag.

Shreve, S.E., (2005), *Stochastic Calculus for Finance*, New York: Springer-Verlag.

***Assessment*: Examination (80%), Coursework (20%)**

Lecturer: David Hobson

STATISTICS	**ST909**	**15 CATS**
Term 2	**Continuous Time Finance for Interest Rate Models**	

Prerequisites: ST401 Stochastic Methods in Finance
or ST403 Brownian Motion or ST908 Probability and Stochastic Processes

Commitment: 3 x 1 hour lectures per week

Content:

Mathematical Foundations

1. Monotone convergence, dominated convergence and Fatou's lemma for conditional expectation. Optional sampling theorem. Finite variation processes as integrators, quadratic variation for continous martingales, Meyer's Theorem.

2. Continuous Local Martingales, properties of the stochastic integral with respect to continuous local martingales. Continuous semimartingales as integrators, integration by parts and multidimensional Ito's formula for continuous semimartingales,Levy's Theorem.

3. Radon-Nikodym derivative, Girsanov's Theorem for semimartingales, Novikov's condition Martingale Representation Theorem

Option Pricing in Continuous Time

4. Pricing via PDEs (brief review)
Pricing via equivalent martingale measures, fundamental valuation formula, arbitrage and admissible strategies. Completeness for the Black Scholes economy. Pricing kernels

5. Implied volatility, market implied distributions. Stochastic volatility and incomplete markets. Multicurrency Economy.

Term Structure Models

5. ctd. Short rate models. Introduction to main examples, implementation of Hull-White

6. Review of main types of term structure models including Pure discount Bond, Heath-Jarrow-Morton , Flesaker-Hughston.

7. Market Models (Brace, Gaterek and Musiela approach), specification in terminal and spot measure.

8. Pricing callable interest rate derivatives with market models, drift approximation and separability, implementation via Longstaff-Schartz Greeks via Monte Carlo for market models, pathwise method, likelihood ratio method.

9. Markov-functional models

10. Practical issues in choice of model for various exotics, Bermudan swaptions, TARNS Calibration: global versus local

Examination: (80%) 2 class tests (20%)

Lecturer: Jo Kennedy