

Communicating Statistics

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Summary

The world is full of people who need to be able to use statistical methods in their work. That is why applied statistics is such an interesting and challenging career: it presents the statistician with so many different problems. In particular the staff of manufacturing industries need to be skilled in the use of statistical tools. The managers, the engineers and the physical scientists can benefit greatly from an integration of statistical methods into their work. Sadly most of them are not aware of these benefits. Statisticians are frustrated by that ignorance. We know that we have so much to offer that could have a major impact, through the manufacturing industries, on the national economy. That is why we must address the question of communicating statistics. A change of culture is needed to bring about a greater acceptance by non-statisticians of statistical methods. But it is *our* culture, not theirs, which must first be changed. Instead of publishing so much to ourselves, through our own conferences and journals, we should reach out to those who need us, to convince them that they really do need us, so that they will come banging on our doors demanding our help. I make several positive suggestions about how we might achieve this. I appeal for more ideas and seek positive discussion.

'I'm on fire to explain. I don't indulge in scholarly depth.'

Isaac Asimov

Do they understand you?

Many years ago there was a steel company in Yorkshire which had, within its production control department, an operational research (OR) section. At that time, I was a free-lance technical journalist. One day, the managing director of the steel company asked me if I would work for him.

'Our OR scientists do some good work,' he said, 'but they don't write very good reports.'

My job was to write reports for the OR scientists, or at least to help them to write so that other people could benefit from the results of their investigations.

Sadly, for several months, nobody would allow me to help. I took to walking round the works, seeking ways in which I could be useful to other people. A large part of the works was known as the plate mill. Here there were several mills and other equipment for cutting, grinding, polishing, descaling, heat treating and transporting materials. There was so much equipment that it could be classed as a 'job shop' through which there were many possible routes for a job to pass. Thus, whenever the demand for the resources was high, which was most of the time, a major problem was to prescribe the best of all possible routes to every one of many jobs in such a way that the total use of all resources was optimal: the overall cost was as low as possible and delays, in terms of queuing times, were as short as possible.

I found that the job shop problem was a classic and that many papers had been published. So why had the schedulers in the plate mill not implemented any of the solutions? I showed them some of the published papers.

'We couldn't use those,' they told me, 'because we don't understand them.'

Eventually I produced a relatively simple solution, not absolutely optimal but quite close. I wrote a report beginning:

'The trouble with most theoretical approaches to the solutions of practical problems is that, although they may provide the best solutions, the academic theories and descriptions make little sense to the practical man. Similarly, the theoretician rarely considers the need to translate an apparently mathematical solution into a simple clerical function.'

These words, I thought, were unexceptional since they expressed the reason for my employment.

The head of OR, the late K D Tocher, arranged for me to go to Lancaster University for a six-weeks crash course in OR. From then on I became fascinated by mathematics, statistics, probability and computing. I took an external degree from University College London, became head of process computing and statistics at the British Steel Corporation's Sheffield laboratories and began to forget that other people did not share quite the same interests.

A metallurgist was doing some regression analysis with a program which failed to produce any results. In those days programs were not endowed with warning messages as they are today.

‘Why is it failing?’ he asked.

‘Your matrix is singular’, a statistical colleague replied.

The metallurgist was disgruntled and felt unhelped.

I made a similar gaffe at about the same time. I had been assigned to a naval committee for the assessment of structural steels used for building ships. All the other committee members were metallurgists or engineers. They had done a series of experiments in which the control variables were compositional and process and there were several response variables which were mechanical properties. My analysis was by canonical correlation. When I presented the results to the committee the chairman asked me to explain the method, which I did by writing the matrix algebra on the blackboard up to the point where eigenvectors are needed.

‘I won’t trouble to explain this to you,’ I said, ‘because the method is exactly the same as you would use to determine the principal directions of a second-order stress-strain tensor.’

They all nodded their heads, apparently in agreement, so I sat down. But over the next few weeks several of them approached me singly and apologised for their ignorance with words like: ‘I didn’t really take in the mathematical part of my course’.

I knew that they had not understood. Worse: I feared that they thought that I was deliberately misleading them under a camouflage of mathematics.

I realised that I was forgetting the essential purpose of technical journalism: to communicate technical information to other people in such a way that they could use it.

Theoretical drift

Over the years I have watched statistics change. It divided into theoretical statistics and applied statistics. Then applied statistics divided into theoretical applied statistics and applied-applied statistics. Experimental design, which interests me because in the world of practical research it aims to discover the most information for the least effort, has divided into pure experimental design theory and applied experimental design procedures. It is true that valuable improvements in the practical methods may emerge, from the purely theoretical studies, and often do, but the path of transfer is hard and forbidding.

The development of optimal experimental design theory by people who have no experience in practical research struck me long ago as ludicrous. Worse: emphasis on the mathematical theory of experimental design can make the practitioner feel inadequate and wonder whether he dare to admit in print that he is using old-fashioned and elementary methods. There is indeed a need for a theory of optimal design but it has value only when it is conveyed to the practitioner.

One of the most useful recent developments has been that of constructing trend free run orders for factorial designs (Cheng and Jacroux, 1988). The usual advice is to randomise the run order of an experiment. But out there in the factory, people will not do that because randomization exacts such a penalty in machine resetting costs. Cheng and Jacroux have been able to produce systematic designs in which the desired effects are trend resistant. The value to the factory manager who is experimenting with his production process is great. But it must be translated to the production manager's literature in a style and language that he will understand.

Papers about theoretical studies are too often obscure to the practitioner. Sometimes I find a theoretical paper with potential practical value but I have to devote several days' study to it to be able to understand it sufficiently to make any use of it. There are other practising statisticians who do not find it so difficult, but there are many more who find it so difficult that they just leave the journals unread on their shelves.

Journal editors should make it clear to all contributors that no theoretical paper will be accepted unless an application of the theory is included, with data, and expressed in a way that all practitioners will understand. Even better: every paper should start with an application to show that the theory is going somewhere useful.

The journals change too. The Royal Statistical Society's (RSS's) *Applied Statistics* was established to present either new or existing methodology within the framework of practical applications. There is no doubt that it does this, yet there is resentment among subscribers and we hear complaints that papers are too theoretical, too difficult, too long, impractical, or not sufficiently case oriented. Other journals started with similar intentions but have gone the same way. One is the Institute of Statistician's *The Statistician*. Another is the Journal of Applied Statistics which started life as *BIAS*. At meetings of the

(RSS's) Business and Industrial Section and of similar groups I hear complaints like: 'The journals have been taken over by the academics.'

So what is wrong? The editors of *Applied Statistics* have appealed often for short articles about case studies with little success. There are two sides to the problem.

Applied statisticians employed in business and industry are not there to write papers for publication and they have many demands on their time. If they do find time to write a paper, they will often not be allowed to publish it because some of the content will be classed as confidential. They may be expected to write reports; their performances may indeed be judged by those reports. But such reports are rarely published externally. The difficulty of confidentiality can be bypassed by creating a comparable but fictional industrial process with similar but fictional data.

But then, if the works statistician is permitted to write a paper and to submit it to a journal and is given the time to do it, he may still demur. He may worry that the editors and referees will insist on a style that he wants to avoid because he wants you to read and understand and enjoy his paper and to learn something useful from it. I shall return to this topic later. But it is a widespread worry, and there is some justification for it. I recently heard an editor comment about a submitted paper: 'I like it but I am wondering how it might be spiced up a bit to make it more academically respectable'.

Academic statisticians, in contrast, are employed to write papers as well as to teach. It is a recognised part of their job. Their career paths are determined by the publications listed in their *curricula vitae*. So the achievement of publication is itself a reason for writing a paper. It must appeal to the editors and to the referees. It must be rigorous and theoretical. It must leave no question unanswered. Above all, it must show how clever the author is. The applied statistician who may read it will not be expected to learn anything useful, even if he understands it.

There are a few academic statisticians who break boldly from this mould and write clearly, briefly, graphically, in simple terms that I can understand and in a context that is relevant to my work. To them I am grateful. I include Freund (1962) whose elementary book '*Mathematical Statistics*' gave me a splendid introduction to the subject; Draper and Smith (1966) whose book '*Applied Regression Analysis*' was so clearly illustrated with practical data sets; Scheffé (1966) from whose book '*The Analysis of Variance*' I learned to grapple with

unbalanced data sets; Anderson (1965) whose book *'Multivariate Analysis'* opened a new world for me; Tocher (1952) whose paper, *'The design and analysis of block experiments'* (which I read 20 years later), seemed to say, at that time, all that needed to be said about the design and analysis of experiments; Kalman (1960) whose classic 1960 paper, *'A new approach to linear filtering and prediction problems'*, shone new light on the difficult art of process control.

But, sadly, few practising engineers or applied scientists would share my delight. All these writings were in the wrong style and in the wrong context to capture, let alone to keep, their attention. If we want to interest them in our subject we must look for another approach.

Since all academic statisticians are also employed to teach they must surely have learned how to convey the subject to students who have, as yet, Over the years I have watched statistics no knowledge of it. I appeal to them to write their papers in the simple pedagogical style demanded by their students instead of resorting, through their academic snobbery, to the obscurantist style which I have dubbed 'akademisch'.

These thoughts, and others about teaching statistics to non-statisticians, came flooding to my mind when I was asked to address the 1992 RSS conference on *Communicating Statistics*.

By whom? To whom?

Any discussion of communication must address the questions:
'By whom? To whom?'

I shall restrict my attention to

(a) by academics to non-academics and

(b) by statisticians to non-statisticians.

The second of these may be analysed further:

- (i) by teachers of statistics to students of other subjects;
- (ii) by applied statisticians to other employees in business and industry.

Answers to these questions will suggest answers to the further question of 'How?' when we consider what media, style and content we should adopt for our communications.

Why bother?

Before addressing these questions, perhaps we should ask: 'Why bother?'

I believe strongly that the economic fortune of the UK depends on the success in the world markets of our manufacturing industries. We hear so often of great discoveries, inventions and developments in Britain that have been exploited elsewhere and we wonder what has gone wrong. We see goods that have for long been made here now being imported from the Far East. We hear of the decline of British industry relative to that of other European states. People debate the aetiology and therapies for *the malaise of British industry*.

A great movement has grown during the last ten years to tackle these problems: total quality management (TQM). The customer will receive what he wants at a price that he can afford. He can rely on the quality. He will have no cause for complaint. He will come back for more. National fortunes will thrive because, with better quality products, our manufacturers will be more able to meet foreign competition and to restore the balance of payments.

But something is wrong. Something is missing from the movement to total quality, though not everywhere. There are some companies that are reported to be doing it right. At the recent meeting (June 1992) arranged jointly by the RSS's Quality Improvement Committee and the Royal Society of Arts we heard senior executives of British Telecom and of Milliken Industries describe how their TQM policies had improved their operations. At the same meeting the Ashridge-Economist Intelligence Unit reported on how some of Europe's leading companies had improved their performances through implementing quality management. At another meeting of the Business and Industrial Section Dr David Price of British Steel told us how the implementation of statistical process control had improved the quality of their products and attracted substantial orders.

Unfortunately there are many more who are paying lip service to total quality and implementing standard procedures without understanding what they are doing. They are doing this so that they can claim certification under British Standard BS 5750 which is a set of guidelines, published by the British

Standards Institution, for improving the quality of products and services. But without understanding they will fail as surely as they would if they had never heard of TQM.

What do they not understand? They do not understand variability. Many engineers do not appreciate uncertainty. In general, I believe that they look at the world through deterministic eyes. If anything goes wrong they look for a special cause and tackle the problem by troubleshooting. The simplest example is in process control. You have a set point for the output and then you adjust the control for every deviation without distinguishing between common cause (intrinsic) variation and special cause variation. The consequence is that the total variation becomes greater than it would if the process were allowed to run uncontrolled.

Again, I sometimes meet an engineer (or chemist or metallurgist) who applies regression analysis to some experimental data. He then uses the fitted function to predict a result and complains that it is not accurate.

Within the Business and Industrial Section of the RSS we have debated these problems and we are constructing our own remedy through our Quality Improvement Forum which meets several times a year and has several outward reaching projects. We have arranged several public meetings, such as that at the Royal Society of Arts; we are promoting a series of two-day workshops in several regions of the country; we are planning to produce a high quality video about quality improvement; we are studying BS 5750 and other standards to suggest improvements; we are represented on the Parliamentary and Scientific Committee.

Change of culture

The obvious solution to the problem of lack of understanding is that businessmen, engineers and other physical scientists need a change of culture. They need to understand the benefits of applied probability and statistics; they need to understand how the methods are applied to their own work; they need to be fully converted to a frame of mind which will make them automatically question sources of variability in everything that they do and, without outside prompting, adopt the statistical approach.

That indeed would be a massive change of culture. I have argued that it would rapidly pay dividends because it would fuel technological progress in our

manufacturing industries and thereby increase the competitiveness of products and services.

But do we have *any* hope whatever of even being heard, let alone evoking other than a yah-boo response, if we stand up and shout to the industrial world at large and to engineers and scientists in particular: ‘You must change your culture. You must understand the great benefits that statistical methods will bring to your businesses’?

We do not.

We have no hope unless we change our culture from that of academic superiority to one of services to those industries that need our help in creating wealth.

So there is my answer to the question: ‘Why bother?’. You may have others. My answer is that our national quality of life will be improved and secured if we can communicate the philosophy, as well as the methods, of statistics to engineers and others in the manufacturing and the service industries. And we can achieve that only if we change our culture.

So what is our present culture?

Have you written and published a paper? Why did you do it? Where was it published? Who has read it? Has it been cited and, if so, in what journals?

My impression is that most papers written by statisticians for publication in statistical journals are intended to be read by other statisticians and when they are cited they are cited by other statisticians in papers published in statistical journals.

Our culture is one of incestuous arrogance. The formula for a paper is: ‘Here is a problem, this is the way I tackled it, here is my solution, aren’t I clever? Furthermore, I have dressed it up with an obscure vocabulary and written it in a prolix and pseudo-objective style, so aren’t I immensely clever?’

Have you spoken at a meeting recently? Who were the audience: other statisticians? Why have you not been to a local group meeting of the Institute of Metals, the Institution of Production Engineers, the Society of Chemical Industry, the Plastics and Rubber Institute, the Institution of Electrical Engineers?

Perhaps they did not ask. Of course they did not ask. Scientists and engineers have little time, if any, for statistics because they judge much of it to be irrelevant to what they are doing. Ask them if they think that our communications with them are poor. They will not even have thought about it because they are ignorant of their needs and of the benefits that statistics can impart. If pressed, they would say they do not need statistics. They think deterministically. If you press the point they will still demur because they perceive statistics to be 'difficult' and 'anything' difficult can be of no use in tackling the simple problems of product design and production.

I saw a report about some research into superconductivity and it was obvious to me that with so many contributing variables there would be great economies in time and effort if formally designed experiments were used. I offered my services but was told that this was research of a physical-chemical nature in which there was no need for statistical method. The economies of experimental design may be obvious to a statistician but they are not obvious to a physicist.

Similarly, the Glass Research Laboratories in Sheffield wrote to me that there was no place for statistically based experimental design in their work.

Make them want us

So we have a problem. But we must start with ourselves. We must break out of our own incestuous enclosure. As statisticians we must look at the serious problems that are facing industry and use our abilities to solve those problems. We should then write articles for the business and technical press, not for the statistical journals, in which we tell stories of where statistics did make a difference. We should realise that people in industry are interested in financial effects. We must concentrate our efforts on interesting real examples in which statistical methods have had such effects and we must develop the art of demonstrating this. Then we must persist in demonstrating our skills until we are invited to help.

The way in which we tell these stories is vital. If we continue to pretend, as many statisticians do, that statistics is one of the mathematical sciences, editors will return the articles. If instead we write to demonstrate that our subject can lead to better scientific investigation of practical problems of interest to the engineer and whose solution will have commercial advantage, then the editors

will be more receptive, especially if we use a style and language that their readers like. Snee (1990) develops this further. He says that we should 'hold special conferences and workshops at the interface between statistics and engineering, integrate statistics into our engineering and science curricula, change the nature of the papers we publish in our journals, award papers other than those that focus on narrow academic pursuits'.

Publish to them

I recommend that as a Society we harness our effort to produce articles for submission to the technical press that serves the chemical, process and production engineer, and business and commerce. We should employ a technical editor whose full-time job would be to commission those articles and to channel them to appropriate magazines.

But we will not do it. And I shall tell you why we will not do it. We will not do it because our existing culture constrains us. We are too wrapped up in our present procedures of writing for each other to demonstrate our mutual cleverness and to win academic promotion, and we insist on maintaining refereed standards of scholarship, or publishing papers that contain something new.

But is that really the reason? Maybe this academic floor show is only a front. Perhaps the real problem is that most statisticians do not see what is needed and lack the ability to translate what they do into what would be seen as beneficial by others. Is it because we cannot do it, or we do not know how? Is it because we are lazy, that we would rather sit in our university or polytechnic offices instead of going out into the world and making an effort to help engineers to solve their problems? Is it because we cannot find the time? Perhaps we have not yet thought about it. I am asking us to think about it now. Do we really care? We will when the manufacturing industries decline so far that they do not produce the revenue to feed the universities.

Yes, most statisticians are inadequate. It may be true that engineers know little of statistical methods, but most statisticians know even less of engineering. We are unable to discuss engineering or scientific problems in the language of the engineer or scientist. It is a rare statistician who can become deeply involved in the scientific or engineering context of a problem. We remain aloof. 'Bring me the data and I'll analyse them'; then 'Oh dear, what a pity you didn't come to

me before you did the experiment so that I could have designed it better for you’.

But I have also heard a statistician say: ‘You can’t expect me to understand that because I am not a chemist’, even though the level of chemistry needed to understand a problem may be no more than is expected at school.

Integrated teaching

Why are we so specialised that we cannot remember our school science? Why have we become so compartmentalised? Is it because modular teaching is so convenient? We must beware of this compartmentalization, of the sterility of specialization. From my experience in industry, I am convinced that successful statisticians must understand the engineering, the chemistry, the manufacturing processes and the instrumentation. Furthermore, we must be able to communicate in their own language with chemists, materials scientists, and every sort of engineer, and we must be able to persuade these people to expect help from us in providing scientific method to their work. Somehow, we must be able to persuade them that they need us, our philosophy and our methods.

Richard Feynman, in his *Lectures on Physics*, said about compartments: ‘If our small minds, for some convenience, divide this glass of wine into parts - physics, biology, geology, astronomy, psychology, and so on - remember that nature does not know it! So let us put it all back together, not forgetting ultimately what it is for. Let it give us one more final pleasure: drink it and forget it all!’

The short-term solution is for us, the qualified statisticians, to make more effort to get out there and to involve ourselves in the chemistry, the metallurgy and the engineering. I know that there are a few who are fully involved, but only a few. The rest of us are needed. But we must prove that need, not wait to be invited.

Longer-term solutions, I suggest, are the following.

- (a) Recruit more graduates in engineering and the physical sciences into training courses in applied statistics and into industrial statistics departments where statistical education will be provided at the level that is needed. This means the teaching about statistical tools and how to use them in the place of work.

(b) Provide more undergraduate courses of a generalist nature to produce polymath consultants. Students of statistics should not be allowed to forget the chemistry, physics, biology and practical engineering that they learned at school. Their practical laboratory work should be to do experiments in these subjects in which they would learn to apply the methods that they are acquiring in the undergraduate course: the methods of good measurement and recording, of experimental design and analysis, of interpretation and reporting, of hypothesis formulation, of mathematical modelling, of prediction and testing. They would learn to write essays and to make presentations that must be comprehensible to the chemists, engineers and others.

(c) Put more pressure on the managers of education of engineers to ensure that their students understand uncertainty and data analysis and how experimental design can be used to reduce variability, to obtain the most amount of useful information at the lowest cost and to find the conditions for the best achievable performance of a product or a process.

That last question raises another question: 'who should teach statistics? The answer most of you might give is 'A statistician'. Now why is that? Do you believe that only you can explain the subject with full rigour? Do you have no faith in your engineering colleagues?

You know what happens in some colleges. It is agreed that the engineers must learn some statistics. One hour is set aside every Friday afternoon. This is a considerable amount. During a course of three years a student may receive 100 hours of statistics. The students must learn something. But do they? I have heard students say: 'I don't really understand it, but it doesn't matter because it isn't relevant. I'll mug up enough to answer a few questions and then forget it.'

I believe that the only way we can impart the statistical philosophy to most engineering students is by teaching statistics as a part of engineering, or of chemistry, or other applied science, not as a separate module. The teachers should be either engineers or statisticians who are sufficiently familiar with the engineering aspects of the course. And the environment should be friendly. For example, research packages should not be used in undergraduate courses and, wherever possible, a graphical method should be used.

It worked in medicine

There is one area of practical science where statistics has been applied with consistent success and continues to be so applied. This is medicine. What are the reasons for this success?

Human beings vary considerably. There are differences between all of us in our anatomy and physiology, in our behaviour, environment and expectations. There is variation in pathogenesis and in response to treatments. The uncertainty about much of medicine has long been recognised by the teachers of medicine, by researchers in medicine and by publishers of medicine.

Teachers of medicine, researchers of medicine and epidemiology and editors of medical journals are well aware that symptoms, signs and tests are subject to variations of patients, physiological and pathological conditions, observer skills and experiences, and instrumental accuracy and precision. As technology has progressed, doctors and nurses have met increasingly more quantitative data, rather than descriptive information, when dealing with patients, tests and treatments. This has led to the requirement that all medical and most nursing students must learn at least the elements of statistical methods as a foundation for understanding chance and probability associated with diagnosis, therapy and prognosis and to develop in them a critical judgment of everything that they are taught in all other aspects of academic and clinical medicine.

Most medical research depends on statistical methods, notably in the evaluation of diagnostic tests, clinical trials of new treatments and in epidemiology. At some time in their careers almost all doctors and many nurses participate in clinical trials and other investigations such as social surveys. Many of them, perhaps not all, realise that their conscientious participation and exact adherence to the protocols are strengthened by an understanding of how studies are designed and managed and how the resulting data are analysed and interpreted.

All doctors, whether general practitioners or specialists, must be able to read the medical literature critically with objective discernment and benefit to their work. This is possible only with a good understanding of the statistical methods which pervade the literature, especially since several reports have shown that much of the statistical material in the medical literature is improperly conceived, executed or interpreted.

The law exerts its force through the drug regulatory bodies which require the application of approved statistical methods to the design and analysis of clinical trials. The lessons to be learned from the medical world are

- (a) statisticians are involved in the teaching in undergraduate and post-graduate medical and nursing courses,
- (b) medical faculties insist on some teaching of statistics to all students,
- (c) statisticians are often equal members of research teams and joint authors of published papers,
- (d) post-graduate courses in medical statistics are available to doctors, nurses and other medical scientists,
- (e) the editors of professional medical journals increasingly insist on good explanation of statistical methods in reports of medical research,
- (f) many medical journals now have statisticians on their refereeing panels and
- (g) there are occasional joint meetings of statisticians and medics on special topics.

These all point to initiatives that we might take in the engineering industries. Success will, however, be bought only with greater effort and persistence simply because the medical world recognises the variation that is intrinsic to their subject whereas many engineers still behave as if their subject is deterministic.

Furthermore, the term 'medical statistician' is recognised by society and employers as a special breed. This might be emulated through post-graduate courses and qualifications in 'industrial statistics', open to engineers and other scientists as well as to statisticians.

Cookery-books

I shall make one more provocative statement before I finish. We often hear people aghast at the thought of cookery-book statistics. Some British Standards have been so castigated, as are elementary text-books and computer programs. Commissioning editors for major publishers ask us to write books of practical

guidance. 'There's a gap in the market,' they tell us, 'but not, of course, for cookery-books'.

Well, why is there not? The answer seems to be that nobody should be doing statistics unless they have statisticians at their elbows to guide them. But out there in the real world there are thousands of people who need to do statistics, who know that they need to do statistics, and who actually try to do statistics but have no such guidance available. They may even believe that they can do it without such guidance. They turn to elementary texts and computer programs (much software, known as shareware, is distributed at little more than the cost of distribution) and struggle on, picking out the bits that they think they understand and ignoring the rest. They may attribute their lack of understanding to poor explanation.

'They must be doing it wrong', you exclaim. 'So they shouldn't be doing it at all.'

You hold up the current fashion for the Taguchi method with all its faults as an example.

Despite that exclamation, they will continue to do it, and possibly incorrectly.

Perhaps a better response from us would be to help them to do it wrongly in the best possible way. Let us produce more cookery-books and more easy-to-use programs, and let us encourage their use by everybody who can benefit and carry the message that if they want to do better they should study more and seek our guidance.

Our audience, our customers, are out there. They need us, even if they do not realise it. We must change our culture, our philosophy, our public relations and our use of language to reach them.

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