INDIAN STATISTICAL INSTITUITE

STUDENTS' BROCHURE

MASTER OF STATISTICS

203, BARRACKPORE TRUNK ROAD
KOLKATA 700108

INDIAN STATISTICAL INSTITUTE
STUDENTS' BROCHURE
M.STAT. PROGRAMME

1. GENERAL INFORMATION

1.1 Scope

The M.Stat. programme offers advance level training in the theory, methods and applications of Statistics along with specialized training in selected areas of Statistics and allied fields. Depending on the area of specialization, students would be able to pursue an academic/research career in Statistics, Mathematics, Economics, Computer Science and allied fields. They would be able to work competently as Statisticians and specialists in research institutions and scientific laboratories, government departments or industries.

1.2 Duration

The total duration of the M.Stat. programme is four semesters. An academic year usually starts in July-August and continues till May, consisting of two semesters with a recess in-between. Usually, there is a study-break of one week before the semestral examinations in each semester. All M.Stat. students are required to undergo a training in ``National and International Statistical Systems'' at the CSO, New Delhi for three weeks at the end of their First Year (usually May-June). The timetable of the classes preferably should not have an off-day at the beginning or the end of the week.

1.3 Course Structure

The M.Stat. programme has two streams: the NB-stream for students getting admitted through the entrance test and the B-stream for all the students. The set of courses to be taken in a semester depends on the stream, the choice of optional courses and the choice of specialization. Other than the twenty credit courses, the students in the M.Stat. programme undergo a training in National and International Statistical Systems at the C.S.O., New Delhi, which is a non-credit course and forms a part of the M.Stat. programme.

1.4 Examinations and Scores

The final (semestral) examination in a course is held at the end of the semester. Besides, there is a mid-semestral examination in each course. The calendar for the semester is announced in advance. The mid-semestral examinations are held over a maximum period of two weeks.

The composite score in a course is a weighted average of the scores in the mid-semestral and semestral examinations, homework, assignments, and/or project work in that course; the weights are announced beforehand by the Dean of Studies, the In-charge, Students' Academic Affairs, or the Class Teacher, in consultation with the teacher concerned . The minimum composite score to pass a course is 35%.

If the composite score of a student falls short of 45% in a credit course, or 35% in a non-credit course, the student may take a back-paper examination to improve the score. At most one back-paper examination is allowed in each course. Moreover, a student can take at most four back-paper examinations (for credit courses) in the first year and only two (for credit courses) in the second year. The decision to allow a student to appear for the back-paper examination is taken by the appropriate Teachers' Committee. The back-paper examination covers the entire syllabus of the course. When a student takes back-paper examination in a credit course, his final score in that course is the higher of

the back-paper score and the earlier composite score, subject to a maximum of 45%.

If a student gets less than 35% in at most one course after the back-paper examination, but gets 60% or more in average in other courses of that academic year excluding the course under consideration, the student can appear for a compensatory paper in the course under consideration. A student can appear in at most one compensatory paper every academic year. However, in the final year of the programme, the student can *either* appear in the compensatory paper, if the conditions stated above are met, *or* repeat the year if the existing rules so allow; and not do both. The student must inform the Dean of Studies or the In-Charge, Academic Affairs in writing in advance regarding his/her choice. No compensatory paper will be allowed in a course where backpaper is not allowed, e.g., Statistics Comprehensive in B. Stat. programme. The compensatory examinations for all subjects will be held once in an academic year. A student can score at most 35% in a compensatory paper. If a student scores more than 35% in a compensatory paper, the composite score in the course will be 35%. Any student who scores less than 35% in a compensatory paper will have to discontinue the programme regardless of the year of study in the academic programme.

There will be supplementary examination for mid-semestral, semestral, back-paper and compensatory examinations withing a month of the examination missed by a student due to medical or family emergenccies. The student should submit a written application to the Dean of Studies or the In-Charge, Academic Affairs for appearing in the supplementary examination, enclosing supporting documents. On receipt of such application from a student with supporting documents, the Dean of Studies or the In-Charge, Academic Affairs will decide, in consultaion with the relevant Teachers' Committee, on whether such examination will be allowed. The student can score at most 60% in the supplementary examinations to mid-semestral and semestral examinations. For the back-paper or the compensatory papers, the maximum the student can score in the supplementary examination, is 45% or 35% respectively.

A student may take more than the allotted quota of backpaper examinations in a given academic year, and decide at the end of that academic year which of the backpaper examination scores should be disregarded.

1.5 Satisfactory Conduct

A student is also required to maintain satisfactory conduct as a necessary condition for taking semestral examination, for promotion and award of degree. Unsatisfactory conduct will include copying in examination, rowdyism, other breach of discipline of the Institute, unlawful/unethical behaviour and the like. Violation of these is likely to attract punishments such as withholding promotion / award of degree, withdrawing stipend and/or expulsion from the hostel / Institute.

Ragging is banned in the Institute and any one found indulging in ragging will be given punishment such as expulsion from the Institute, or suspension from the Institute/classes for a limited period and fine. The punishment may also take the shape of (i) withholding Stipend/Fellowship or other benefits, (ii) withholding of results, (iii) suspension or expulsion from hostel and the likes. Local laws governing ragging are also applicable to the students of the Institute. Incidents of ragging may also be reported to the police.

The students are also required to follow the following guidelines during the examinations:

i. Students are required to take their seats according to the seating arrangement displayed. If any student takes a seat not allotted to him/her, he/she may be asked by the invigilator to hand over

the answer script (i.e., discontinue the examination) and leave the examination hall.

ii. Students are not allowed to carry inside the examination hall any mobile phone with them–even in switched-off mode. Calculators, books and notes will be allowed inside the examination hall only if these are so allowed by the teacher(s) concerned (i.e., the teacher(s) of the course), or if the question paper is an open-note/open-book one. Even in such cases, these articles cannot be shared.

iii. No student is allowed to leave the examination hall without permission from the invigilator(s). Further, students cannot leave the examination hall during the first 30 minutes of any examination. Under no circumstances, two or more students writing the same paper can go outside together.

iv. Students should ensure that the main answer booklet and any extra loose sheet bear the signature of the invigilator with date. Any discrepancy should be brought to the notice of the invigilator immediately. Presence of any unsigned or undated sheet in the answer script will render it (i.e., the unsigned or undated sheet) to be cancelled, and this may lead to charges of violation of the examination rules.

v. **Any student caught cheating or violating examination rules for the first time will get 'Zero' in that examination. If the first offence is in a backpaper examination, the student will get 'Zero' in the backpaper**. (The other conditions for promotion, as mentioned in Section 1.7 of the Students' Brochure will continue to hold).

vi. If any student is caught cheating or violating examination rules for the second/third time and he/ she

(a) is in the final year of any programme and *not* already repeating, then he/she will have to repeat the final year without stipend;

(b) is in the final year of any programme and already repeating, then he/she will have to discontinue the pogramme;

(c) is *not* in the final year of any programme, then he/she will have to discontinue the programme even if he/she was not repeating that year.

Any student caught cheating or violating examination rules for the second/third time, will be denied further admission to any programme of the Institute.

Failing to follow the examination guidelines, copying in the examination, rowdyism or some other breach of discipline or unlawful/unethical behaviour etc. are regarded as **unsatisfactory conduct**.

The decisions regarding promotion in Section 1.7 and final result in Section 1.8 are arrived at taking the violation, if any, of the satisfactory conducts by the student, as described in this Section.

1.6 Promotion

A student is considered for promotion to the next year of the programme only when his/her conduct has been satisfactory. Subject to the above condition, a student is promoted from First Year to Second Year if the average composite score in all credit courses taken in the first year is not less than 45%, and no composite score in a course is less than 35%, and at most 4 courses with composite course less than 45%.

1.7 Final Result

At the end of the second year, the overall average of the percentage composite scores in all the credit courses taken in the two-year programme is computed for each student. The student is awarded the

M.Stat. degree in one of the following categories according to the criteria he/she satisfies, provided, in the second year, he/she does not have a composite score of less than 35% in a course, and his/her conduct is satisfactory.

Final Result	Score
M.Stat., First Division with Distinction	(i) The overall average score is at least 75%, and (ii) the composite score in at most two credit courses is less than 45%.
M.Stat., First Division	(i) Not in First Division with Distinction, (ii) the overall average score is at least 60%, and (iii) the composite score in at most four credit courses is less than 45%.
M.Stat., Second Division	(i) Not in First Division with Distinction or First Division, (ii) the overall average score is at least 45%, and (iii) the composite score in at most four credit courses is less than 45%.

All other students are considered to have failed. The students who fail but obtain at least 35% average score in the second year, have not taken any compensatory examination in the final year and have satisfactory conduct are allowed to repeat the final year of the M.Stat. programme without stipend; the scores obtained during the repetition of the second year are taken as the final scores in the second year. A student is not given more than one chance to repeat the second year of the programme.

1.8 Award of Certificate

A student passing the M.Stat. degree examination is given a certificate which includes (i) the list of all credit courses taken in the two-year programme along with the respective composite scores, (ii) the list of all non-credit courses passed and (iii) the category (First Division with Distinction or First Division or Second Division) of his/her final result.

The certificate is awarded in the Annual Convocation of the Institute following the last semestral examinations.

1.9 Prizes and Medals

Students are awarded prizes in form of book awards for good academic performances in each semester as decided by the Teachers' Committee.

The most outstanding M.Stat. student of the Institute, as decided by a committee based on his/her performance in an invited lecture, is given a gold medal for Mahalanobis International Symposium on Statistics prize. The best M.Stat. student of the Institute, as decided by the Teachers' Committee based on the academic performance, is given the ISI Alumni Association – Mrs. M. R. Iyer Memorial gold medal. The best project in M.Stat. IInd year is given the TCS award.

1.10 Class Teacher

One of the instructors of a class is designated as the Class Teacher. Students are required to meet their

respective Class Teachers periodically to get their academic performance reviewed, and to discuss their problems regarding courses.

1.11 Attendance

Every student is expected to attend all the classes. If he/she is absent, he/she must apply for leave to the Dean of Studies or the In-charge, Students' Academic Affairs. Failing to do so may result in disciplinary action.

1.12 Stipend

Stipend, if awarded at the time of admission, is valid initially for the first semester only. The amount of stipend to be awarded in each subsequent semester will depend on academic performance and conduct, as specified below, provided the requirements for continuation of the academic programme (excluding repetition) are satisfied; see Section 1.6.

Performance in course work:

All composite scores used in the following are considered after the respective back-paper examinations.

i. If all the requirements for continuation of the programme are satisfied, and the average composite score is at least 60% and the number of credit course scores less than 45% is at most one in any particular semester, the full value of the stipend is awarded in the following semester.
ii. If all the requirements for continuation of the programme are satisfied, and the average composite score is at least 45% and the number of credit course scores less than 45% is at most one in any particular semester, then half stipend is awarded in the following semester.
iii. In all cases other than i. and ii. above, no stipend is awarded in the following semester.

Attendance:

i. If the overall attendance in all courses in any particular semester is less than 75%, no stipend is awarded in the following semester.

Conduct:

i. The Dean of Studies, the In-charge, Students' Academic Affairs or the Class Teacher, at any time, in consultation with the respective Teachers' Committee, may withdraw the stipend of a student fully for a specific period if his/her conduct in the campus is found to be unsatisfactory.

Note: The net amount of the stipend to be awarded is determined by simultaneous and concurrent application of all clauses described above; but, in no case, the amount of stipend to be awarded or to be withdrawn should exceed 100% of the prescribed amount of stipend.

Stipends can be restored because of improved performance, but no stipend is restored with retrospective effect.

Stipends are given after the end of each month for eleven months in each academic year. The first stipend is given two months after admission with retrospective effect provided the student continues in the M.Stat. programme for at least two months. Stipends are also given to the M.Stat. students during their CSO training programme at New Delhi.

Contingency grants can be used for purchasing a scientific calculator and other required accessories for the practical class, text books and supplementary text books and for getting photostat copies of required

academic material. All such expenditure should be approved by the Class Teacher. No contingency grants are given in the first two months after admission.

1.13 Library Rules

Any student is allowed to use the reading room facilities in the library and allowed access to the stacks. The M.Stat. students have to pay a security deposit of Rs. 250 (in Kolkata) /Rs. 200 (in Delhi) in order to avail him/herself of the borrowing facility. A student can borrow at most four books at a time.

Any book from the Text Book Library (TBL) collection may be issued out to a student only for overnight or weekend provided at least one copy of that book is left in the TBL. Only one TBL book is issued at a time to a student. Fine is charged if any book is not returned by the due date stamped on the issue-slip. The library rules, and other details are posted in the library.

1.14 Placement

Students who have successfully completed the M.Stat. programme are now well placed in government and semi-government departments, public and private sector undertakings, and industries/service organizations. Most of the students of the Institute get employment offers even before they complete the qualifying degree examinations.
There are Placement Committees in Kolkata and Delhi, which arrange campus interviews by prospective employers.

1.15 Hostel Facilities

The Institute has hostels for male and female students in its premises in Kolkata and Delhi. However, it may not be possible to accommodate all students in the hostels. Limited medical facilities are available free of cost at Kolkata and Delhi campuses. Students, selected for stay in the hostels, will have to pay Rs. 605 (in Kolkata) / Rs. 650 (in Delhi) as hostel deposit, whereas the hostel rent of Rs. 60 per month (in Kolkata) / Rs. 75 per month (in Delhi), is deducted from their monthly stipend.

The Institute campus in Kolkata is about 12 km from the city centre. The Delhi campus is about 20 km from the city centre.

1.16 Change of Rules

The Institute reserves the right to make changes in the above rules, course structure and the syllabi as and when needed.

2. DETAILED COURSE STRUCTURE

The M.Stat. programme is offered in two different streams, namely, B-stream and NB-stream. The students also need to do either a two-year *Applications* specialization or one of the following specializations in the second year:

- *Advanced Probability (AP)*
- *Actuarial Statistics (AS)*
- *Applied Statistics and Data Analysis (ASDA)*
- *Biostatistics and Data Analysis (BSDA)*
- *Industrial Statistics and Operations Research (ISOR)*
- *Mathematical Statistics and Probability (MSP)*
- *Quantitative Economics (QE)*

A student, who does not do *Applications* specialization, must follow the usual first year curriculum in his/her stream, as given below. Students with B.Stat. (Hons.) degree from the Institute and getting a direct admission to the M.Stat. programme is put in the B-stream and has to choose between the usual first year curriculum for the B-stream and the *Applications* specialization. A student, who joins the programme by qualifying in the entrance test, is placed in NB-stream or B-stream with usual respective first year curricula or *Applications* specialization by the Selection Committee.

After the first year, students who opted for the *Applications* specialization can either continue to follow the curriculum for the specialization, or discontinue the *Applications* specialization and opt for a different specialization, one among the one-year ones mentioned above. Those opting for a different specialization will have to take the following courses concurrently in the second year:

i. a non-credit course in C/C++ programming and
ii. the courses prerequisite for the chosen specialization.

At least one month before the beginning of the second year, a student wishing to change specialization must make a written application to the Dean of Studies through the Class Teacher seeking permission to discontinue the *Applications* specialization and indicating the choice of a different specialization. The Class Teacher in consultation with the Teachers' Committee will decide on the application of the switchover.

Students, who did not do *Applications* specialization in the first year, can opt for any specialization including *Applications* in the second year.

Offering a specialization in a particular centre is subject to the interest of the students and the availability of the adequate resources. The Dean of Studies will inform the students in advance about the availability of the specializations and the respective centres. Each specialization has a number of prerequisites in terms of specific courses. The maximum class size of any particular specialization in a centre is also limited. The final selection of students for various specializations is determined by the Dean of Studies in consultation with the Teachers' Committee. All the courses listed below are allocated three or four lecture sessions and one practical-cum-tutorial session per week. The practical-cum-tutorial session consists of one or two periods. These periods are meant to be used for discussion on problems, practicals, discussion of computer outputs, assignments, for special lectures and self-study etc. All these need not be contact hours.

2.1 First Year Curriculum for Students without Specialization

First Year, First Semester

	NB-stream		B-stream
1.	Linear Models and Markov Chain	1.	Large Sample Statistical Methods
2.	Real Analysis	2.	Measure Theoretic Probability
3.	Sample Surveys and Design of Experiments	3.	Sample Surveys and Design of Experiments
4.	Large Sample Statistical Methods	4.	Applied Stochastic Processes
5.	Statistical Inference I	5.	Statistical Inference I

First Year, Second Semester

	NB-stream		B-stream
1.	Regression Techniques	1.	Regression Techniques
2.	Multivariate Analysis	2.	Multivariate Analysis
3.	Programming and Data Structures	3.	Metric Topology and Complex Analysis
4.	Elective Course I	4.	Elective Course I
5.	Elective Course II	5.	Elective Course II

List of First Year Second Semester Elective Courses:

1. Time Series Analysis (required for AS, ASDA, BSDA and QE specializations)
2. Optimization Techniques (required for ISOR specialization)
3. Metric Topology and Complex Analysis (required for MSP and AP, available only to NB-stream students)
4. Nonparametric and Sequential Analysis (available only to NB-stream students)
5. Measure Theoretic Probability (required for MSP and AP, available only to NB-stream students)
6. Discrete Mathematics

2.2 Applications specialization

The Applications specialization is open to all students of the M.Stat. programme. A student has to do 15 compulsory and 5 elective credit courses over 4 semesters, with 5 courses in each semester. He/she has to do a non-credit training course on "National and International Statistical Systems" at the end of the first year, offered in collaboration with the Central Statistical Organization, New Delhi, as described in Section 2.3.

First Year

	First Semester		Second Semester
1.	Analysis I	1.	Probability and Stochastic Processes II
2.	Probability and Stochastic Processes I	2.	Linear Models and GLM*
3.	Methods of Statistical Inference I*	3.	Statistical Inference II*
4.	Linear Algebra	4.	Multivariate Analysis*
5.	Elements of Sample Surveys and Design of Experiments*	5.	Regression Techniques*

Second year

	First Semester		Second Semester
1.	Analysis II	1.	Probability and Stochastic Processes III
2.	Statistical Computing*	2.	Project
3.	Time Series Analysis*	3.	Elective III
4.	Elective I	4.	Elective IV
5.	Elective II	5.	Elective V

The courses marked * will have an emphasis on practicals using suitable statistical packages.

A partial list of Elective Courses:

1. Metric Topology and Complex Analysis
2. Measure Theory
3. Advanced Linear Algebra and Matrix Analysis
4. Functional Analysis
5. Topics in Fourier Analysis
6. Applied Multivariate Analysis
7. Advanced Sample Surveys
8. Topics in Design of Experiments
9. Survival and Actuarial Models
10. Nonparametric Inference
11. Actuarial Methods
12. Generalized Inverse and Applications
13. Graph Theory
14. Microeconomics I
15. Macroeconomics I
16. Microeconomics II
17. Game Theory
18. Finance
19. Special Topics

The elective courses may also be chosen from any of the M.Stat. courses offered in the second year.

2.3 Training Course on "National and International Statistical Systems"

It is a non-credit course offered at the end of the first year in collaboration with the Central Statistical Organization, New Delhi. The duration of this course is three weeks. In case of failure in this course, even after the back-paper examination, a student may be allowed, in exceptional cases, to undergo training for a second time at his/her expense at the end of the second year of the M.Stat. programme.

2.4 Second Year Curriculum for Various One-year Specializations

The specializations to be offered at different centres are announced beforehand. Each student is asked to give his/her options for different specializations. Each student will be admitted to a particular specialization based on his/her options and academic background. A student has to take ten courses in the second year, out of which a specified number of courses has to be taken from the selected specialization; the other courses may be taken from the entire list of courses offered in the second year. The courses to be offered in each semester for different specializations are announced beforehand depending on availability of resources.

2.4.1 Advanced Probability (AP) Specialization

Prerequisite courses: Metric Topology and Complex Analysis and Measure Theoretic Probability.

A student in the AP specialization has to take four compulsory courses and six elective courses, at least three of which must be from the Main List of Elective Courses for AP. The remaining elective courses

may be chosen from any of the M.Stat. courses offered in the second year.

	First Semester		Second Semester
1.	Advanced Probability I	1.	Stochastic Processes I
2.	Functional Analysis	2.	Stochastic Processes II
3.	Elective I	3.	Elective IV
4.	Elective II	4.	Elective V
5.	Elective III	5.	Elective VI

Main List of Elective Courses (at least THREE courses from this list)

2. Ordinary and Partial Differential Equations
3. Advanced Functional Analysis
4. Ergodic Theory
5. Quantum Probability
6. Stochastic Integration
7. Multidimensional Diffusions
8. Theory of Large Deviations
9. Probability on Banach Spaces
10. Statistical Mechanics
11. Inference in Stochastic Processes
12. Topics in Set Theory
13. Topics in Fourier Analysis
14. Linear Lie Groups and Their Representations
15. Calculus on Manifolds
16. Percolation Theory
17. Martingale Problems and Markov Processes

Supplementary List of Elective Courses

1. Special Topics in AP

2.4.2 Actuarial Statistics (AS) Specialization

Prerequisite course: Time Series Analysis.

A student in the AS specialization has to take four compulsory courses and six elective courses, at least four of which must be from the Main List of Elective Courses for AS. The remaining elective courses may be chosen from any of the M.Stat. courses offered in the second year.

	First Semester		Second Semester
1.	Actuarial Methods	1.	Actuarial Models
2.	Life Contingencies	2.	Survival Analysis
3.	Elective I	3.	Elective IV
4.	Elective II	4.	Elective V
5.	Elective III	5.	Elective VI

Main List of Elective Courses (at least FOUR courses from this list)

1. Statistical Computing
2. Game Theory I

3. Microeconomic Theory I
4. Macroeconomic Theory I
5. Theory of Finance I
6. Theory of Finance II
7. Applied Multivariate Analysis
8. Life Testing and Reliability
9. Theory of Games and Statistical Decisions
10. Stochastic Processes I
11. Econometric Methods
12. Statistical Methods in Demography

Supplementary List of Elective Courses

1. Special Topics in AS

2.4.3 Applied Statistics and Data Analysis (ASDA) Specialization

Prerequisite course: Time Series Analysis.

A student in the ASDA specialization has to take six compulsory courses including a project and four elective courses, at least two of which must be from the Main List of Elective Courses for ASDA. The remaining elective courses may be chosen from any of the M.Stat. courses offered in the second year.

	First Semester		Second Semester
1.	Advanced Design of Experiments	1.	Advanced Sample Surveys
2.	Analysis of Discrete Data	2.	Applied Multivariate Analysis
3.	Statistical Computing	3.	Elective III
4.	Elective I	4.	Elective IV
5.	Elective II	5.	Project

Main List of Elective Courses (at least TWO courses from this list)

2. Survival Analysis
3. Statistical Methods in Genetics I
4. Biostatistics
5. Life Testing and Reliability
6. Theory of Games and Statistical Decisions
7. Econometric Methods
8. Quantitative Models in Social Sciences
9. Pattern Recognition and Image Processing
10. Analysis of Directional Data

Supplementary List of Elective Courses

1. Special Topics in ASDA

2.4.4 Biostatistics and Data Analysis (BSDA) Specialization

Prerequisite course: Time Series Analysis.

A student in the BSDA specialization has to take seven compulsory courses including a project and three elective courses, at least one of which must be from the Main List of Elective Courses for BSDA.

The remaining elective courses may be chosen from any of the M.Stat. courses offered in the second year.

First Semester	Second Semester
1. Statistical Methods in Genetics	1. Survival Analysis
2. Analysis of Discrete Data	2. Statistical Methods in Public Health
3. Statistical Computing	3. Statistical Methods in Biomedical Research
4. Elective I	4. Elective III
5. Elective II	5. Project

Main List of Elective Courses (at least ONE courses from this list)

1. Advanced Design of Experiments
2. Advanced Sample Surveys
3. Applied Multivariate Analysis
4. Life Testing and Reliability
5. Theory of Games and Statistical Decisions
6. Statistical Ecology
7. Statistical Methods in Genetics II
8. Statistical Methods in Demography
9. Pattern Recognition and Image Processing
10. Analysis of Directional Data

Supplementary List of Elective Courses

1. Special Topics in BSDA

2.4.5 Industrial Statistics and Operations Research (ISOR) Specialization

Prerequisite course: Optimization Techniques.

A student in the ISOR specialization has to take seven compulsory courses including a project and three elective courses, which can be chosen from any of the M.Stat. courses offered in the second year.

First Semester	Second Semester
1. Advanced Design of Experiments	1. Management Applications of Optimization
2. Life Testing and Reliability	2. Industrial Applications of Stochastic Processes
3. Quality Control and Its management	3. Optimization Techniques II
4. Elective I	4. Elective III
5. Elective II	5. Project

There is no Main List of Elective Courses for ISOR Specialization.

Supplementary List of Elective Courses

1. Optimization Techniques III
2. Optimization Techniques IV
3. Network Analysis
4. Sampling Inspection
5. Scheduling Theory
6. Industrial Engineering and Management
7. Special Topics in ISOR

2.4.6 Mathematical Statistics and Probability (MSP) Specialization

Prerequisite courses: Metric Topology and Complex Analysis and Measure Theoretic Probability.

A student in the MSP specialization has to take four compulsory courses and six elective courses, at least three of which must be from the Main List of Elective Courses for MSP. The remaining elective courses may be chosen from any of the M.Stat. courses offered in the second year.

An MSP student with the B.Stat. (Hons) background can opt for a two-semester dissertation in lieu of two main elective courses provided he/she has the average of at least 80% marks in all the Statistics and Probability courses of the B.Stat. (Hons.) curriculum and at least 85% marks in the first year of the M.Stat. curriculum.

First Semester	Second Semester
1. Advanced Probability I	1. Stochastic Processes I
2. Functional Analysis	2. Statistical Inference II
3. Elective I	3. Elective IV
4. Elective II	4. Elective V
5. Elective III	5. Elective VI

Main List of Elective Courses (at least THREE courses from this list)

1. Nonparametric Inference
2. Advanced Design of Experiments
3. Advanced Sample Surveys
4. Theory of Games and Statistical Decisions
5. Sequential Analysis and Optimal Stopping
6. Topics in Bayesian Inference
7. Time Series Analysis
8. Asymptotic Theory of Inference
9. Pattern Recognition and Image Processing
10. Statistical Computing
11. Analysis of Direction Data
12. Dissertation

Supplementary List of Elective Courses

1. Topology and Set Theory
2. Graph Theory and Combinatorics
3. Advanced Algebra
4. Harmonic Analysis
5. Topics in Mathematical Logic
6. Algebraic Topology
7. Application of Analysis to Geometry
8. Descriptive Set Theory
9. Advanced Probability II
10. Second-order Processes
11. Topics in Mathematical Physics
12. Special Topics in MSP

2.4.7 Quantitative Economics (QE) Specialization

Prerequisite course: Time Series Analysis.

This specialization is available to students with B.Stat. background who have had Group I (Economics) elective courses, and to students with B.Sc. (Stat/Math) background who have had Economics as a full subject. A student in the QE specialization has to take four compulsory courses and six elective courses, at least four of which must be from the Main List of Elective Courses for QE. The remaining elective courses may be chosen from any of the M.Stat. courses offered in the second year.

First Semester	Second Semester
1. Microeconomic Theory I	1. Macroeconomic Theory I
2. Game Throry I	2. Elective III
3. Econometric Methods	3. Elective IV
4. Elective I	4. Elective V
5. Elective II	5. Elective VI

Main List of Elective Courses (at least FOUR courses from this list)

1. Microeconomic Theory II
2. Macroeconomic Theory II
3. Agricultural Economics
4. Industrial Organization
5. Economic Development I
6. Modern Growth Theory
7. Social Choice and Political Economy
8. Incentives and Organizations
9. Privatization and Regulation
10. Economic Development II
11. Econometric Applications II
12. Game Theory II
13. Bayesian Econometrics
14. Intertemporal Economics
15. Theory of Planning
16. Social Accounting
17. Public Economics
18. Regional Economics
19. International Economics I
20. International Economics II
21. Advanced Topics in International Economics
22. Mathematical Programming with Applications to Economics
23. Monetary Economics
24. History of Economic Thought
25. Environmental Economics
26. Theory of Finance I
27. Theory of Finance II
28. Theory of Finance III
29. Political Economy and Comparative Systems

Supplementary List of Elective Courses

1. Special Topics in QE

3. BRIEF SYLLABI

The syllabi given for the first year courses and the second year compulsory courses should be adhered to by the instructor as much as possible. The syllabi for the second year elective courses are meant to serve as guidelines.

3.1 First Year Courses for Students without Specialization:

Compulsory Courses :

Large Sample Statistical Methods

i. Review of various modes of convergence of random variables and central limit theorems. Cramer-Wold device. Scheffe's theorem. Polya's theorem. Slutsky's theorem.
ii. Asymptotic distribution of transformed statistics. Derivation of the variance stabilizing formula. Asymptotic distribution of functions of sample moments like sample correlation coefficient, coefficient of variation, measures of skewness and kurtosis, etc.
iii. Asymptotic distribution of order statistics including extreme order statistics. Bahadur's result on asymptotic behaviour of sample quantiles.
iv. Large sample properties of maximum likelihood estimates and the method of scoring.
v. Large sample properties of parameter estimates in linear, nonlinear and generalized linear models.
vi. Pearson's chi-square statistic. Chi-square and likelihood ratio test statistics for simple hypotheses related to contingency tables. Heuristic proof for composite hypothesis with contingency tables as examples.
vii. Asymptotic behaviour of posterior distributions and Bayes estimates, preferably without proof but using heuristic justification based on Laplace approximation.
viii. Large sample nonparametric inference (e.g., asymptotics of *U*-statistics and large sample distribution of various rank based statistics, large sample behaviour of Kolmogorov-Smirnov statistics).
ix. Brief introduction to locally asymptotic normal theory and asymptotic optimality.

References :

- R. J. Serfling, *Approximation Theorems in Mathematical Statistics.*
- C. R. Rao, *Linear Statistical Inference and Its Applications.*
- H. Cramer, *Mathematical Methods of Statistics.*
- A. van der Vaart, *Stochastic Converge.*

Statistical Inference I

i. Game theoretic formulation of a statistical decision problem with illustration. Bayes, minimax and admissible rules. Complete and minimal complete class. Detailed analysis when the parameter space is finite.
ii. Sufficiency, minimal sufficiency and completeness. Factorization theorem. Convex loss and Rao-Blackwell theorem. Unbiased estimates and Cramer-Rao inequality. Stein estimate and shrinkage for multivariate normal mean. (If time permits: Karlin's theorem on admissibility.)
iii. Tests of hypotheses. MLR family. UMP and UMP unbiased tests. Detailed analysis in

exponential models.

iv. Bayes estimates and tests. Bayesian credible region. Non-informative priors.
v. (If time permits: Equivariance of estimates and inavariance of tests. Optimum equivariant estimates and invariant tests.)
vi. Discussion of various paradigms of statistical inference.

References :

- T. S. Ferguson, *Statistical Decision Theory.*
- E. L. Lehmann, *Theory of Point Estimation.*
- E. L. Lehmann, *Testing of Statistical Hypotheses.*
- P. J. Bickel and K. A. Doksum, *Mathematical Statistics.*
- J. O. Berger, *Statistical Decision* Theory.
- R. L. Berger and G. Casella, *Statistical Inference.*

Sample Surveys and Design of Experiments

Sample Surveys (1/2 semester)

Introduction to unified theory of sampling, sampling designs and sampling schemes, correspondence. Classes of estimators, homogeneous linear estimates and unbiasedness condition. Godambe's nonexistence theorem, Basu's difference estimator. Horvitz-Thompson estimator, its variance estimators, Lahiri-Midzuno-Sen scheme, nonnegativity of Sen-Yates-Grundy estimator: PPS sampling, Hunsen-Hurwitz estimator, Desraj's ordered estimators for WOR selection, Murthy's symmetrized Desraj estimator, Var. estimator. Brief mention of IPPS Schemes.

Double sampling on successive occasions, double sampling for stratification; cost and variance functions.

Nonresponse; Hunsen-Hurwitz estimator. Politz-Simmons technique for Not At Home's, RRT: Warner's model, related and unrelated questions, nonresponse stratum and double sampling.

Practicals and data analytic illustrations on above topics.

Suggested books :

- William G. Cochran, *Sampling Techniques.*
- M. N. Murthy, *Sampling: Theory and Methods.*
- P. Mukhopadhyay, *Theory and Methods of Survey Sampling.*

Design of Experiments (1/2 semester)

Review of non-orthogonal block designs under fixed effects models, connectedness, orthogonality and balance; applications; notion of mixed effects models.

BIBD: definition, applications, analysis and efficiency, construction (only OS1 and OS2); introduction to row-column designs and their applications.

Symmetrical factorials, fractional factorials, introduction to orthogonal arrays and their applications.

Practicals on the above topics using statistical packages for dataanalytic illustrations.

Suggested books :

- Aloke Dey, *Theory of Block Designs.*
- D. Raghavarao and L. V. Padgett, *Block Designs: Analysis, Combinatorics and Applications.*
- Angela Dean and Daniel Voss, *Design and Analysis of Experimens.*

Real Analysis

(for NB-stream only - this course is meant to prepare students for Measure Theoretic Probability, to be taught in the second semester)

A quick review of real number system, open/closed sets sequences and series, continuous functions, mean value theorem and Taylor expansions. Riemann integral, sequences of functions, uniform convergence, power series, continuity and differentiability in several variables.

Suggested book :

- T. M. Apostol, *Mathematical Analysis.*

Linear Models and Markov Chain

(for NB-stream only)

Linear Models:
Linear statistical models, illustrations, Gauss-Markov model, normal equations and least square estimators, estimable linear functions, g-inverse and solution of normal equations. Error space and estimation space. Variances and covariances of BLUEs. Estimation of error variance. Fundamental theorems of least squares and applications to the tests of linear hypotheses.
Fisher-Cochran theorem, distribution of quadratic forms.

Suggested books :

- C. R. Rao, *Linear Statistical Inference and Its Applications.*
- A. M. Kshirsagar, *A Course in Linear Models.*
- D. D. Joshi: *Linear Estimation and Design of Experiments.*

Markov Chain:

Independence, Random walk, discrete time/discrete space Markov chains - basic theory, examples including queueing/ birth-death chains/branching processes.

Suggested book :

- S. Karlin and H. M. Taylor, *A First Course in Stochastic Processes.*

Measure Theoretic Probability

(for B-stream only)

Measure and integration: σ-fields and monotone class theorem, probability measures, statement of Caratheodory extension theorem, measurable functions, integration, Fatou, MCT, DCT, product spaces, Fubini. (about 1/2 time to be spent)
Probability: 1-1 correspondence between distribution functions and probabilities on $\mathbb{R}$, independence, Borel-Cantelli, weak and strong laws in the i.i.d. case, Kolmogorov 0-1 law, various modes of convergence, characterstic functions, uniqueness/inversion/Levy continuity theorems, proof of CLT for the i.i.d. case with finite variance. (about 1/2 time to be spent)
[The order of coverage depends on teacher. For instance 1-1 correspondence can come soon after Caratheodory extension theorem.]

References :

- P. Billingsley, *Probability and Measure.*

Applied Stochastic Processes

(for B-stream only)

Introduction : Brief overview of modelling -- deterministic/stochastic; discrete time / continuous time.

At least three topics from the following list, but not more than four.

i. Branching Processes: review of discrete time branching process, extinction probabilities and asymptotic behaviour brief excursion to continuous time branching process, two-type branching process, branching process with general lifetime variable (Bellman-Harris process).
ii. Modelling in Genetics: Brief review of genetics, including the Hardy-Wienberg laws, their ramifications including mutation and fitness coefficient, inbreeding and changes of coefficient of inbreeding over generations, Markovian models: sibmating,Wright-Fisher, Moran, Kimura models, Wright-Fisher model with varying generation sizes, hidden Markov models.
iii. Continuous Time Markov Chain: Pure birth/pure death process, birth and death process, general theory, multi-dimensional processes, some non-homogeneous processes.
iv. Epidemic Modelling: Simple and general epidemics - both deterministic as well as stochastic. Threshold theorems (with or without proof). Greenwood, Reed-Frost models, Neyman-Scott models of spatial spread of epidemics.
v. Queueing Processes: Introduction, Markovian queueing model, Little's formula, queues with finite capacity, finite source queues, tandem queues, Erlangian models, models with general arrival and/or service patterns.
vi. Point Processes: Renewal process, marked point process/compound Poisson process, filtered point/Poisson process, self-exciting point process, doubly stochastic Poisson process.

References :

- S. Karlin, H. M. Taylor: *A First Course in Stochastic Processes.*
- N. T. J. Bailey, *The Elements of Stochastic Processes.*
- D. R. Cox and H. D. Miller, *The Theory of Stochastic Processes.*
- T. E. Harris, *The theory of Branching Processes.*
- W. J. Ewens, *Mathematical population genetics.*
- J. F. C. Kingman, *Mathematics of genetic diversity.*
- N. T. J. Bailey, *The mathematical theory of infectious diseases and its applications.*
- D. Gross and C. M. Harris, *Fundamentals of Queueing Theory.*
- U. N. Bhat, *Elements of Applied Stochastic Processes.*
- H. C. Tijms, *Stochastic Modelling and Analysis.*
- H. M. Taylor and S. Karlin, *An Introduction to Stochastic Modelling.*
- D. R. Cox and V. Isham, *Point Processes.*
- D. L. Snyder, *Random Point Processes.*
- W. J. Ewens and G. R. Grant, *Statistical Methods in Bioinformatics.*
- M. S. Waterman, *Introduction to Computational Biology.*

Regression Techniques

Review of multiple linear regression, partial and multiple correlation.
Violation of linear model assumptions: consequences, diagnostics and remedy (including properties of residuals and leverages).
Robust regression techniques: LAD and LMS regression (brief exposure).
Model building: subset selection, lack-of-fit tests.

Collinearity: diagnostics and strategies (including ridge & shrinkage regression and dimension reduction methods).
Discordant observations: diagnostics and strategies.
Topics from:

i. Nonlinear and Generalized Linear Models: inference and diagnostics.
ii. Introduction to nonparametric regression techniques : Kernel, local polynomial and spline based methods.
iii. Strategies for missing and censored data.

Presentation of projects and discussion.
Data analysis with computer packages.

Suggested books :

- Thomas P. Ryan, *Modern Regression Methods.*
- Douglas C. Montgomery, *Introduction to Linear Regression Analysis.*
- David A. Belsley, Edwin Kuh and Roy E. Welsch, *Regression Diagnostics: Identifying Influential Data and Source of Collinearity.*
- Peter J. Rousseeuw and Annick M. Leroy, *Robust Regression and Outlier Detection.*

Multivariate Analysis

Review of: multivariate distributions, multivariate normal distribution and its properties, distributions of linear and quadratic forms, tests for partial and multiple correlation coefficients and regression coefficients and their associated confidence regions. Data analytic illustrations.
Wishart distribution (definition, properties), construction of tests, union-intersection and likelihood ratio principles, inference on mean vector, Hotelling's T^2.
MANOVA.
Inference on covariance matrices.
Discriminant analysis.
Basic introduction to: principal component analysis and factor analysis.
Practicals on the above topics using statistical packages for data analytic illustrations.
References :

- T. W. Anderson, *An Introduction to Multivariate Statistical Analysis.*
- R. A. Johnson and D. W. Wichern, *Applied Multivariate Statistical Analysis.*
- K. V. Mardia, J. T. Kent and J. M. Bibby, *Multivariate Analysis.*
- M. S. Srivastava and C. G. Khatri, *An Introduction to Multivariate Statistics.*

Programming and Data Structures

(for NB-stream only)

Programming in a structured language such as C.

Data Structures: definitions, operations, implementations and applications of basic data structures. Array, stack, queue, dequeue, priority queue, doubly linked list, orthogonal list, binary tree and traversal algorithm, threaded binary tree, generalized list.

Binary search, Fibonacci search, binary search tree, height balance tree, heap, B-tree, digital search tree, hashing techniques.

References :

- Brian W. Kernighan and Dennis M. Ritchie, *The C Programming Language.*

- Byron S. Gottfried, *Theory and Problems of Programming with C.* (Schuam's Outline Series).
- A. Aho, J. Hopcroft and J. Ullman, *Data Structures and Algorithms.*
- T. A. Standish, *Data Structure Techniques.*
- A. M. Tanenbaum and M. J. Augesestein, *Data Structures using PASCAL.*

Metric Topology and Complex Analysis

(for B-stream only)

Metric spaces, open/closed sets, compactness, completeness, Baire category theorem, connectedness, continuous functions and homeomorphisms. Product spaces, $C[0,1]$ and L^p spaces as examples of complete spaces. (about 1/3 time to be spent)

Analytic functions, Cauchy-Riemann equations, Cauchy/Morera theorems, Cauchy integral formula, Liouville's theorem, singularities and Cauchy residual formula, contour integration, Rouche's theorem, fractional linear transformations. (about 2/3 time to be spent)

Suggested books :

- G. F. Simmons, *Introduction to Topology and Modern Analysis.*
- W. Rudin, *Real and Complex Analysis.*

Elective Courses :

Optimization Techniques I

i. Review of Lagrange method of multipliers, maxima and minima of differentiable functions of several variables, some exercises.
ii. Constrained optimization problems, several types of LP, NLP, ILP. Combinatorial optimization problems, several types of LP and ILP problems that occur in applications, formulation of problems.
iii. Convex sets, flats, hyperplanes, interior and closure, compact convex sets.
iv. Extreme points of convex sets, supporting hyperplanes, basic feasible solutions, correspondence between extreme points and basic feasible solutions.
v. Development of the simplex method, including artificial variables in two phases.
vi. Dual problems. A constructive proof of the duality result using the simplex tableau, interpretation of dual variables as shadow prices on resources, complementary slackness.
vii. Branch and bound method for integer linear programming, general principles, Balas' implicit enumeration algorithm.
viii. Introduction to Bellman's dynamic programming set-up, Bellman's principle of optimality, the use of this principle for solving some problems (such as the knapsack problem, shortest path problem etc.)

Suggested books :

- R. Webster, *Convexity.*
- M. S. Bazaraa and C. M. Shetty, *Nonlinear Programming: Theory and Algorithms.*
- Hamdy A. Taha, *Integer Programming.*
- Robert Garfinkel and George L. Nemhauser, *Integer Programming.*

Time Series Analysis

Review of various components of time series, plots and descriptive statistics.
Discrete-parameter stochastic processes: strong and weak stationarity, autocovariance and

autocorrelation.
Spectral analysis of weakly stationary processes: Periodogram, fast Fourier transform.
Models: Moving average, autoregressive, autoregressive moving average and autoregressive integrated moving average processes, Box-Jenkins model, state-space model.
Linear filters, signal processing through filters.
Inference in ARMA and ARIMA models.
Forecasting: ARIMA and state-space models, Kalman filter.
Model building: Residuals and diagnostic checking, model selection.
Strategies for missing data.
Time-frequency analysis: short-term Fourier transform, wavelets.
Data analysis with computer packages.

Suggested books :

- Robert H. Shumway and David S. Stoffer, *Time Series Analysis and Its Applications.*
- Peter J. Brockwell and Richard A. Davis, *Introduction to Time Series and Forecasting.*
- Wayne A. Fuller. *Introduction to statistical time series.*

Discrete Mathematics

i. Generating functions, recurrence relations, Polya's theory of counting, Ramsey theory.
ii. Graphs, connectedness, paths, cycles. Regular graphs. Strongly regular graphs. Eigenvalues of graphs. Peron-Frobenius theorem. Characterization of connectedness byspectrum. Classification of graphs with largest eigenvalue atmost 2 (Dynkin diagrams).
iii. Steiner 2-designs and their strongly regular graphs. Steiner t-designs. Witt designs and Golay codes.
iv. Probabilistic Methods in Combinatorics and Number Theory, Second Moment method, FKG inequalities, superconcentrators, random graphs (if time permits).

References :

- P. J. Cameron and J. H. van Lint, *Designs, Graphs, Codes and Their Links.*
- N. Alon, J. H. Spencer, *The Probabilistic Method.*
- B. Bollobas, *Random Graphs.*
- R. Motwani and P. Raghavan, *Randomized Algorithms.*

Nonparametric and Sequential Analysis

(for NB-stream only)

Nonparametric Methods: Formulation of the problems, order statistics and their distributions. Tests and confidence intervals for population quantiles. Sign test. Test for symmetry, signed rank test, Wilcoxon-Mann-Whitney test, Kruskal-Wallis test. Run test, tests for independence. Concepts of asymptotic efficiency. Estimation of location and scale parameters.
Sequential Analysis: Need for sequential tests. Wald's SPRT, ASN, OC function. Stein's two stage fixed length confidence interval. Illustrations with Binomial and Normal distributions. Elements of sequential estimation.
Practicals using statistical packages.

References :

- E. L. Lehmann, *Nonparametrics: Statistical Methods Based on Ranks.*
- J. Hajek and Z. Sidak, *Theory of Rank Tests.*

- P. J. Bickel and K. A. Doksum, *Mathematical Statistics.*
- R. L. Berger and G. Casella, *Statistical Inference.*

Measure Theoretic Probability

(for NB-stream only)

See the compulsory course for B-stream.

Metric Topology and Complex Analysis

(for NB-stream only)

See the compulsory course for B-stream.

3.2 Second Year Courses for One-year Specializations:

3.2.1 Advanced Probability Courses

Compulsory Courses :

Advanced Probability I

i. Radon Nikodym Theorem. Conditional Expectation. Regular conditional probability. Relevant measure theoretic development.
ii. Finite and infinite products. Kolmogorov-Tulcea Theorems.
iii. Discrete parameter martingales with various applications including *U*-statistics. Path properties of continuous parameter martingales.

Functional Analysis

i. Basic metric spaces and locally compact Hausdorff spaces. Riesz representation theorem and Stone-Weierstrass theorem.
ii. Three fundamental principles of Banach Spaces (Hahn-Banach, Uniform boundedness and open mapping theorems).
iii. Hilbert spaces, operators. Spectral theorem.

Stochastic Processes I

Selected topics from the following :

i. Weak convergence of probability measures on polish spaces including C[0,1].
ii. Brownian motion : Construction, simple properties of paths. Brief introduction to Stochastic Calculus.
iii. Markov processes and generators.

Stochastic Processes II

Poisson Process, point processes, infinite particle systems, interacting particle systems.

Main Elective Courses :

Ordinary and Partial Differential Equations

Linear ODE, power series method and orthogonal polynomials, Picard's theorem, generalities of PDE; heat, Laplace and wave equations, initial value problems and boundary value problems.

Advanced Functional Analysis

Any of the following topics or some other general area of functional analysis:

i. Geometry of Banach Spaces. Choquet's theory of integral representation of compact convex sets, basis in Banach spaces, weak compactness, vector measures.
ii. Topics in Operator Theory. Direct integral decomposition of unitary operators, operator models (Nagy-Poias), functional calculus for commuting operators.

Ergodic Theory

i. Measure-preserving transformations, recurrence, ergodicity, ergodic theorems, mixing.
ii. Isomorphism, conjugacy and spectral isomorphism.
iii. Measure-preserving transformations with discrete spectrum. Eigenvalues and eigenfunctions. Discrete spectrum. Group rotations and Halmos-Von Neumann representation theorem.
iv. Entropy: entropy of a partition, entropy of a measure-preserving transformation, methods of calculating entropy, Kolmogorov-Sinai theorem, Bernoulli automorphisms, Kolmogorov automorphism.

Quantum Probability

Prerequisite: Operator Theory in Advanced Functional Analysis.
Events, observables and states - Gleason's theorem. Expectation, variance and moments. Heisenberg's uncertainty principle. Evolution as a one-parameter unitary group, Schrodinger and Heisenberg equations. Tensor products, symmetric and antisymmetric tensor products, Boson and Fermion Fock spaces. Weyl representation, geometric derivation of infinitely divisible distributions and processes with independent increments. Creation, conservation and annihilation processes, quantum stochastic integrals and quantum Ito's formula. Solution of quantum stochastic differential equations with bounded constant operator coefficients.

3.2.2 Actuarial Statistics Courses

Compulsory Courses :

Actuarial Methods

Prerequisites: Statistical Inference I, Time Series Analysis, Regression Techniques.

i. Review of decision theory and actuarial applications.
ii. Loss distributions: modelling of individual and aggregate losses, moments, fitting distributions to claims data, deductibles and retention limits, proportional and excess-of-loss reinsurance, share of claim amounts, parametric estimation with incomplete information.
iii. Risk models: models for claim number and claim amount in short-term contracts, moments, compound distributions, moments of insurer’s and reinsurer’s share of aggregate claims.

iv. Review of Bayesian statistics/estimation and application to credibility theory.
v. Experience rating: Rating methods in insurance and banking, claim probability calculation, stationary distribution of proportion of policyholders in various levels of discount.
vi. Delay/run-off triangle: development factor, basic and inflation-adjusted chain-ladder method, alternative methods, average cost per claim and Bornhuetter-Ferguson methods for outstanding claim amounts, statistical models.
vii. Review of generalized linear model, residuals and diagnostics, goodness-of-fit, applications.
viii. Review of time series analysis, filters, random walks, multivariate AR model, cointegrated time series, non-stationary/non-linear models, application to investment variables, forecasts.
ix. Assessment of methods through Monte-Carlo simulations.

References :

- N. L. Bowers, H. U. Gerber, J. C. Hickman, D. A. Jones and C. J. Nesbitt, *Actuarial Mathematics,* 2nd ed. Society of Actuaries, 1997.
- S. A. Klugman, H. H. Panjer, G. E. Willmotand and G. G. Venter, *Loss Models: From Data to Decisions*. John Wiley & Sons, 1998.
- C. D. Daykin, T. Pentikainen and M. Pesonen, *Practical Risk Theory for Actuaries.* Chapman & Hall, 1994.

Life Contingencies

i. Assurance and annuity contracts: definitions of benefits and premiums, various types of assurances and annuities, present value, formulae for mean and variance of various continuous and discrete payments, various conditional probabilities from ultimate and select life tables, mthly payments, related actuarial symbols, inter-relations of various types of payments.
ii. Calculation of various probabilities from life tables: notations, probability expressions, approximations, select and ultimate tables, alternatives to life tables.
iii. Calculation of various payments from life tables: principle of equivalence, net premiums, prospective and retrospective provisions/reserves, recursive relations, Thiele's equation, actual and expected death strain, mortality profit/loss.
iv. Adjustment of net premium/net premium provisions for increasing/decreasing benefits and annuities: actuarial notations, calculations with ultimate or select mortality, with-profits contract and allied bonus, net premium, net premium provision.
v. Gross premiums: Various expenses, role of inflation, calculation of gross premium with future loss and equivalence principle for various types of contracts, alternative principles, calculation of gross premium provisions, gross premium retrospective provisions, recursive relations.
vi. Functions of two lives: cash-flows contingent on death/survival of either or both of two lives, functions dependent on a fixed term and on age.
vii. Cash-flow models for competing risks: Markov model, dependent probability calculations from Kolmogorov equations, transition intensities.
viii. Use of discounted emerging costs in pricing, reserving and assessing profitability: unit-linked contract, expected cash-flows for various assurances and annuities, profit tests and profit vector, profit signature, net present value and profit margin, use of profit test in product pricing and determining provisions, multiple decrement tables, cash-flows contingent on multiple decrement, alternatives to multiple decrement tables, cash-flows contingent on non-human life risks.
ix. Cost of guarantees: types of guarantees and options for long term insurance contracts, calculation through option-pricing and stochastic simulation.

x. Heterogeneity in mortality: contributing factors, main forms of selection, selection in insurance contracts and pension schemes, selective effects of decrements, risk classification in insurance, role of genetic information, single figure index, crude index, direct/indirect standardization, standardized mortality/morbidity ratio (SMR).

References :

- N. L. Bowers, H. U. Gerber, J. C. Hickman, D. A. Jones, and C. J. Nesbitt, *Actuarial Mathematics,* 2nd ed. Society of Actuaries, 1997.
- A. Neill, *Life Contingencies*. Heinemann, 1977.
- B. Benjamin and J. H. Pollard, *The Analysis of Mortality and Other Actuarial* Statistics, 3rd ed. Institute of Actuaries and Faculty of Actuaries, 1993.
- P. M. Booth, R. G. Chadburn, D. R. Cooper, S. Haberman and D. E. James, *Modern Actuarial Theory and Practice* Chapman & Hall, 1999.

Actuarial Models

Prerequisite: Introduction to Stochastic Processes (for B-stream) or Large Sample Theory and Markov Chain (for NB-stream).

Corequisite: Survival Analysis.

i. Principles of actuarial modelling: model selection, interpolation/extrapolation issues and diagnostics.
ii. Review of various types of stochastic processes; their actuarial applications.
iii. Review of Markov chain; frequency based experience rating and other applications.
iv. Markov process (Poisson process, Kolmogorov equations, illness-death and other survival models, effect of duration of stay, Markov jump processes).
v. Review of survival models, future life random variable and related actuarial notations, two-state model for single decrement.
vi. Review of nonparametric estimation and Cox model-based regression.
vii. Models of transfer between multiple states: general Markov models of transfers, standard actuarial notations for transfer probabilities and rates, their equations.
viii. Estimation of transition intensities: MLE under piecewise constant assumption, Poisson approximation.
ix. Central Exposed to Risk: data type, computation, estimation of transition probabilities, census approximation of waiting times, rate intervals, census formulae for various definitions of age.
x. Graduated estimates: reasons for comparison of crude estimates of transition intensities/probabilities to standard tables, statistical tests and their interpretations, test for smoothness of graduated estimates, graduation through parametric formulae, standard tables and graphical process, modification of tests for comparing crude and graduated estimates and to allow for duplicate policies.

References :

- N. L. Bowers, H. U. Gerber, J. C. Hickman, D. A. Jones, and C. J. Nesbitt, *Actuarial Mathematics,* 2nd ed. Society of Actuaries, 1997.
- V. G. Kulkarni, *Modeling, Analysis, Design, and Control of Stochastic Systems.* Springer, 1999.
- G. Grimmett and D. Stirzaker, *Probability and Random Processes,* 3rd ed. Oxford University Press, Oxford, 2001.
- E. Marubini and M. G. Valsecchi, *Analysing Survival Data from Clinical Trials and Observational Studies.* John Wiley & Sons, 1995.

Survival Analysis

i. Introduction: Survival data, hazard function (continuous and discrete).
ii. Nonparametric inference: Kaplan-Meier estimate, Nelson-Aalen estimate.
iii. Comparison of survival curves.
iv. Survival models: Exponential, Weibull, log-normal, gamma etc. regression models, Proportional hazards model.
v. Parametric inference: Censoring mechanisms and likelihood, large-sample likelihood theory, iterative methods for solution.
vi. Binomial and Poisson models for discrete data.
vii. Proportional Hazard model: Methods of estimation, estimation of survival functions, time-dependent covariates.
viii. Markov Models: Two-state model, illness-death model, maximum likelihood estimator and its properties.
ix. Rank tests with censored data.
x. Survival data with competing risks.

Main Elective Courses :

Statistical Computing

See the compulsory course for ASDA.

Game Theory I

See the compulsory course for QE.

Microeconomic Theory I

See the compulsory course for QE.

Macroeconomic Theory I

See the compulsory course for QE.

Theory of Finance I

Prerequisite: Game Theory I.

i. Choice under uncertainty and stochastic dominance, mean-variance portfolio theory leading to the capital asset pricing model, two fund separation and linear valuation, multifactor models, elements of arbitrage pricing theory.
ii. Elements of stochastic processes, second order processes, continuity, integration, differentiation, stochastic differential equations of the first and second order.
iii. Derivatives, hedging strategies, Greeks, option pricing, risk neutral pricing, forwards and futures, term structure of interest rates, swaps, binomial trees, Black-Scholes analysis, alternatives to Black-Scholes, management of market risk (VaR etc.).
iv. Structure of stock markets in general and USA in particular, definition and testing of different levels of efficient market hypothesis, regulations, role of different agents.

References :

- C. Huang and R. H. Litzenberger, *Foundations of Mathematical Finance*.
- J. E. Ingersoll, *Theory of Financial Decision Making*.
- P. G. Hoel, S. C. Port and C. J. Stone, *Introduction to Stochastic Processes.*
- I. Karatzas, *Introduction to Mathematics of Finance.*
- B. Oksendal, *Stochastic Differential Equation*.
- J. C. Hull, *Options, Futures and other Derivatives.*
- A. Pliska, *Discrete Time Mathematical Finance.*
- R. A. Jarrow and S. M. Turnbull, *Derivative Securities*.
- J. Dalton, *How the Stock Market Works*.

Theory of Finance II

Prerequisite: Game Theory I.

i. Corporate finance, mainly valuation of assets, time value, selection of projects, debt-equity choice, pecking order hypothesis, budgeting, corporate structure, tax regulations and governance, agency problems, separation of ownership and control. Stock market operation including Initial Public Offering (IPO).
ii. Banking finance including regulations, structure of banks, market imperfections and need for financial intermediaries, lender-borrower relationship.
iii. Indian financial System, banking sector, NBFCs, RBI and SEBI, securities and money market structure, regulations, development of stock markets.

References :

- D. Blake, *Financial Market Analysis*.
- R. A. Brealey and S. C. Myers, *Principles of Corporate Finance*.
- X. Freixas and J.-C. Rochet, *Microeconomics of Banking*.
- H. R. Machiraju, *Indian Financial System.*

Applied Multivariate Analysis

See the compulsory course for ASDA.

Life Testing and Reliability

See the compulsory course for ISOR.

Theory of Games and Statistical Decisions

i. Game theory as a tool for making statistical decisions; Elements of theory of two person zero-sum games and minimax theorem.
ii. Theory of statistical decisions (detailed discussion for the general parameter and the action spaces):
    a) Randomization, optimality, Bayes rules, minimax rules, admissible rules. Invariance and sufficiency. Complete class and essential complete class of rules. Examples. Topology of the set of randomized decision rules.
    b) Minimax theorems.
    c) Complete class theorem.
    d) Results on admissibility and minimaxity.

References :

- D. Blackwell and M. A. Girshick, *Theory of Games and Statistical Decisions.*
- T. S. Ferguson, *Mathematical Statistics: A Decision Theoretic Approach.*
- A. Wald, *Statistical Decision Functions.*
- L. D. Brown, *Fundamentals of Statistical Exponential Families.*
- J. O. Berger, *Statistical Decision Theory and Bayesian Analysis.*
- S. A. Klugman, H. H. Panjer, G. E. Wilmot, *Loss models: from Data to Decisions.* Chapman and Hall, 1994.

Stochastic Processes I

See the compulsory course for AP.

Econometric Methods

See the compulsory course for QE.

Statistical Methods in Demography

See the compulsory course for BSDA.

3.2.3 Applied Statistics and Data Analysis Courses

Compulsory Courses :

Advanced Design of Experiments

i. Optimality criteria, A-, D-, E-optimality, universal optimality of BBD and generalized Youden Square Designs.
ii. Orthogonal arrays, Rao's bound, construction, Hadamard matrices.
iii. Orthogonal arrays as fractional factorial plans, main effect plans for 2-level factorials.
iv. Response surface designs, method of steepest ascent, canonical analysis and ridge analysis of fitted surface.
v. Robust designs and Taguchi methods.

Topics from the following:

i. Mixture experiments.
ii. Asymmetric factorials, orthogonal factorial structure, Kronecker calculus for factorials, construction.
iii. Optimal regression designs for multiple linear regression and quadratic regression with one explanatory variable, introduction to D-optimal design measure.
iv. Cross-over designs, applications, analysis and optimality.
v. PBIB designs with emphasis on group divisible designs.
vi. Nested designs.

Analysis of Discrete Data

Measures of association.
Structural models for discrete data in two or more dimensions.

Estimation in complete tables. Goodness of fit, choice of a model.
Generalized Linear Model for discrete data, Poisson and Logistic regression models.
Log-linear models.
Elements of inference for cross-classification tables.
Models for nominal and ordinal response.
Data Analysis with computer packages.
References :

- A. Agresti, *An Introduction to Categorical Data Analysis.*

Statistical Computing

i. Review of simulation techniques for various probability models, and resampling.
ii. Computational problems and techniques for
    a) robust linear regression
    b) nonlinear and generalized linear regression problem
    c) tree-structured regression and classification
    d) cluster analysis
    e) smoothing and function estimation
    f) robust multivariate analysis
iii. Analysis of incomplete data: EM algorithm, single and multiple imputation.
iv. Markov Chain Monte Carlo and annealing techniques.
v. Neural Networks, Association Rules and learning algorithms.

References :

- S. M. Ross, *Simulation,* Second edition.
- R. A. Thisted, *Elements of Statistical Computing.*
- W. N. Venables and B. D. Ripley, *Modern Applied Statistics with S-Plus,* Third Edition.
- Peter J. Rousseeuw and Annick M. Leroy, *Robust Regression and Outlier Detection.*
- P. McCullagh and J. A. Nelder, *Generalized Linear Models.*
- L. Breiman, *Classification and Regression Trees.*
- Brian Everitt, *Cluster Analysis.*
- R. J. A. Little, D. B. Rubin, *Statistical Analysis with Missing Data.*
- T. Hastie, R. Tibshirani and J. Friedman, *The Elements of Statistical Learning: Data Mining, Inference and Prediction.*

Advanced Sample Surveys

i. Unified theory of sampling, non-existence theorems relating to labelled populations. Traditional model-based and Bayesian theories of inference in finite population sampling. Sufficiency, Bayesian sufficiency, completeness. Optimal and various other useful sampling strategies. Integration of different principles and methods of sampling in adopting composite sampling procedures in actual practice.
ii. Randomized response technique, post-stratification, small area estimation, synthetic estimation, repeated sampling, balanced replication, Jack-knifing.
iii. Organizational aspects of planning large-scale sample surveys, non-sampling errors, non-response. Familiarity with NSS work and some specific large-scale surveys.

Applied Multivariate Analysis

Graphical representation of multivariate data.

Dimension reduction methods: Review of Principal Component and Factor Analyses, Canonical Correlation analysis, Correspondence Analysis, Multidimensional Scaling.
Classification methods: Review of Discriminant Analysis, Cluster analysis.
Nonparametric and robust methods of multivariate analysis.
Data analysis with relevant statistical packages.

Project

Guidelines:

Students shall identify project supervisors; supervisors can only be a regular or visiting faculty of the Institute. Student shall inform the Dean of Studies or the In-charge, Students' Academic Affairs through the Class Teacher, in writing the name of the supervisor within the due date. Student should inform the Dean of Studies or the In-charge, Students' Academic Affairs through the Class Teacher in writing, also within the due date, if (s)he is unable to identify a supervisor within the said due date; arrangement shall be made by the Dean of Studies or the In-charge, Students' Academic Affairs to assign a supervisor.
Student shall submit a Project Proposal, prepared in consultation with supervisor, to the Dean of Studies or the In-charge, Students' Academic Affairs through the Class Teacher within the due date. Project Proposals must have written approval of supervisors.
Since project is a full course, students are expected to interact for four hours a week on an average with supervisors. Supervisors shall inform the Dean of Studies or the In-charge, Students' Academic Affairs directly when students are irregular in interaction.
A supervisor may supervise at most three students on three different projects.
If a supervisor is unable to continue as supervisor, for whatsoever might be the reason, the supervisor must find a substitute who shall supervise the same project (just as a teacher of a course who is unable to teach a course, finds a substitute to continue teaching the same course).
Weightage for Project shall be 20% for mid-semester assessment by supervisor and 80% for semester-end assessment by supervisor and two other examiners who are regular or visiting faculty of the Institute. Regular faculty of the other recognized university / institute may also be considered as examiners. The supervisor will identify the two other examiners and submit their names directly to the Dean of Studies or the In-charge, Students' Academic Affairs by the due date.
Student shall submit to supervisor one hard copy of work done for mid-semester evaluation by a date to be decided by supervisor. Supervisor shall forward the hard copy of work done by the student together with a mid-semester score out of 100 to the Dean of Studies or the In-charge, Students' Academic Affairs directly within the due date.
Student shall submit four hard copies (one for supervisor, two for two other examiners and one for office) of Project Report to the supervisor within the due date. The supervisor should forward copies to the relevant people.
Student shall make an oral presentation of project work within due date and time before supervisor and two other examiners; semester-end assessment shall be on Project Report, oral presentation and defence. Weightage for semester-end assessment shall be at least 60% on Project Report and at least 30% on oral presentation and defence, adding up to 100%. The final weightage should be decided by the supervisor in consultation with the examiners. The supervisor will inform the Dean of Studies or the In-charge, Students' Academic Affairs about the final weightage, while submitting the name of the examiners. The supervisor will also inform the student as well. Supervisor and the two other examiners may score separately or give a combined score. When supervisor and the two other examiners score separately, simple average shall be the combined score.

Date and time for Project Presentation shall be decided by supervisor in consultations with two other examiners. The Dean of Studies or the In-charge, Students' Academic Affairs should be informed about the Project Presentation preferably a week in advance, with a minimum of three working days' notice. The Dean's Office will announce the Project Presentation, which will be open to interested people, at suitable places. However, the evaluation will be open only to the supervisor and the examiners.
Project is a regular course. In case a student obtains less than 45% in the composite score, (s)he will be offered an opportunity to appear for the backpaper examination. The student should submit a revised Project Report (in quadruplicate, as mentioned above) by the last working day before the backpaper examinations for M. Stat. IInd Year begin. There will be a Project Presentation during the week of the backpaper examination --- the date will be finalized by the supervisor in consultation with the examiners and be conveyed to the Dean of Studies or the In-charge, Students' Academic Affairs for announcement as done in the usual Project Presentation. The scoring will be based only on the new Project Presentation. The maximum score possible will be 45%. The other rules and regulations regarding Backpaper examination for a regular subject will also apply.
Supervisor shall forward the semester-end score out of 100 to the Dean of Studies or the In-charge, Students' Academic Affairs directly within due date.
Guidelines for M. Stat. II year Project shall be communicated to students and all regular faculty of the institute by the Dean of Studies or the In-charge, Students' Academic Affairs on the first day of second semester. A copy of this guideline will also be made available online on the webpage of the Dean's Office.
In case of doubts, the Dean of Studies may be consulted.

Main Elective Courses :

Survival Analysis

See the compulsory course for AS.

Statistical Methods in Genetics I

See the compulsory course for BSDA.

Biostatistics

Discrete and continuous time stochastic models, diffusion equation, stochastic models for population growth and extinction (includes branching process), interacting population of species - competition and predation, chemical kinetics, photosynthesis and neuron behaviour. Deterministic and stochastic models for epidemics and endemics, interference models, vaccination models, geographical spread, parasitic diseases, parameter estimation related to latent, infection and incubation periods. Bioassay. case studies.

Life Testing and Reliability

See the compulsory course for ISOR.

Theory of Games and Statistical Decisions

See the elective course for AS.

Econometric Methods

See the compulsory course for QE.

Quantitative Models in Social Sciences

Selected topics from the following and/or any other areas in social sciences of statistical relevance.

i. Psychology: Stochastic models for learning. Models for choice behaviour. Stochastic models for test scores.
ii. Sociology: Latent structure models. Applications of graph theory; preference, social interactions, indifference, energy modelling, social inequalities etc. Structural models.
iii. Economics: Demand models, income inequality, etc.
iv. Management science: Inventory models. Scheduling. Queues.

Pattern Recognition and Image Processing

Pattern Recognition

Review of Bayes classification: error probability, error bounds, Bhattacharya bounds, error rates and their estimation.

Parametric and nonparametric learning, density estimation.

Classification trees.

k-NN rule and its error rate.

Neural network models for pattern recognition: learning, supervised and unsupervised classification.

Unsupervised classification: split/merge techniques, hierarchical clustering algorithms, cluster validity, estimation of mixture distributions.

Feature selection: optimal and suboptimal algorithms.

Some of the other approaches like the syntactic, the fuzzy set theoretic, the neurofuzzy, the evolutionary (that is, based on genetic algorithms), and applications.

Some recent topics like data mining, support vector machines, etc.

References :

- K. Fukunaga, *Introduction to Statistical Pattern Recognition*, 2nd edition. New York: Academic Press, 1990.
- P. A. Devijver and J. Kittler, *Pattern Recognition: A Statistical Approach.* Prentice-Hall, 1982.
- A. K. Jain and R. C. Dube, *Algorithms for Clustering Data.* Prentice-Hall, 1988.
- B. S. Everitt, *Cluster Analysis.* Halsted Press, 1993.
- K. S. Fu, *Syntactic Pattern Recognition and Applications.* Prentice-Hall, 1982.
- J. C. Bezdek, *Pattern Recognition with Fuzzy Objective Function Algorithms.* Plenum Press, 1981.
- T. Hastie, R. Tibshirani and J. H. Friedman, *Elements of Statistical Learning.* Springer-Verlag, 2001.
- B. D. Ripley, *Pattern Recognition and Neural Networks.* Cambridge University Press, 1996.
- S Theodoridis and K Koutroumbas, *Pattern Recognition.* Academic Press, 1999.

Image Processing

Introduction, image definition and its representation.

Typical IP operations like enhancement, contrast stretching, smoothing and sharpening, greylevel thresholding, edge detection, medial axis transform, skeletonization/ thinning, warping.

Segmentation and pixel classification.

Object recognition.

Some statistical (including Bayesian) approaches for the above, like Besag's ICM algorithm,

deformable templates approach of Grenander and colleagues, and so on.
References :

- T. Y. Young and K. S. Fu, *Handbook of Pattern Recognition and Image Processing,* vols. 1 & 2. Academic Press, 1986.
- A. Jain, *Fundamentals of Digital Image Processing.* Prentice-Hall, 1989.
- K. R. Castleman, *Digital Image Processing.* Prentice-Hall, 1996.
- K. V. Mardia and G. K. Kanji, *Statistics and Images.* Carfax, 1993.

Analysis of Discrete Data

See the compulsory course for ASDA.

3.2.4 Biostatistics and Data Analysis Courses

Compulsory Courses :

Statistical Methods in Genetics I

Mendel's laws, Estimation of allele frequencies, Hardy-Weinberg law, Mating tables, Snyder's ratios, Models of natural selection and mutation, Detection and estimation of linkage (recombination), Inheritance of quantitative traits, Stochastic models of carcinogenesis.

Analysis of Discrete Data

See the compulsory course for ASDA.

Statistical Computing

See the compulsory course for ASDA.

Survival Analysis

See the compulsory course for AS.

Statistical Methods in Public Health

Longitudinal data analysis (Repeated measures design, Growth models, Regression models, etc.).
Epidemiology (Case-control studies, Estimation of prevalence and incidence, Age at onset distributions, Assessing spatial and temporal patterns, etc.).
Theory of epidemics (Simple and general epidemics, Recurrent epidemics and endemicity, Discrete-time models, Spatial models, Carrier models, Host-vector and venereal disease models, etc.).

Statistical Methods in Biomedical Research

Bioassay (Direct and indirect assays, quantal and quantitative assays, parallel line and slope ratio assays, design of bioassays, etc.)
Clinical trials (Different phases, comparative and controlled trials, random allocation, parallel group designs, crossover designs, symmetric designs, adaptive designs, group sequential designs, Zelen's designs, selection of subjects, ethical issues, outcome measures, protocols, sample size determination, etc.).

Review of theory and application of generalized linear model, quasilikelihood and generalized estimating equations, correlated binary data, overdispersion.

Project

See the compulsory course for ASDA.

Main Elective Courses :

Advanced Design of Experiments

See the compulsory course for ASDA.

Advanced Sample Surveys

See the compulsory course for ASDA.

Applied Multivariate Analysis

See the compulsory course for ASDA.

Life Testing and Reliability

See the compulsory course for ISOR.

Theory of Games and Statistical Decisions

See the compulsory course for AS.

Statistical Ecology

Population dynamics, Spatial patterns in one-species populations, Spatial relations of two or more species, Many-species populations.

Statistical Methods in Genetics II

i. Evolution of DNA sequences - Kimura's two-parameter and Jukes-Cantor models.
ii. DNA sequence alignment - Needleman-Wunsch and Smith-Waterman algorithms.
iii. Basic local alignment search tool.
iv. Gene trees and species trees.
v. Estimation of evolutionary and population genetic parameters from DNA sequence data.
vi. Gene mapping methodologies:
    a) transmission-disequilibrium test,
    b) linkage disequilibrium mapping,
    c) quantitative trait locus mapping.
vii. Genome databases.

Statistical Methods in Demography

Sources of demographic data. Mortality analysis and models. Population growth, composition and distribution, projection models, stable population theory, life tables. Health statistics.

Pattern Recognition and Image Processing

See the elective course for ASDA.

Supplementary Elective Courses :

Special Topics in BSDA

Topics may be chosen from the following list:
Risk assessment. Analysis of family data. Mathematical models in Biology. Multi-point mapping. Environmental statistics. Statistical methods in AIDS research. Statistical applications in Molecular Biology.

3.2.5 Industrial Statistics and Operations Research Courses

Compulsory Courses :

Advanced Design of Experiments

See the compulsory course for ASDA.

Life Testing and Reliability

i. Different life-time distributions and their properties, mean time between failures, hazard rates, different failure models and the test for their validity, problems of inference (estimation and testing) for the parameters of common life-time distributions, estimation from uncensored and censored samples, concepts of accelerated life-testing, Bayesian approach to reliability estimation.
ii. Fault tree analysis, coherent systems, basic concepts of component and system reliability. Reliability bounds. Nonparametric classes of life-time distributions. Maintained systems and system availability. Special topics (models for software reliability, multivariate life distributions, systems with redundancy, stress-strength models etc).

Quality Control and Its Management

i. Control Charts: Statistical Process control and different types of control charts (including control chart for short run process, group control chart, EWMA chart, modified control chart, R&R study, Bayesian Control charts Process capability analysis, capability indices).
ii. Acceptance sampling: : Single, double, multiple, sequential and published plans; continuous, chain and bulk sampling plans, Bayesian sampling plans.
iii. Management of Quality Control : Concepts of quality planning, control, assurance and improvement, Elements of quality management system, TQC, TQM quality circle, system standards, organization of six-sigma programmes in the industry. Role of statistical techniques in quality management.

Management Applications of Optimization

i. Application of linear programming to transportation problems. The properties of basis matrices arising in the transportation problem and their implications to the pivot algorithms. The stepping stone and *u*-*v* methods of solving a transportation problem.

ii. The use of labeling algorithm for constructing a maximal independent set of admissible cells and its use in solving the bottle-neck assignment problem. The linear assignment problem and its solution by the Hungarian Method. The primal-dual approach to solving a transportation problem.
iii. Out of kilter method for maximum commodity flow through a given network at minimal cost.
iv. CPM and PERT methods for analyzing a project and deriving the project cost curve.
v. Branch and bound method (revision) and cutting plane methods for solving an integer-programming problem. Various applications of integer programming and combinatorial optimization. The traveling salesman problem and its applications. Use of heuristic algorithms.
vi. Bellman's optimality principle and its use in solving optimization problems.
vii. Portfolio selection problem and the use of Lemke's method for portfolio selection and the mean-variance model. Stochastic programming models for financial risk management.

Industrial Applications of Stochastic Processes

i. Queueing Theory: Introduction to queuing problems. Revision of Markov chains and processes. Markov Chain models for simple queueing processes. The *M/M/C* model, *M/M/C* model with finite waiting space, and models with a finite source of customers, (machine interference problem). Little's formula, Markovian queues in tandem, semi-Markovian queueing systems: *M/G/1*, *M/G/1* with service vacations and *G/M/1*. Batch arrivals and bulk queues. The notion of queueing network. Jackson and Kelly networks. The use of queueing network in manufacturing systems.
ii. Inventory control: Elementary models. The newspaper vendor problem and related models. The (s,S) policies and periodic review models. Models for perishable items. Concepts of supply-chain management.
iii. Replacement: Replacement of items that fail gradually and stochastically. The use of renewal theory in comparing replacement policies.
iv. Blackwell model of dynamic programming. Discounted and limiting average payoff. Applications.
v. Time series models and their use in forecasting. (depends on interest and if the optional subject on time series analysis has not been taken by the students).

References :

- S. Karlin and H. M. Taylor, *A First Course in Stochastic Processes.*
- S. M. Ross, *Introduction to Probability Models.*
- V. G. Kulkarni, *Modeling and Analysis of Stochastic Systems.*

Optimization Techniques II

i. Convex sets and their elementary topological properties, extreme points, simplex method (quick revision).
ii. Separation theorems for convex sets and theorems of the alternative.
iii. The derivation of the duality theorems of linear programming using theorems of the alternative. The dual simplex and primal dual algorithms. Sensitivity and post optimal analysis.
iv. Degenaracy and cycling. Anticycling pivot selection rules in the simplex type methods.
v. Issues of computational complexity and the need for alternative methods. Klee_Minty example. Interior point methods for linear programming (Karmarkar's).
vi. The problem of finding a maximum flow through a given network using labeling algorithm. The max-flow-min-cut theorem. Generalizations to networks with multiple sources and sinks.

Feasibility theorem for circulation and its application. The Konig-Egervary theorem.

vii. Optimization involving differentiable functions. Karush-Kuhn-Tucker necessary optimality conditions under constraint qualifications. Convex and generalized convex functions and the sufficiency of KKT conditions.

viii. The linear complementarity problem as a unifying format. Lemke's algorithm.

Reference :

- H. A. Taha, *Integer Programming: Theory, Applications and Computations.*

Project

See the compulsory course for ASDA.

Supplementary Elective Courses :

Optimization Techniques III

Formulating models in integer and binary variables. Integer programming and graphs. Matching and covering on graphs. Enumeration methods. Cutting plane methods. Knapsack and group knapsack problem. Integer programming over cones. Set covering and partitioning problem. Travelling salesman problem. Dynamic programming for various discrete optimization problem.

Optimization Techniques IV

Caratheodory, Krein-Millman, and other separation theorems for convex sets. Theorems of alternatives. Convex functions. Properties of differentiable convex sets. Programming problem with a differentiable objective function and differentiable constraint functions Kuhn-Tucker necessary conditions. Fritz-John necessary conditions. Some constraint qualifications and their geometry. A problem with a differentiable convex objective function. LCP formulation of quadratic programming problem. Lenke-Howson algorithm. Karush-Kuhn-Tucker conditions for a programming problem with a pseudo-convex objective function and differentiable quasi-convex constraint functions. Fractional LP and its LCP formulation. Sequential unconstraint minimization technique.

Network Analysis

Definition and formulations. Maximum value flow algorithm for single commodity, pure network flow problem, primal dual algorithm for transportation and assignment problem shortest chain algorithms, minimum spanning tree algorithms, single commodity minimum cost flow algorithm, critical path method, generalized network flow problems, multi-commodity flow problems, dynamic network flow algorithm and routing applications.

Sampling Inspection

Operating characteristic function, Hamaker's conjecture, curtailed inspection. Switching rules. Dodge and Romig's systems and its generalizations. Bayesian sampling plans. Minimax regret and other sampling plans.

Scheduling Theory

Deterministic scheduling problems, single machine problems, branch and bound approach. Sequence-dependent set-up times and travelling salesman problem. Parallel machines problem. Flow shop

scheduling and job shop scheduling.

Industrial Engineering and Management

Operations management. Management time study, work sampling, incentive and job evaluation. Materials management value analysis, plan layout and inventory management. Organization staff line relationship, communication, administration, management of change. Cost of budgetary control-cost accounting, control of materials, labour and overhead, incentive schemes. Market research.

3.2.6 Mathematical Statistics and Probability Courses

Compulsory Courses :

Advanced Probability I

See the compulsory course for AP.

Functional Analysis

See the compulsory course for AP.

Stochastic Processes I

See the compulsory course for AP.

Statistical Inference II

Overview of classical inference.
Selected topics from the following:

i. Principles of data reduction
   a) Sufficiency : Results of Halmos-Savage, Basu-Ghosh, and Bahadur. Brief discussion on undominated cases. Applications.
   b) Invariance : Invariant decision rules, equivariant estimation, invariant tests; discussion on admissibility, minimax property etc. of invariant rules.
ii. Foundations of statistics : Coherence, Bayesian analysis, Likelihood principle (results and concepts of Barnard, Birnbaum, Basu, etc.).
iii. Advanced and current topics in the frequentist and Bayesian theory of estimation and tests of statistical hypotheses.

Main Elective Courses :

Nonparametric Inference

Selected topics from the following :

i. Estimation : *U*-statistics and the corresponding asymptotic theory, von-Mises' functional, jack-knife and boot-strap methods, asymptotic efficiency.
ii. Rank tests, permutation tests, asymptotic theory of rank tests under null and alternative (contiguous) hypotheses, asymptotic efficiency.
iii. Nonparametric regression.
iv. Bayesian nonparametric analysis.

v. Estimation of density function.
vi. Robustness, *M*-estimates.
vii. *L*-estimates.

Advanced Design of Experiments

See the compulsory course for ASDA.

Advanced Sample Surveys

See the compulsory course for ASDA.

Theory of Games and Statistical Decisions

See the elective course for AS.

Sequential Analysis and Optimal Stopping

Selected topics from the following:

i. SPRT; its optimality, OC and ASN.
ii. Invariant SPRT and their termination probabilities. Sufficiency and invariance in sequential analysis. Stopping time of invariant SPRT.
iii. Non-linear renewal theorem and its application in sequential analysis.
iv. Stopping time, principle of backward induction, monotone case, extended stopping time and triple limit theorem.
v. Kiefer-Weiss problem, use of heat equation in stopping problems, bandit problems.

Topics in Bayesian Inference

Selected topics from the work of de Finneti, Savage, Lindley, Basu, Berger and others.

Time Series Analysis

See the elective course for the first year.

Asymptotic Theory of Inference

Selected topics from the following:

i. Parametric and semi-parametric estimation (Ref. Ibragimov and Khasminski); contiguity and related results.
ii. Asymptotic most powerful tests (parametric).
iii. Consistency of maximum likelihood estimates (Bahadur-Wald).
iv. Large deviations and Bahadur efficiency.
v. Asymptotic Theory of nonparametric estimation (if the course on nonparametric inference is not offered).
vi. Berry-Esseen bound and related results.
vii. Martingale approach to inference.
viii. Inference for Stochastic Processes (Branching processes, diffusion processes, queuing models, etc.).

Pattern Recognition and Image Processing

See the elective course for ASDA.

Statistical Computing

See the compulsory course for ASDA.

Supplementary Elective Courses :

Topology and Set Theory

Topological spaces, continuity, countability axioms.
Subspaces, products, quotients. Weak topology generated by a family of maps.
Separation properties including Urysohn and Tietze extension theorem, etc.
Compactness, Tychonoff's theorem; one-point and stone-Cech compactification.
Connectedness, path-connectedness.
Metrization theorem of Urysohn. Completeness.
Nets and filters convergence in compact spaces.
Definition and examples of manifolds.

Graph Theory and Combinatorics

Elementary principles of combinatorics; inclusion and exclusion. Ramsey problem.
Graphs: isomorphism, adjacency and incidence matrices, degree sequence, Havel-Hakimi Theorem. Erdos-Gallai Theorem.
Paths, connectedness, trees; characterizations. Minimal connector problem. Kruskal's algorithm. Cut vertices, cut edges. Examples. Euler chain characterization theorem; examples. Hamiltonian graph. Different degree sequences vs. Hamiltonicity. Travelling salesman problem. Applications.
Edge colouring, vertex colouring numbers. Total chromatic number. Vizing-Gupta theorem. Bipartite graphs. Applications.
Planar graphs. Subdivision, Kuratowski's characterization. Examples. The five-colour theorem and the statement of the four-colour theorem.
Directed graphs. Applications.
Flows, cuts, max-flow min-cut theorem; applications and examples.

Advanced Algebra

Selected topics from the following :

i. Theory of modules. Left and right modules, submodules and quotient modules, module homomorphisms, direct summand product, free modules, exact sequences. Tensor products over commutative rings, groups of homomorphisms and their principal properties.
ii. Commutative Algebra: Ideals, prime ideal, maximal ideal, nilradical and Jacobian radical, operations on ideals, extension and contraction. Rings and modules of fractions, local properties, extended and contracted ideals in rings of fractions. Primary decomposition. Chain conditions, Noetherian rings, Certin rings, Discrete valuation rings and Dedekind domains.
iii. Galois Theory: Field extensions,fundamental theorems, splitting fields. The Galois group of a polynomial, finite fields, separability, cyclic extensions, cyclotomic extensions. Solvable and radical extensions, Kummer theory.
iv. Representations of finite groups: Concept of representation. Complete reducibility, uniqueness

of decomposition. Group ring and regular representation, space of class functions, orthogonal relations, induced characters, induced representations, positive decomposition of regular character, Brauer's theorem.

Harmonic Analysis

i. Fourier Series: Definitions and simple consequences. Convolutions, summability kernels. Summability (Cesaro and Abel) in norm and pointwise. Lebesgue's differentiation theorem. Order of magnitude of Fourier coefficients. Fourierseries of square summable functions. Absolutely convergent Fourier Series. Fourier-Stieltjes coefficients, positive-definite sequences, Helglotz theorem.
ii. Convergence of Fourier Series in norm, pointwise. Hardy's theorem.
iii. Fourier transform on the line, convolutions, inversion theorem, Plancherel theorem, Schwartz space and Tempered Distributions.
iv. Conjugate function and functions analytic in the unit disc: Kolmogorov theorem, Riesz' Theorem, Hardy spaces, invariant subspaces of $H_2(T)$, Beurling's theorem. Factoring.
v. Some applications of Fourier Transforms and Distribution theory to PDE.

Note: It is recommended that only one of (d) or (e) is covered.

Algebraic Topology

Homotopy, homotopy-equivalence, contractibility.
Fundamental groups. Continuous maps. Invariance under homotopy-equivalence.
Covering spaces. Computation of $\pi_1(S^1,*)$ proof of path-lifting and injectivity under π_1.
Applications. Brouwer fixed point theorem in 2 dimensions. Fundamental theorem of algebra, algebraic deductions from elementary covering space theory.

Application of Analysis to Geometry

Differentiable manifolds. Derivatives and tangents. Inverse function theorem and immersions. Submersions. Local submersion theorem. Pre-image theorem. Transversality. Homotopy and stability. Sard's theorem and its applications. Morse functions. Embedding manifolds in Euclidean space. Manifolds with boundary. Mod 2 intersection theory. Winding numbers and Jordan-Brouwer separation theorem. Borsuk-Ulam theorem. Oriented intersection theory. Lefschetz' fixed-point theory. Vector fields and Poincare-Hopf theorem. Hopf degree theorem. Euler characteristic and triangulation.
Reference :

- V. Guillemin and A. Pollack, *Differential Topology.*

Descriptive Set Theory

Polich spaces, Cantor set, space and irrationals, transfer theorems.
Hierarchy of Borel sets, Borel functions, Borel isomorphism theorem.
Analytic sets, co-analytic sets, projective sets, separation and reduction principles, uniformisation of Boral Sets. Cardinalities and regularity properties of analytic and co-analytic sets.
Recursive functions, arithmetical and analytic point classes, codings, uniformity and good parameterizations, Recursion theorem. Pre-well ordering property. Parametrizaiton theorems, scale property, standard basis theorems, Kondo's theorem.

Advanced Probability II

Any one topic from the following :

i. Markov process, generators. Brownian motion as a Markov process (if this topic is not covered in Advanced Probability I).
ii. Stochastic integrals and Ito calculus.
iii. Gaussian process (Ref. Kuelb).
iv. Empirical processes (Ref. Pollard/Wineller et al.).
v. Large deviations.
vi. Strong representations (Ref. Bahadur-Kiefer, Revesz).
vii. I.D. laws, stable and semi-stable laws; semi-stable laws on $\mathbb{R}$ or Branch spaces.

Second-order Processes

Operators on a Hillbert space. Spectral measures. Spectral theorem, normal operators. Stone's theorem on one-parameter unitary groups.
Second-order processes, processes with orthogonal increments. Integrals with respect to processes with orthogonal increments.
Weakly stationary processes with discrete and continuous time.
Prediction problem. Deterministic and non-deterministic processes. Wiener-Kolmogorov-Szego solution of the prediction problem for discrete time. Optimal filter (both signal and observation are weakly stationary).
Introduction to stochastic integrals, Stochastic differential equations, Bucy-Kalman filter.

Topics in Mathematical Physics

i. Classical Mechanics: Generalized coordinates, Lagrange's equation, motion in a central field, dynamics of a rigid body, general principles of mechanics.
ii. Electrodynamics: Maxwell's equations, electrodynamics of material media. Plane electromagnetic wages. Theory of relativity. Relativistic dynamics.
iii. Quantum Mechanics: Schrodinger equation, harmonic oscillators, operators in quantum mechanics; theory of scattering, electron, basic principles ofsecond quantization and quantum field theory.
iv. Statistical Physics: Ideal gas, Boltzmann statistics, Bose and Fermi statistics, Theormodynamics, King model, phase transition.

Suggested books :

- L. D. Landau and E. M. Lifshitz, *Mechanics.*
- G. Goldstein, *Classical Mechanics.*
- L. D. Landau and E. M. Lifshitz, *Field Theory.*
- P. G. Bergman, *Introduction to the Theory of Relativity.*
- L. D. Landau and F. M. Lifshitz, *Quantum Mechanics.*
- J. L. Powell and B. Crasemann, *Quantum Mechanics.*
- P. A. M. Dirac, *The Principles of Quantum Mechanics.*
- L. D. Landau and E. M. Lifshitz, *Statistical Physics.*
- R. Kube, *Statistical Mechanics.*

3.2.7 Quantitative Economics Courses

Compulsory Courses :

Microeconomic Theory I

i. Theory of consumer behaviour : preference ordering, utility function, budget set, demand, duality theory, theory of revealed preference, aggregate demand.
ii. Theory of the firm : production set, cost minimization, profit maximization, supply, duality theory, aggregate supply.
iii. Equilibrium in a single market, stability, comparative statics.
iv. Imperfect competition and market structure.
v. Decision-making under uncertainty : lotteries, measures of risk.

Game Theory I

i. Non-Cooperative Games
   a) Games in normal form.
   b) Rationalizability and iterated deletion of never-best responses.
   c) Nash equilibrium : existence, properties and applications.
   d) Two-person Zero Sum Games.
   e) Games in extensive form : perfect recall and behaviour strategies.
   f) Credibility and Subgame Perfect Nash Equilibrium.
   g) Bargaining.
   h) Repeated Games; Folk Theorems.
ii. Introduction to Cooperative Games (TU games)

Econometric Methods

i. Discrete and Limited Dependent Variables Model: types of discrete choice models, linear probability model, the probit and the logit models and Tobit model.
ii. Analysis of Panel Data: Fixed effects model, random effects model (error components model), fixed or random effects – Wu-Hausman test, Swamy's random coefficient model.
iii. Specification testing and Diagnostic Checking: inferential problems in misspecified or inadequately specified models; tests based on ML principle – W, LR and Rao's (RS) tests; White's information matrix test; tests for non-nested hypothesis – Davidson and McKinnon's J test and the encompassing test.
iv. Simultaneous equation systems; structural and reduced forms, least squares bias problems; identification problem, estimation methods, introduction to VAR.
v. Cointegration: a general cointegrated system, two variable model: Engle-Granger method, system estimation method – Johansen procedure; error correction model and tests for cointegration; vector autoregression and Granger causality.
vi. ARCH model: properties of ARCH/Garch model, different interpretations, various generalizations, estimation and testing.
vii. Other methods of testing (excluding LS and ML methods): generalized method of moments (GMM) and method of least absolute deviation : basics of non-parametric regression – idea of smoothing, smoothing techniques, the kernel method and choosing the smoothing parameter.
viii. Introduction to Bayesian Econometrics: Bayes' theorem, prior probability density functions,

point estimates of parameters and prediction.

Macroeconomic Theory I

i. Review of Keynes, Classics and Structuralist macroeconomics.
ii. Friedman and New Classical Economics.
iii. New Keynesian Economics.
iv. Introduction to macro models of optimal behaviour over time: Ramsey-Solow and Overlapping Generations model.
v. Real Business Cycle Theory.

Main Elective Courses :

Microeconomic Theory II

i. General equilibrium of an exchange economy.
ii. General equilibrium with production.
iii. Welfare economics : the fundamental theorems of welfare economics, core of an economy, introduction to Social Choice theory
iv. Asymmetric information, market failure, theory of second best and strategic interactions.
v. Introduction to non-Walrasian equilibrium.

Macroeconomic Theory II

Selected topics out of the following list :

i. Open Economy Issues.
ii. Overlapping Generations models: advanced topics.
iii. Public Debt.
iv. Asset Pricing.
v. Optimal taxation.
vi. Theories of Inflation.
vii. Equilibrium search and matching.
viii. Growth and Distribution.
ix. Modern theories of Unemployment.

Agricultural Economics

i. Growth and Fluctuations of Agricultural Output.
ii. Surplus Labour.
iii. Farm Efficiency.
iv. Tenurial Efficiency.
v. Interlinked Factor Markets.
vi. Marketable Surplus.
vii. New Technology.
viii. Effect of Liberalization on Agriculture.

Industrial Organization

i. Structure conduct performance paradigm.
ii. Static oligopoly models, homogeneous goods, Cournot and Bertrand models, differentiated

products, horizontal and vertical differentiation, models with free entry, contestable markets, Cournot and price setting, models with free entry.

iii. Measures of concentration and performance.
iv. Dynamic oligopoly models : entry deterrence, limit pricing, attrition and reputation models, collusion and cartels.
v. Price discrimination, price dispersion and search theory.
vi. R&D and adaptation/adoption of technology: private vs. social incentives for R&D models of adoption, diffusion and transfer of technology.
vii. Mergers and takeovers, firm size ad vertical integration, corporate finance.
viii. Regulation of monopolies, rate of return regulation, regulation of firms with unknown costs/demands.
ix. Multinational firms.
x. Quality, durability and warranty.
xi. Advertising.
xii. Joint venture, licensing and patents.

Economic Development I

i. The dual economy: surplus labour, wage rigidity and unemployment.
ii. Underdevelopment as a path dependant process: vicious circles, balanced vs. unbalanced growth and big push theory.
iii. Growth, development and income distribution.
iv. Rural markets and institutions.

Modern Growth Theory

i. Review of traditional growth models, efficiency results, barriersto growth, technical progress.
ii. AK models of growth – alternative foundation.
iii. Education and growth.
iv. Market structure and innovation.
v. Obsolescence, Schumpeterian growth.
vi. Distribution and Political Economy of growth.
vii. Open growing economies, trade policies.

Social Choice and Political Economy

Selected topics from the following:

i. Classical aggregation theory : Arrow's theorem, Harsanyi's theorem, aggregation with rich informational structures.
ii. Stochastic Dominance, Lorenz and generalized Lorenz orderings, ethical approaches to measurement of inequality and poverty.
iii. Classical voting theory : the Gibbard-Satterthwaite theorem, results on restricted domains, the median voter result, stochastic outcome functions.
iv. The theory of implementation in complete and incomplete information settings.
v. The theory of elections, legislatures and agenda control.
vi. The theory of interest groups : lobbying, bureaucracies, endogenous coalition formation.
vii. Models of corruption, political economy of the state.

Incentives and Organizations

i. Theory of incentives : adverse selection, moral hazard, multiple agents, contract dynamics.
ii. Organization theory : team theory, message space size, costly information processing models.
iii. Incentive-based approaches : supervision, managerial slack, limited commitment.
iv. Applications to the theory of the firm : decentralization, hierarchies, transfer pricing, managerial compensation, cost allocation.

Privatization and Regulations

i. Regulation of competition, externalities and natural monopolies, vertical integration, mergers and takeovers, bureaucracies and corruption.
ii. Public sector performance in India and other developing countries.
iii. Privatization, theory and experiences.

Economic Development II

i. Economic Development and Planning of Dual Economics : Choice of Techniques, Marketable Surplus, Rural-Urban Migration, Unemployment.
ii. Role of trade and factor mobility in economic development; international technology transfer and relative technological backwardness of less developed countries.
iii. Endogenous growth : increasing returns and technological progress; multiple equilibria and underdevelopment trap.

Econometric Applications II

Some subset of the following topics will be covered depending upon the interest of the instructor and the students:

i. Income and allied size distributions: stochastic models of income distribution, measurement of income inequality, problems of measurement, Indian studies on inequality and poverty.
ii. Advanced demand analysis: demand systems, zero expenditure and corner solutions, nonlinear budget frontiers, rationing, sources of dynamics inconsumer behaviour, durable goods, non-parametric demand analysis.
iii. Production analysis: frontier production function, measurement of productivity and technical change, flexible forms, aggregation, properties and estimation of multi-output production and cost functions.
iv. Application of Econometrics to macroeconomic problems: macroeconometric models – economic issues in the specification and estimation, illustrative applications, uses in forecasting and policy evaluation.
v. Estimation of structural models of firm behaviour: dynamic programming models, policy effects on productivity, capital formation and product-mix of firms, models of firm heterogeneity – measurement of product quality and efficiency differences among firms.
vi. Empirical models of the labour market: duration analysis, labour supply and labour demand functions including the impact of unionisation, studies on the Indian labour market.

Game Theory II

i. Games of Incomplete Information
   a) Bayes-Nash equilibrium.
   b) Applications to industrial organization.

c) Reputation models.

ii. Auction theory
   a) First and second price auctions.
   b) The Revenue Equivalence Theorem.
   c) Revenue optimal auctions in the independent values case.
   d) Efficient auctions in the common-values case.

iii. The theory of equilibrium selection
   a) Sequential and trembling hand perfect equilibria.
   b) Forward induction.

iv. Mechanism Design
   a) Strategy-proof mechanisms: the Gibbard-Satterthwaite Theorem.
   b) Transferable utility and Groves-Clarke theory.
   c) Bayesian Incentive compatibility.

v. Topics in evolutionary game theory

vi. Advanced topics in cooperative games

Bayesian Econometrics

i. Principles of Bayesian analysis.
ii. Simple univariate normal linear regression models.
iii. Analysis of single equation nonlinear models.
iv. Multivariate regression models.
v. Comparison and testing of hypothesis.
vi. Simultaneous equations econometric models.

Intertemporal Economics

i. Models of intertemporal accumulation.
ii. Efficient programmes, characterizations of efficiency, efficiency and present value maximization.
iii. Optimal programmes, optimality criteria in discounted and undiscounted models, existence of optimal programmes.

Theory of Planning

i. Political economy of the state, alternative viewpoints.
ii. Modeling government behaviour, rational choice models, median voter model, legislatures and special interest groups, bureaucracy models.
iii. Planning models, centralized planning, informationally decentralized planning processes, Lange-Lerner, MDP procedures, team theory.
iv. Incentives within the public sector.
v. Performance incentives for managers, decentralized organization of production, multidivisional firms, cost centres and profit centres, cost allocation transfer pricing, labour policies : Soviet and East European firms.
vi. Cost-benefit analysis.
vii. Pricing public sector outputs, marginal cost and average cost pricing, peak load pricing, priority pricing.

Social Accounting

i. The economic process and various concepts.
ii. A system of social/national accounts.
iii. National accounts and various estimates.
iv. 'Real' gross domestic product and 'real' national income.
v. Estimation of national income in India.
vi. Preparation of an input-output (IO) table.

Public Economics

i. Welfare objectives of the State : interpersonal utility comparisons.
ii. Principles of taxation.
iii. Theory of Second Best, problems of externalities & public goods.
iv. Incentives and mechanism design, Gibbard-Satterthwaite theorem.
v. Tax incidence in static (partial and general equilibrium) models.
vi. Tax incidence in Dynamic Models.
vii. Optimal taxation and public production.
viii. Dynamics, incidence and efficiency analysis of taxes.
ix. Economics of corruption.
x. Economics of Public Sector Enterprises.
xi. Procurement policies : incentive contracts and auction theory.
xii. Regulation of private firms.

Regional Economics

i. Introduction to regional planning.
ii. Review of the Indian situation.
iii. Concepts and techniques used in regional planning.
iv. Regional decision making and regional balance.
v. Functional spatial configuration and regional synthesis.

International Economics I

i. Various comparative-advantage based competitive theories of international trade including the Ricardian model, the Heckscher-Ohlin model and the sector specific model and their generalizations.
ii. Theory of commercial policy, tariffs, taxes and quantitative restrictions in traditional trade models.
iii. Imperfectly competitive models and intra-industry trade models of international trade.
iv. Trade, growth and development.
v. International factor movements.

International Economics II

i. Dynamics of Small Open Economies in Infinite Horizon and Overlapping Generations Models.
ii. Non traded goods, Real Exchange Rate and the Terms of Trade.
iii. Uncertainty and International Financial Markets.
iv. Money and Exchange rates under flexible and fixed prices.
v. Sovereign Debt.

Advanced Topics in International Economics

i. Political economy of trade policy.
ii. International trade and endogenous growth.
iii. Trade and environment.
iv. Trade and distribution.
v. Exchange rate dynamics in a small country setting.
vi. Agency problems and international lending.
vii. The New-Keynesian Models of the Open Economy.
viii. International capital mobility and development.

Mathematical Programming with Applications to Economics

i. Static linear and non-linear programming problems.
ii. Dynamic problems: calculus of variations, optimal control theory and dynamic programming.

Monetary Economics

i. Transaction, precautionary and speculative demands for money.
ii. Money in an overlapping generation model, general equilibrium Baumol-Tobin model, cash-in-advance model.
iii. Currency and credit with long lived agents in overlapping generations set-up.
iv. Monetary policy, (non-) neutrality.
v. Money, inflation and stability, money vs. interest rate targeting.

History of Economic Thought

i. Introduction – relevance of the subject, the idea of a mainstream.
ii. Mercantilism – economic and political background, issues and doctrines.
iii. The physiocratic breakthrough – focus upon production, the framework of reproduction and concept of 'produit net', 'tableau economique' and the concept of circular flow, the physiocratic system.
iv. Classical political economy (CPE) – Adam Smith's break and continuity with mercantilism; the physiocratic input: transformation of the framework of reproduction through the motion of 'stock'; the framework of value, distribution and accumulation; the idea of free competition: price formation through equalization of rates of profit– natural rule and market price; Ricardo's "elimination" of rent; the Ricardian system and its evolution through time.
v. Marx and the Marxist tradition – the 'labour' standpoint : view of history, concept of 'surplus' and class analysis.
vi. The marginalist revolution – unresolved problems of CPE; fresh search for 'first principles'; unification of different branches economic theory under marginal calculations and demand – supply analysis.
vii. The Walrasian tradition – the idea of a 'general equilibrium', mathematical development : connection with optimization, the 'welfare' branch.
viii. The Marshallian tradition – the idea of a 'short period', theory of the firm and market structure, the Keynesian breakthrough – re-emergence of macro analysis, macro-micro relations.
ix. The Mengerian tradition – subjectivism and methodological individualism, 'new institutional economics'.
x. The 'present' as history – any mainstream ?

Environmental Economics

i. Theories of externalities and public goods.
ii. Trade and environmental policy.
iii. Design of environmental policy.
iv. Marketable pollution permits.
v. Choice between permits and taxes.
vi. Methods of measuring the benefits of environmental improvements.
vii. Models of resource depletion, exhaustible and renewable resources.

Theory of Finance I

See the elective course for AS.

Theory of Finance II

See the elective course for AS.

Theory of Finance III

Advanced Topics in:

i. Banking finance.
ii. Market microstructure.
iii. Regulation and incentives.

Political Economy and Comparative Systems

i. Classical political economy : Crystallization of the concept of "social structure" in the concept of "class", class division and boundary of production ("productive" vs "unproductive" class/labour) in Quesnay and Smith, the systems of social accounting policy aspects, reaction against "mercantilism : theoretical structure of classical political economy, value, distribution and accumulations, the Ricardian system, the post Ricardian scene, emergence of "socialist" doctrines.
ii. Marxian political economy : the broader perspectives and view of history, "modes of production" (feudalism, capitalism and socialism),the political economy of capitalism, surplus value, theories of crises.
iii. Further developments in the political economy of capitalism : developments within a "class" framework, Kalecki's theory of effective demand and business cycles, abandoning the "class" framework or the turning point in the history of economic thought, birth of "welfare economics", "competition" and "monopoly", Keynes' theory of effective demand and its link up with the theory of growth.
iv. Political economy of socialism : doctrines and experiences.
v. Political economy of LDCs : the intrinisic heterogeneity and amorphousness of LDCs, the "goal" of development in a historical perspective, the concept of "dual economy", global perspectives.

3.3 Courses for Applications Specialization:

Compulsory Courses :

Analysis - I

Real numbers, countability. limit points of sets, lim sup and lim inf. open and closed sets, sequences and series, basic tests for convergence of a series, power series, product series.
Limit, continuity, properties of continuous functions.
Derivatives. basic properties. mean value theorem and applications, L'Hopital's rule, Taylor's theorem.
Riemann integration, first and second fundamental theorems of calculus, change of variable, integration by parts, mean value theorems for integrals.
Suggested books :

- R. G. Bartle and D. R. Sherbert, *Introduction to Real Analysis.*
- W. Rudin, *Principles of Mathematical Analysis.*
- T. Tao, *Analysis,* Vol. I.

Probability and Stochastic Processes- I

Review of basic concepts of probability, random variables and common distributions.
Random vectors, joint distributions, joint m.g.f., mixed moments, variance covariance matrix. Independence, sums of independent random variables, Poisson approximation to the normal distribution, multinomial distribution, Conditional expectation and variances, Order statistics, Sampling distributions. Characteristic functions.
Concepts of convergence of a sequence of r.v.s.
Kolmogorov strong law of large numbers, monotone convergence theorem and dominated convergence theorem (all without proof).
Continuity theorem for characteristic functions, Lindeberg's CLT and its particular cases.
Suggested books :

- R. V. Hogg and T. T. Craig, *Introduction to Mathematical Statistics.*
- V. K. Rohatgi and A. K. Ed. Ehsanes Saleh, *Introduction to Probability Theory and Statistics.*
- P. G. Hoel, S. C. Port and C. J. Stone, *Introduction to Probability Theory.*
- P. Billingsley, *Probability and Measure.*
- W. Feller, *Introduction to Probability and its Applications,* Vols. I & II.
- M. Loeve, *Probability Theory.*
- B. V. Gnedenko, *Theory of Probability.*

Methods of Statistical Inference – I

Sufficient statistics and minimal sufficient statistics, ancillary statistics, completeness, exponential families and their properties, Basu's theorem. Jensen's inequality.
Different kinds of loss functions, risk function, Rao-Blackwell Theorem with general loss functions, Information inequality: multiparameter case and extensions, UMVUE. Maximum likelihood estimation.
Elements of Bayesian Inference: Bayes Risk, Posterior, Bayes Credible Region, Minimax Estimates.
Neyman Pearson Lemma, distributions with MLR property, UMP unbiased tests, LMP tests, Neyman structure, P-values and its examples, Interval estimation, Sequential Probability Ratio test, Stein's two-stage procedure.

Suggested books :

- G. Casella and R. L. Berger, *Statistical Inference*.
- C. R. Rao, *Linear Statistical Inference* and its Applications.
- E. L. Lehmann and G. Casella, *Theory of Point Estimation*.
- E. L. Lehmann, *Testing Statistical Hypotheses*.
- P. J. Bickel and K. A. Doksum, *Mathematical Statistics : Basic Ideas and Selected Topics*.

Linear Algebra

Vector spaces with real and complex scalars; subspaces, linear dependence and independence, basis, dimension, sum and intersection of subspaces. Linear equations: homogeneous and nonhomogeneous systems, solution space, consistency and general solution, numerical examples.
Inner product and norm: geometric interpretation, Gram-Schmidt orthogonalization process, orthogonal projection, projection on a subspace. Linear transformations and Matrices : rank, trace, elementary operations, canonical reductions, orthogonal matrices, symmetric matrices, inverse, sweep-out method. Operations with partitioned matrices. Determinant: definition and properties, computation. Characteristic roots and vectors: numerical examples.
Quadratic forms: classification and transformations, canonical reduction of real symmetric matrices, spectral decomposition, Cayley-Hamilton theorem.
Generalized inverse: properties, applications. Projection operators on . as idempotent matrices: properties.
Suggested books :

- C. R. Rao, *Linear Statistical Inference and its Applications*.
- A. R. Rao and P. Bhimsankaram, *Linear Algebra*.
- R. B. Bapat, *Linear Algebra and Linear Models*.

Elements of Sample Surveys and Design of Experiments

Sample Surveys
Review of simple random sampling, stratification, ratio and regression estimators, two-stage sampling. Sampling designs, homogeneous linear unbiased estimators, Godambe's non-existence theorem. PPS sampling with and without replacement. Horvitz-Thompson estimator and its variance estimators. Some sampling schemes with inclusion probability proportional to size. Non-sampling errors and their handling.
Design of Experiments
Review of standard designs; Intra-block analysis of a general block design; concepts of connectedness and variance-balance. Balanced incomplete block designs and elementary construction of such designs. Factorial experiments and designs, concepts of orthogonal factorial structure and balance. Response surface designs.
Suggested books :

- W. G. Cochran, *Sampling Techniques*.
- M. N. Murthy, *Sampling Theory and Methods*.
- Aloke Dey, *Theory of Block Design*.
- D. Raghavarao, *Constructions and Combinatorial Problems in Design of Experiments*.
- A. Dean and D. Voss, *Design and Analysis of Experiments*.
- M. C. Chakravarty, *Mathematics of Design and Analysis of Experiments*.

Probability and Stochastic Process - II

Markov chains with stationary transition probabilities, properties of transition functions, classification of states, Stationary distribution of a Markov chain, existence and uniqueness, convergence to the stationary distribution.
Methods based on Markov chains for simulation of random vectors. MCMC algorithm.
Random Walks, queueing processes, branching processes.
Gambler's ruin problem, transient states.
Suggested books :
W. Feller, *An Introduction to Probability Theory and its Applications*, Vol.-II.
S. Karlin and H. M. Taylor, *A First Course in Stochastic Processes*.
P. G. Hoel, S. C. Port and C. J. Stone, *Introduction to Stochastic Processes*.
S. Ross, *Introduction to Probability Models*.

Linear Models and GLM

Linear statistical models, illustrations, Gauss-Markov model, normal equations and least squares estimators, estimable linear functions, *g*-inverse and solution of normal equations. Error space and estimation space. Variances and covariances of BLUEs. Estimation of error variance. Fundamental theorems of least squares and applications to tests of linear hypotheses.
Fisher-Cochran theorems. distribution of quadratic forms.
Generalized Linear Models, Logistic regression, Log-linear models.
Practical on matrix computations, least squares estimation and testing using statistical packages.
Suggested books :
C. R. Rao, *Linear Statistical Inference and its Applications*.
S. R. Searle, *Linear Models*.
T. P. Ryan, *Modern Regression Methods*.
D. C. Montogomery, E. A. Peck and G. G. Vining, *Introduction to Linear regression analysis*.

Methods of Statistical Inference – II

Delta method. Asymptotic properties of sample quantiles, Asymptotic relative efficiency of estimators, M.L.E.s and their large sample properties, Method of scoring.
Transformations and variance stabilizing formulae, Asymptotic distributions of functions of sample moments. Likelihood ratio tests and their large sample properties, Pearson's chi-square, contingency tables.
Non-parametrics; Kolmogorov-Smirnov tests, sign test, signed rank test, run test, Kruskal-Wallis test, Mann-Whitney test, Hodges-Lehmann estimators, Censored data, Kaplan-Meier estimators.
Suggested books :
G. Casella and R. L. Berger, *Statistical Inference*.
T. S. Ferguson, *Mathematical Statistics - A Decision Theoretic Approach*.
E. L. Lehman and G. Casella, *Theory of Point Estimation*.
T. P. Hettmensperger, *Statistical Inference Based On Ranks*.
C.R. Rao, *Linear Statistical Inference and its Applications*.
E. L. Lehmann, *Elements of Large Sample Theory.*
Robert Serfling, *Approximation Theorems of Mathematical Statistics*.
P. K. Sen and J. M. Singer, *Large Sample Methods in Statistics : An Introduction with Applications*.
J. Hajek, Z. Sidak and P. K. Sen, *Theory of Rank Tests*.

Multivariate Analysis

See the compulsory course in Section 3.1.

Regression Techniques

See the compulsory course in Section 3.1.

Analysis – II

Improper Riemann integrals, tests of convergence.
Sequence and series of functions and their behaviour vis-a-vis continuity, differentiability and integration.
Multivariate Calculus: Limit of a function, difference with the single variable case, differentiation.
Implicit function theorem and the inverse function theorem.
Differentiation with respect to a vector, Jacobians.
Suggested books :

- W. Rudin, *Principles of Mathematical Analysis*.
- Terence Tao, *Analysis,* Vol.-II.

Statistical Computing

C++ programming, use of packages as available at the time, like S+, SyStat, SAS etc., simulation, resampling techniques like jack-knife and bootstrap, EM algorithm, IRLS.
Suggested books :

- D. Kundu and A. Basu, *Statistical Computing.*
- S. M. Ross, *Simulation*.

Time Series Analysis

See the elective course in Section 3.1.

Probability and Stochastic Processes – III

Markov pure jump processes, Poisson process, Birth and Death processes. Finite state continuous time Markov chains.
Renewal processes, Poisson process as a renewal process, elementary renewal theorem. Statement (without proof) of other renewal theorems. Simple queueing systems. Introduction to Brownian Motion.
Suggested books :
H. M. Taylor and S. Karlin, *An Introduction to Stochastic Modelling*.
J. Medhi, *Stochastic Processes*.
S. M. Ross, *Introduction to Probability Models*.

Project

It is envisaged that students, individually or in a group, are assigned to a faculty member. They will need to work on suitable projects arising out of real life problems and which involve application of statistical techniques. Help may be sought from colleagues in other units and industry in this regard.

Elective Courses :

Metric Topology and Complex Analysis

See the compulsory course in Section 3.1.

Measure Theory

σ-fields and monotone class theorem, Measures, Caretheodory Extension theorem, Lebesgue measure, Integral of a measurable function with respect to a measure.
Fatou's lemma, Monotone Convergence theorem, Dominated Convergence theorem.
Hahn Jordan decomposition, Lebesgue decomposition, Radon Nikodym derivative, Product measure, Fubini's theorem.
Convergence in measure, almost everywhere convergence, Kolmogorov Inequality. Kolmogorov three series criterion, strong law of large numbers.
Conditional Probability and conditional expectations, their simple properties, Martingales (discrete parameter), uniform integrability.
Suggested books :
P. Billingsley, *Probability and Measure*.
R. B. Ash, *Real Analysis and Probability.*

Advanced Linear Algebra / Matrix Analysis

This is a prerequisite for Functional Analysis.
Norms, limits and convergence in matrix spaces.
Analysis of matrix decompositions : QR, LR, SVD and Spectral.
Extremal Principles for eigenvalues.
Sensitivity of eigenvalues and eigenvectors.
Nonnegative matrices and their applications.
Suggested books :
R. B. Bapat and T. E. S. Raghavan, *Nonnegative Matrices and Applications*.
R. Bhatia, *Matrix Analysis*.
G. W. Stewart, *Introduction to Matrix Computations*.

Functional Analysis

Basic metric spaces and locally compact Hausdorff spaces. Riesz representation theorem and Stone-Weierstrass theorem.
Three fundamental principles of Banach Spaces (Hahn-Banach, Uniform boundedness and open mapping theorems).
Hilbert spaces, operators. Spectral theorem.

Topics in Fourier Analysis

Fourier Series of continuous functions, their convergence and divergence, Cesaro and Abel convergence, mean convergence, Applications.
Topics to be chosen from:
Fourier Transforms on L_1 and L_2 spaces. Basic theorems and their applications.
Discrete Fourier Transform, Fast Fourier Transform, Wavelets on $\mathbb{Z}$ and $\mathbb{Z}^n$.
Boundary value problems.

Suggested books :
R. Bhatia, *Fourier Series*.
M. W. Frazier, *An Introduction to Wavelets through Linear Algebra*.
R. R. Goldberg, *Fourier Transforms*.
T. W. Korner, *Fourier Analysis*.

Applied Multivariate Analysis

See the compulsory course for ASDA.

Advanced Sample Surveys

See the compulsory course for ASDA.

Topics in Design of Experiments

Recovery of interblock information in block designs. Optimality criteria and discussion of optimal block designs. Symmetric and asymmetric factorials. Fractional factorials and orthogonal arrays, including optimality of fractional factorials based on orthogonal arrays and construction of orthogonal arrays, Repeated measurement designs.

Survival and Actuarial Models

Concepts of Time, Order and Random Censoring.
Life distributions - Exponential Gamma, Weibull, Lognormal, Pareto, Linear Failure rate. Parametric inference Point estimation, Confidence Intervals, scores, tests based on LR, MLE.
Life tables, Failure rate, mean residual life and their elementary properties, Ageing classes-IFR, IFRA, NBU, NBUE, HNBUE and their duals, Bathtub Failure rate.
Estimation of survival function-Actuarial Estimator, Kaplan-Meier Estimator, Estimation under the assumption of IFR / DFR.
Tests of exponentiality against non-parametric classes--Total time on test, Deshpande test, Two sample problem--Gehan test, Log rank test, Mantel-Haenszel Test, Tarone-Ware tests. Rank tests with censored data.
Binomial and Poisson models for discrete data.
Markov Models: Two-state model, illness-death model, maximum likelihood estimator and its properties.
Semi-parametric regression for failure rate--Cox's proportional hazards model with one and several covariates.
Survival data with competing risks.
Suggested books :

- D. R. Cox and D. Oakes, *Analysis of Survival Data*.
- A. J. Gross and V. A. Clark, *Survival Distributions: Reliability Applications in the Biomedical Sciences*.
- R. C. Elandt-Johnson and N. L. Johnson, *Survival Models and Data Analysis*.
- R. G. Miller, *Survival Analysis*.
- M. J. Crowder, *Classical Competing Risks*.

Nonparametric Inference

Nonparametric Methods: Formulation of the problems, order statistics and their distributions. Tests and

confidence intervals for population quantiles. Sign test. Test for symmetry, signed rank test, Wilcoxon-Mann-Whitney test, Kruskal-Wallis test. Run test, tests for independence. Concepts of asymptotic efficiency. Estimation of location and scale parameters. Sequential Analysis: Need for sequential tests. Wald's SPRT, ASN, OC function. Stein's two stage fixed length confidence interval. Illustrations with Binomial and Normal distributions. Elements of sequential estimation. Practicals using statistical packages.

Suggested books :

- E. L. Lehmann, *Nonparametrics: Statistical Methods Based on Ranks*.
- J. Hajek and Z. Sidak, *Theory of Rank Tests*.
- P. J. Bickel and K.A. Doksum, *Mathematical Statistics*.
- G. Casella and R. L. Berger, *Statistical Inference*.

Actuarial Methods

See the compulsory course for ASDA.

Generalized inverse and applications

Basic properties of generalized inverse (*g*-inverse), least-squares and minimum-norm *g*-inverse and Moore-Penrose inverse, Partitioned matrices, constrained *g*-inverse, Group inverse and Drazin inverse. Determinantal identities.
g-inverse over general algebraic structures.
Applications in statistics, Markov chains, iterative methods.
Computational aspects.

Suggested books :

- S. L. Compbell and C. D. Meyer, *Generalized Inverses of Linear Transformations*.
- A. Ben-Israel and T. N. E. Greville, *Generalized Inverses: Theory and Applications*.

Graph Theory

Graph: isomorphism, adjacency and incidence matrices, degree sequence, Havel-Hakimi Theorem, Erdos-Gallai Theorem.
Paths, connectedness, trees; characterization. Minimal connector problem. Kruskal's algorithm. Cut vertices, cut edges.
Euler chain characterization theorem; Hamiltonian graph. Different degree sequences vs. Hamiltonicity. Travelling salesman problem. Applications.
Edge colouring, vertex colouring numbers. Vizing-Gupta theorem. Bipartitie graphs. Applications. Planar graphs, statement of Kuratowski's characterization. Examples. The five-colour theorem and the statement of the four-colour theorem, graphs on surfaces. Directed graphs. Applications.
Flows, cuts, max-flow min-cut theorem; applications and examples.
Ramsey theory.
Eigenvalues of graphs.

Suggested books :

- D. B. West, *Introduction to Graph Theory.*
- T. A. Bondy and U. S. R. Murthy, *Graph Theory with Applications*.

Microeconomics I

See the compulsory course for QE.

Macroeconomics I

See the compulsory course for QE.

Microeconomics-II

General equilibrium theory: existence of competitive equilibrium, stability, core equivalence, Welfare economics: Fundamental theorems of welfare economics, market failure, public goods and externalities, Social choice theory: majority voting, Arrow's Impossibility Theorem, Economics of information: Moral hazard and adverse selection.

Game Theory

Non-cooperative games: normal and extensive form representations. Nash equilibrium and applications, credibility and subgame perfection, bargaining, games of incomplete information and auctions.
Cooperative games: games in characteristic form, solution concepts such as the core, Shapley value, nucleolus and the bargaining set, axiomatic bargaining theory.

Finance

Microeconomics I is a prerequisite for this course.
Preference representation under uncertainty, stochastic dominance and risk, the portfolio frontier, value maximization and the separation theorem.
The CAPM model, valuation of securities, Asymmetric information and efficiency.