

J.N.K. Rao – A Tribute

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1. Jon Rao, a living legend

We are deeply honoured and privileged to write about Professor J.N.K. Rao as a researcher and a human being. This is, indeed, an extremely difficult task. Professor Rao's research contributions are so enormous and have generated such a profound worldwide impact on statistical sciences and its innovative and diversified applications in other sciences that it is impossible to sketch even a brief account of it in the limited space of this write-up. Moreover, like everyone in our society, we are so deeply indebted to him for his humanitarian qualities that it is really hard for us to find words that aptly and sufficiently convey our feelings and emotions about him.

Dr. Jonnagadda Nalini Kanth Rao, a distinguished research professor of the highest level of international eminence, is a living legend with brilliance in the areas of survey sampling and statistical inference. It is by no means an exaggeration to say that Professor Rao is an encyclopaedia on small area estimation in particular and survey sampling in general. He is not only a giant of statistical sciences with a towering stature, but also an embodiment of humanitarian traits such as gentleness, kindness and humbleness.

Professor J.N.K. Rao, popularly known as Jon Rao, was born in Eluru, Andhra State, India on May 16, 1937. Jon received his first two degrees in India, namely, bachelor's degree in mathematics from the Andhra University in 1954 and master's degree in statistics from the University of Bombay in 1956. During 1956-58, he worked as a research scholar at the Forest Research Institute, Dehradun, India, before going to the Iowa State University, for pursuing his Ph.D. degree in Statistics, which he received in 1961.

Jon started his teaching career as an assistant professor at the Iowa State University between 1961 and 1963. In 1963-64, he worked as a sampling expert at the National Council of Applied Economic Research, India. This was followed by an associate professorship at the Graduate Research Center of the Southwest, Dallas, in 1964-65. During 1965-67, he was an associate professor at the Department of Statistics, Texas A&M University, where he became a

professor in 1967 and took a leave of absence during 1968-69 to work as a visiting professor at the Indian Statistical Institute, Calcutta. For family reasons, he moved to Canada in 1969, where he continued with his research and teaching as a professor at the University of Manitoba during 1969-1973. Later he moved to the Carleton University at Ottawa. There he was a professor at the School of Mathematics and Statistics, and became a distinguished research professor after his retirement in 2000. Jon has been a member of the advisory committee on methods of statistics at Statistics Canada and consultant to the same organization on the most important issues related to sampling methodologies and their applications.

The depth and breadth of Jon's research and its impact on survey methodology and survey statistician form a foundational basis for researchers in their pursuit of the study of sampling theory and its applications in diverse fields. Since his earliest studies on time series models, and then moving on to the analysis of rotating samples, to linear and logistic models, to ratio estimation and the analysis of samples with probability proportional to size, his work has always led to major advances both in methodological and applied contexts. Jon's research interests cover such astoundingly wide-ranging areas as small area estimation, missing data and imputation, re-sampling methods for variance estimation, analysis of survey data, categorical data analysis, multiple frame surveys, integrated surveys with many characteristics under study, PPS sampling without replacement (popular as RHC method) and alternative estimators in PPS sampling when size measure is unrelated to a variable of interest (which may happen in surveys with multiple variables). His trendsetting research expands to cover inferential issues; most importantly the matrix formulation of general ANOVA mixed models and derivation of maximum likelihood (ML) estimators of both fixed effects and variance components and development of EM algorithm that led to the development of restricted maximum likelihood (REML) estimation. His revolutionary research focuses on variance estimation when only one unit is selected from each stratum using a linear regression model with unequal error variances and expressing the variance of the stratified mean as a linear combination of the error variances, followed by the development of a new method of estimating the error variances that in turn lead to a new variance estimator for the stratified mean, which became the foundation of the development of C.R. Rao's MINQUE method of estimating variance components.

His more recent studies on small area estimation represent an indispensable reference point for all scholars who want to apply this methodology to the analysis of survey data. It has been applied widely by leading international organizations, providing support for the definition of appropriate economic policy guidelines. His two Wiley text books (Rao, 2003) and Rao and Molina, 2015) on Small Area Estimation serve as a masterpiece for survey statisticians and researchers in this all important area. The scientific importance of Jon's work lies in both his methodological contributions and the resulting applications that they have generated in assorted fields. His research has had a major impact, for example, in the definition of policies to reduce poverty and to identify specific actions with regard to educational or health issues, both in advanced economies and in the developing world.

In addition to his phenomenal research impact, Jon has had a major influence on official statistics agencies through his participation on advisory boards and panels, and his role as advisor and consultant. He has also inspired several generations of survey statisticians through his teaching, mentoring and research collaboration. Moreover, so far Jon has supervised over 30

students for their doctoral degrees and over 15 students for their master's degrees. Three of his former Ph.D. students are Fellows of the American Statistical Association. Several of his former students achieved top positions at Statistics Canada and elsewhere.

It is no wonder that Jon's brilliant, path-breaking contributions have been globally acclaimed through prestigious awards and recognitions. To cite only a few examples, he has been listed among the ISI highly cited researchers in mathematical sciences. He has also been honoured with the Fellowship of the American Statistical Association in 1964, the Fellowship of the American Association for Advancement of Science in 1965, the Fellowship of the Institute of Mathematical Statistics in 1972, and the Fellowship of the Royal Society of Canada in 1991. Jon's 1981 paper in JASA (with A.J. Scott) on analysis of categorical survey data was listed among the 19 landmark papers in survey statistics during the period 1934-1990. He was the president of the Indian Society of Agricultural Statistics golden jubilee conference, Delhi, 1996, the 8th annual Morris Hansen Lecturer, 1998, and the Program Chair, International Statistical Institute Meetings, Finland, 1999. He received the Appreciation Award from Statistics Canada, 2001 "in recognition of outstanding and distinguished contributions to the effectiveness of Statistics Canada". The Statistical Society of Canada Honorary Membership Award 2004 was another feather in the cap of Jon "for landmark contributions to a wide range of topics in survey sampling theory and methods". Jon was invited twice to deliver the annual distinguished lecture of the Joint Program in Survey Methodology, University of Maryland. He chaired the Mahalanobis Award Committee of the International Statistical Institute in 2017.

Jon received the Gold Medal from the Statistical Society of Canada in 1993, the Wakesberg Award for Survey Methodology in 2005, and honorary doctorates from the University of Waterloo (2008) and the Catholic University of Sacred Heart, Italy (2013). During the Small Area Estimation 2017, 61st ISI World Statistics Congress Satellite Meeting held at Paris, Jon was honoured with the Gold Medal Award for outstanding contributions to small area estimation.

Jon rendered extremely influential editorial service as associate or advisory editor of major international journals, such as Journal of the American Statistical Association, The Annals of Statistics, Statistica Sinica, The Canadian Journal of Statistics, Survey Methodology, Journal of Statistical Planning and Inference, and so on. He has also been on the editorial board of the Wiley Series on Survey Methodology. He has been an elected council member of the International Association of Survey Statisticians and the International Statistical Institute. Other professional bodies that greatly benefited by having Jon as member include the US Bureau of Census Advisory Committee on Methodology, Statistics Canada Advisory Committee on Methodology since its inception in 1985, and Panel on Estimates of Poverty for Small Geographic Areas, National Academy of Sciences, USA, to name only a few. He has also been a consultant to Statistics Canada on Survey Methodology since 1974.

Jon's great simplicity, his ability to listen and give advice, his seriousness, his willingness to help others are some of the characteristics that make him a perfect human being and tempt us to imbibe in ourselves these qualities, especially at a time when even in the world of research, apparent progress tends to overshadow real and substantial scientific advances. He is not only a world-famous scholar but also a great human being, known to everyone for his benevolence. An adherent of traditional Indian values, Jon has always been a caring husband and a caring father in

his family. His son J. Sunil Rao, a well-known biostatistician presently working as the director of Biostatistics Division and interim chair of the School of Public Health Sciences at the University of Miami, was elected a Fellow of the American Statistical Association (ASA) in 2011, and father-son ASA Fellow pairs are, indeed, extremely rare.

We are really honoured to have attempted to prepare this write-up on Jon, who is an academician of the highest order of eminence and, at the same time, a great and true friend, philosopher and guide. We wish him a very long and healthy life so that the scientific fraternity keeps benefiting from his wisdom and brilliance and the statistical sciences keep growing further.

2. Research publications of Jon Rao

2.1 Books

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3. Rao, J.N.K. and Molina, I. (2015). *Small Area Estimation*, 2nd Edition. Wiley, Hoboken, NJ.
4. Tintner, G., Rao, J.N.K. and Strecker, H. (1978). *New Results in the Variate Difference Method*. Vandenhoeck and Ruprecht, Göttingen.

2.2 Edited volumes

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2. Krewski, D., Platek, R. and Rao, J.N.K. (Eds) (2016). *Current Topics in Survey Sampling. Proceedings of the International Symposium on Survey Sampling*, Ottawa, May 7- 9, 1980, Revised Edition, Elsevier.
3. Platek, R., Rao, J.N.K., Sarndal, C.E. and Singh, M.P. (Eds.) (1987). *Small Area Statistics*. Wiley, New York.

2.3 Research articles in journals

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