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# TEACHING STOCHASTIC CONCEPTS AT THE BUT FACULTY OF MECHANICAL ENGINEERING

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**Abstract:** The paper is concerned with courses in stochastic disciplines as offered at the Faculty of Mechanical Engineering of Brno University of Technology, their history, present situation, experience gained from teaching, and with related issues. It also provides information on the statistical software available at the faculty, use of computer rooms, degree projects and theses related to teaching in such courses.

## Introduction

For a number of years, the authors of the paper have been teaching in stochastic courses and courses that use stochastic models offered at the Faculty of Mechanical Engineering of Brno University of Technology. These include the following courses:

- the basic Master's degree course,
- full-time, and combined Bachelor's degree course,
- engineering specialization courses,
- mathematical engineering courses,
- doctoral courses.

Due to their contents and the applications involved, there are aspects of the teaching in such courses that are somewhat different from those of a majority of other mathematical courses taught at a technical faculty. The differences are not only in the history but also in the teaching organization and methods, in procedures used to assess the knowledge acquired by the students, in the preparation of teaching texts, and in the way specialised software packages are used.

## 1. Recent history from 1959 to 1990

First a few words about the history of teaching of these subjects. After making attempts at introducing various concepts of engineering education, it was decided in 1959 to establish an independent Faculty of Mechanical Engineering. From that year on until about 1980 there were only sporadic attempts at including stochastic modelling in the basic mathematics course. Such attempts were only the results of single initiatives of individual teachers as their specialisation and the then very strict curricula did not allow more. A different situation was in the manufacturing technology specialisation where basics of statistical methods were part of a specialised course and of the final state examination. On the contrary, as the doctoral study concerns, most of the then "candidate of science aspirants", that is, the then doctoral students both external and internal completed some basic statistic course as part of their doctoral programme. However, the teaching took form of individual consultations as required by the supervisors and was limited by problems in obtaining suitable textbook. Gradually, statistical methods were included to a larger extent in the so-called "post-graduate" courses (now referred to as lifelong learning courses) that the faculty provided at the request of companies and institutes.

The teaching of probability and statistics in the 1980's was positively marked by introducing a new Mathematics IV course with three hours lectures and three hours tutorials a week and with statistical methods being the only subject of the course. This was the result of a unification of curricula at all the faculties of mechanical engineering in the then Czechoslovakia, however, set off by reducing the number of hours per week for the other mathematical subject in the basic course. Moreover, this course was only introduced in the five-year (design) specialisations and not in four-year (technology and automation) courses where its absence was having a very negative effect. Apart from this course, our department at that time provided another two statistical courses in specialised branches of study (manufacturing technology and foundry technology), training of the faculty doctoral students in selected parts of mathematical statistics and special courses of stochastic nature in the doctoral programmes of engineering departments.

## 2. From 1990 until the present

The period from 1990 until the present is markedly different, which can be seen from the following facts. After some turbulence and searching in 1990 with, perhaps well-meant, attempts to curb the teaching of stochastic subjects by a recommended or optional form, it was not only possible, though at the cost of a gradual reduction of the number of lessons per week from 3/2 to 2/2, to maintain the Mathematics IV course, but also to extended it, in connection with the termination of four-year programmes, to all the specialisations at the faculty as part of a unified mathematics course in the first stage of Master's degree study. In recent years, about 500 students have been taking this course

annually. As the full-time and later on also a combined Bachelor's degree programmes were launched, first a Statistics and Probability course was offered in different variants to fit the various study branches, which, now in its unified form for all the branches, has a scope of 2/1. About 220 students complete this course annually. A third basic course is the optional Statistical Software with a scope of 0/1, attended by about 130 students. The teaching of statistical PC programs is dealt with in a separate paragraph. In the above-mentioned period, the statistics courses could also be significantly extended in engineering specifications, that is, at the second Master's degree study stage (year 4 and 5). This is a total of 7 current courses yearly attended by about 160 students. All the above-mentioned courses are shown in Table 1.

**Table 1.** ***Master's and Bachelor's degree study at the BUT FME***

| *Course title* | *Year* | *Winter semester scope* | *Spring semester scope* | *For specialization* |
|---|---|---|---|---|
| Mathematics IV | 2 | | 2/2 z, zk | Master's degree study |
| Statistics and probability | 2 | 2/1 z, zk | | Bachelor's degree study |
| Statistical software | 2 | | 0/1 z | Master's degree study |
| Statistical analysis | 4 | | 2/1 kl | Materials engineering |
| Statistical analysis | 5 | | 2/0 z | Technology of environment |
| Applied statistics | 4 | 2/1 z, zk | | Quality management |
| Technique of experiment | 5 | 2/1 z, zk | | Quality management |
| Analysis in engineering experiment | 5 | | 2/1 z, zk | Physical engineering |
| Applied mathematics | 3 | | 2/1 z | Physical engineering |
| Applied mathematics – data processing | 5 | | 2/2 z, zk | Design of machines and devices |

z = *class note to be obtained in tutorial lessons,* zk = *examination required,* kl = *tutorial lessons ended with an examination*

A specific situation exists in a five-year Mathematical Engineering specialization based directly on the Institute of Mathematics. Established in 1993 due to the then propitious situation at the Faculty and thanks to the enthusiasm of several members of the Institute staff, this specialization is designed to educate engineers equipped with knowledge of mathematical modelling and ability to solve both technical and non-technical tasks and problems. The specialization is based on a long-term research co-operation and mutual consultancy between the Institute and other Faculty institutes and BUT departments as well as other universities, the Academy of Sciences of the Czech Republic, research institutes, institutions, and companies. It is accredited at the Faculty of Mechanical Engineering and organised in co-operation with the Department of Applied Mathematics of the Faculty of Science at Masaryk University Brno. In addition to the basic mechanical engineering subjects, the students are offered the basic mathematical courses, 6 courses of a stochastic nature, next courses related to or using stochastic models (optimization, fuzzy sets, image analysis), courses dealing with numeric methods and functional analysis, they are given robust basics of programming and offered specialised courses. The degree projects assigned are on particular mathematical models of engineering problems and selected theoretical problems, including those requiring the development of PC programs and the actual computing. There are about 110 students in all five years and more than a half of the 20 students graduating annually are assigned a degree project on direct or supporting stochastic models. The courses in the above-mentioned specialisation of a stochastic nature are shown in Table 2. In each academic year, 5 to 7 graduates of this specialisation go on studying for a Ph.D. with several others from other faculty institutes.

**Table 2.** ***Mathematical engineering specialisation at the BUT FME***

| *Course title* | *Year* | *Winter semester scope* | *Spring semester scope* | *Number of credits* | *Tutorial type* |
|---|---|---|---|---|---|
| Probability and statistics I | 2 | | 3/2 z, zk | 6 | C2a |
| Probability and statistics II | 4 | 3/2 z, zk | | 6 | C2a |
| Stochastic processes | 4 | | 3/1 z, zk | 4 | C2a |
| Stochastic modelling | 4 | | 0/2 kl | 3 | C1 |
| Probability and statistics III | 5 | | 2/2 kl | 4 | C2a |
| Analysis of engineering experiment | 5 | | 2/2 z, zk | 5 | C2a |

For more information on all the above courses (persons in charge, follow-up and previous courses, syllabus, requirements, etc.), please visit Internet address [3].

The present doctoral study at the Faculty of Mechanical Engineering includes 4 courses of a stochastic nature (Statistic analysis, Dynamic and multidimensional stochastic models, Empiric models, and Experimental design) attended by about 80 students yearly.

## 3. Further „stochastic“ activities

Some parts of descriptive statistics, basics of probability, mathematical statistics, stochastic processes and their applications, apart from being taught in basic courses, are examined as part of the final state examinations in the Mathematical Engineering and Quality Management specialisations, which are yearly passed by about 45 students. Also the state doctoral examination boards at the Faculty of Mechanical Engineering ask about 25 Ph.D. candidates yearly on applications of such disciplines and, as part of admission tests for Ph.D. study, every year 70 to 90 candidates have to answer questions related to the theory of probability, statistics and their applications. Four Mathematical Engineering doctoral students have been assigned and presented theses focussed, to some extent, on modelling problems with uncertain information by methods of a stochastic nature. Specialists from the Institute of Mathematics have been providing extensive consultancy support for doctoral students preparing their theses at other institutes of the Faculty of Mechanical Engineering and at other faculties.

Another activity worth mentioning is a lecture and a part of a seminar at the BUT University of the Third Age in which, now for a second year, senior students have been learning about statistic methods, aspects of their potential applications in research, industries as well as in everyday life.

## 4. Statistical software

Along with the basic probability and statistics (Mathematics IV) course in the second year of the Master' degree study the Faculty of Mechanical Engineering now offers also an optional Statistical Software course. This course is designed to provide the basic knowledge of and teach the basic skills with Statgraphics and Statistica statistical systems that are used in research and for teaching at the specialised institutes of the faculty, and to give an overview of the statistical functions of the Excel spreadsheet processor.

In 1992, the statistical software course was directly included in the tutorials of the Mathematics IV course. Thanks to the then extent – 3 hours lecture and 3 hours tutorials – about one fourth of the tutorials could be placed in computer rooms using Statgraphics 5.1, with its DOS versions being gradually upgraded to Statgraphics plus 2.4 for WIN. Due to a subsequent reduction of the teaching extent to 2/2, an optional Statgraphics course was introduced in 1996. In 2002 one computer room was equipped with a powerful Statistica 6.0 system. As the students are made familiar with both systems, the course was renamed to Statistical Software. Due to its extent of 0/1 (that is, no lecture and one tutorial lesson), the teaching is provided in 7 two-lesson sessions and it is a follow-up to Mathematic IV both in terms of the time and its content. Even though Statistical software is an optional course, more than one quarter register for it, which is mostly due to the opportunity it offers to work on the application-oriented semestral project required in the Mathematics IV course.

Using statistical software in teaching statistics has resulted in:

- the explanation of the basic probability and statistics notions being more efficient,
- more sophisticated ideas being visualised and understanding made more profound by interactively changing parameters,
- using the system for routine calculations, which offers space for improving the explanation of modelling and interpreting the results obtained,

- the basic methods used to process the data observed becoming more familiar.

Despite all this, the authors believe that, in a basic course, statistical software should only be used as an auxiliary tool and statistics should not be taught only on a computer because this might give the students a false idea that statistical methods are just pressing keys.

**5. Teaching methods**

Except for the Mathematical Software course the teaching takes the traditional form, that is, lectures and tutorial lessons. The lectures in the basic course take place in several lecture groups, which results in a somewhat unified lecturing and requirements for the semestral exams. Moreover, more freedom in lecturing and more diversity in individual lecturers would probably have a negative effect on the sanity of teachers leading the tutorials because it happens fairly often that they teach in tutorials for different lecture groups. The unification is ensured through curricula and textbooks and sometimes also, inadvertently, by the lecturer teaching in another group's tutorial. For lack of time, the part dealing with descriptive statistics is only included in tutorials. Students attending tutorials are marked, apart from methods specific for each teacher, by means of written tests although teachers are sometimes pressed for time. Semestral projects assigned to second-year Master's-degree students in the Mathematics IV course have proved to be useful. The assignments are chosen from manufacturing technology applications and involve processing statistical data by methods of descriptive statistics, assessing their normality, performing point estimates and finding confidence intervals, testing hypotheses to statistically compare two manufacturing procedures, estimating correlation coefficients and judging the independence of the parameters of a casting. No problems requiring regression analysis methods are included in the assignments of semestral projects since the students only learn about them at the very end of the semester. The textual parts of the assignment are identical for every student with only the numeric data differing and the problems correspond to the problems making up the written tests used for the exam. Solutions to these semestral projects have probably become part of a student "grey" database, which will necessitate new assignments. The practical part of the semestral exam consists of 4 problems to be solved on pocket calculators (2 in probability and 2 in mathematical statistics); the theoretical part consists of 4 questions on the importance and properties of the basic notions. Both parts of the exam are written; the students are shown their corrected and marked results. For the practical part, every student may prepare his or her own crib with the basic formulas but without model problems, statistical tables are handed out. The Bachelor's degree Statistics and Probability course is limited by its scope of 2/1 so that part of the computing methods are shifted to the lecture and require individual student work. Otherwise this course is much like Mathematics IV.

The teaching in stochastic courses both in specialisations and in the Mathematical Engineering is much the same with only slight modifications given by the requirements of the specialisations. Teaching for doctoral students mostly takes the form of seminar and consulting.

**6. Experience gained and final comments**

The situation in teaching the students at the BUT Faculty of Mechanical Engineering stochastic models seems to be so good that it can only become worse. To illustrate this, out of a total of 75 courses organised by the Institute of Mathematics of the Faculty of Mechanical Engineering at present, 21 are directly concerned with probability and statistical methods and another 23 courses are related to such methods in some way. However, some of our experiences and facts that we (and some other colleagues) have learned are not so optimistic.

Let us begin with the less encouraging facts. With the majority of students teachers have not been successful in stimulating a real interest among the students in stochastic methods, much less in a stochastic way of thinking. Lower-year students take these courses for a cumbersome duty and they only change their attitude as the end of their study or, more precisely, their degree project draws near. The situation is better in the Mathematical Engine-ering specialisation since students in this specialisation mostly have a clear idea about the reason why they have chosen it and some of them even guessed what was in store for them. Even a considerable number of doctoral students at the Faculty of Mechanical Engineering have not taken a particular liking to stochastic methods even if they see them as very useful. One cannot be much surprised at this since some supervisors include these courses in their programme as sort of "enlightment". However, the doctoral students' interest sharply rises as they proceed to process the measured values and begin to model the non-deterministic problems cropping up as they try to finish their degree projects when they acquire a very positive attitude to statistics. Let us hope that they will keep this attitude even after they successfully present their projects and begin to conduct research or get a practical job.

Success in teaching mathematics in the basic course is much conditioned by the amount of mathematical knowledge and skills that the students have acquired in secondary schools, which is not really large at present. This fact causes very poor knowledge of pre-requisites needed to understand probabilistic and statistical notions so that none of the young teachers with his or her rapid teaching experience will dare construct stochastic models otherwise than on an intuitive basis. As a result, this leads to a conflict between the number of lessons allotted for teaching and our endeavour to win students for statistics, rather than to discourage them (we see winning the students as our holy duty). Studying literature plays its role as well. Up to the present there a good and not-too-sophisticated, calculus-type textbook has been available even though, recently, there has been an increasing number of very good Czech probability and statistics textbooks to be downloaded from the Internet. Their very good hypertext interface indicates that the authors have been paid very well [4] or have become good-work-addicts [5]. At our faculty, we cover the basic stochastic courses with a classic text [1] and a teaching aid for the combined Bachelor's degree study [2] and are considering preparing their hypertext mutation.

Special issues have to be dealt with when teaching statistics on a PC. Let us only add to the information mentioned above that, in stochastic courses at a technical faculty, no doubt, a ready-made, reliable, and stable PC software package should be preferred. Despite being a surprisingly excellent tool in some cases and having a user-friendly interface, the much liked Excel spreadsheet processor does not meet all these requirements being unbalanced, not sufficiently covering the whole spectrum of statistical problems, and lacking method descriptions. For many years we have been using Statgraphics (first its DOS version and later on its Windows upgrades) to our full satisfaction and at present we are also using Statistica 6.0 a very robust system. In selected specialisations we also use S-Plus 6.0, QCExpert and the Matlab/Mathcad statistical libraries. However, ours as well as other experience of statistical software systems shows that, in teaching, they should only be used as an aid. For students to become really familiar with the methods they use to solve their problems, calculations using a pocket calculator will be indispensable still a long time.

Another fast developing area is using statistical applets and special software on the Internet – see, for example, [6]. These may be very efficient teaching aids, however, their more difficult availability, and lower rate of communication in real-time networking with potential copyright problems are still a hindrance to a more widespread use.

There are certainly much more problems connected with teaching in stochastic courses. For example, a methodology of utilizing the results from applied research, co-operation with other institutes, and from statistics applications for dealing with practical problems should deserve special attention. Thanks to the understanding of the management of the Faculty of Mechanical Engineering and a number of colleagues both from the Institute of Mathematics and from other faculty departments (the reason being in some cases that they themselves have experienced our training in statistical methods) we have managed to do some things well in teaching while being still in the dark and searching with others. Teaching mathematics and thus also stochastically oriented subjects tends to have the following results: a book of recipes, skills and applications, a way of thinking and creative work. We have been trying to reach at least the second stage.

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