SONKINA, T. P. and TYOSKIN, O. I. (1984). Confidence limits for the reliability of systems of elements connected in series. *Engrg. Cybernetics* **22** (4) 105–113.
SUDAKOV, R. S. (1974). A problem of interval estimation of the reliability index of a series system. *Engrg. Cybernetics* **12** (3) 55–63.
SUDAKOV, R. S. (1980). On interval estimation. *Engrg. Cybernetics* **18** (1) 54–64.
TATASHEV, A. G. and USHAKOV, I. A. (1981). A problem of reswitching standby elements after a schedule. *Engrg. Cybernetics* **19** (5) 57–65.
TYOSKIN, O. I. (1979). Precise confidence limits for the reliability of redundant systems in the case of failure-free tests of their elements. *Engrg. Cybernetics* **17** (4) 116–123.
USHAKOV, I. A. (1960). An estimate of effectiveness of complex systems (in Russian). In *Reliability of Radioelectronic Equipment* (O. Poslavskii, ed.). Soviet Radio Press, Moscow.
USHAKOV, I. A. (1966). An estimate of reliability of systems with renewal for a stationary process (in Russian). *Radiotekhnika* **5** 43–50.
USHAKOV, I. A. (1969). *Methods for Solving Simplest Problems of Optimal Inventory under Restrictions* (in Russian). Soviet Radio Press, Moscow.
USHAKOV, I. A. (1980). Estimation of reliability from the results of truncated observations. *Engrg. Cybernetics* **18** (5) 76–78.
USHAKOV, I. A. (1981). Method of approximate solution of problems of dynamic standby problems. *Engrg. Cybernetics* **19** (2) 94–101.
USHAKOV, I. A. and LITVAK, YE. I. (1977). Upper and lower bounds on parameters of two-terminal networks. *Engrg. Cybernetics* **15** (1) 59–67.
USHAKOV, I. A. and YASENOVETS, A. V. (1977). Statistical methods of solving problems of optimal standby. *Engrg. Cybernetics* **15** (6) 8–16.
USHAKOV, I. A. and YASENOVETS, A. V. (1978). Two limit problems of optimal standby (in Russian). *Nadezhn. Kach.* **3** 77–82.
ZHEGALOV, S. I. (1986). A method of calculating the probability of failure-free operation of a system with different elements. *Soviet J. Computer Systems Sci.* **24** (1) 147–149.

Part II: Non-Soviet Authors

AALEN, O. O. (1978). Nonparametric inference for a family of counting processes. *Ann. Statist.* **6** 701–726.
BARLOW, R. E. and PROSCHAN, F. (1975). *Statistical Theory of Reliability and Life Testing*. Holt, Rinehart and Winston, New York. (Reprint with corrections, 1981, by To Begin With Publishers, Maryland.)
BIRNBAUM, Z. W., ESARY, J. D. and SAUNDERS, S. C. (1961). Multicomponent systems and structures and their reliability. *Technometrics* **3** 55–77.
BRESLOW, N. and CROWLEY, J. (1974). A large sample study of the life table and product limit estimates under censorship. *Ann. Statist.* **2** 437–453.
EFRON, B. (1967). The two sample problem with censored data. *Proc. Fifth Berkeley Symp. Math. Statist. Probab.* **4** 831–853. Univ. California Press.
FISHER, R. A. and TIPPETT, L. H. C. (1928). Limiting forms of the frequency distribution of the largest or smallest member of a sample. *Proc. Cambridge Philos. Soc.* **24** 180–190.
FÖLDES, A. and REJTÖ, L. (1981). Strong uniform consistency for nonparametric survival curve estimators from randomly censored data. *Ann. Statist.* **9** 122–129.
FRECHET, M. (1927). Sur la loi de probabilité de l'écart maximum. *Ann. Soc. Polon. Math. Cravovie* **6** 93.
GILL, R. D. (1980). *Censoring and Stochastic Integrals*. Mathematical Centre Tracts **124**. Mathematical Centre, Amsterdam.
GILL, R. D. (1983). Large sample behavior of the product-limit estimator on the whole line. *Ann. Statist.* **11** 49–58.
KAPLAN, E. L. and MEIER, P. (1958). Nonparametric estimation from incomplete observations. *J. Amer. Statist. Assoc.* **53** 457–481.
MANN, N. R. and SINGPURWALLA, N. D. (1985). Extreme value distributions. In *Encyclopedia of Statistical Sciences* (N. L. Johnson and S. Kotz, eds.) **2** 606–613. Wiley, New York.
OSAKI, S. and ASAKURA, T. (1970). A two-unit standby redundant system with repair and preventive maintenance. *J. Appl. Probab.* **7** 641–648.

Comment

Richard E. Barlow and Zohel S. Khalil

Rukhin and Hsieh should be thanked for preparing this survey because it must have involved considerable time and effort to dig out and interpret such a large volume of research work. However, this survey article could be by no means a complete review of Soviet work in reliability theory. An excellent short survey of Soviet work in asymptotic methods in reliability theory appeared in *Advances in Applied Probability* by Gertsbakh (1984). Rukhin and Hsieh have expanded their survey to include additional topics in reliability theory. It would have been helpful had they also mentioned the related excellent work of Brown (1987), Brown and Ge (1984) and Keilson (1979, 1986) in this country, because their work is very close and overlaps in many respects the work of the Gnedenko school of reliability at Moscow University.

One of us (Khalil) was a Ph.D. thesis student of Gnedenko at the beginning of the era of the Moscow school of reliability theory. He studied at Moscow University from 1963–1969 and has kept in contact with Gnedenko. Hence, we will first give a short

Richard E. Barlow is Professor of Operations Research and Statistics, University of California, Berkeley, California 94720. Zohel S. Khalil is Professor of Mathematics, Concordia University, Montreal, Quebec H4B 1R6, Canada.

historic review of people and places that prompted the prolific outpouring of contributions to reliability theory by the Moscow school and then contrast the Soviet and U. S. reliability research efforts.

In 1964–1965, Gnedenko established the first research seminar on reliability in the Soviet Union. This seminar took place on a regular weekly basis in the statistics laboratory of Moscow State University of Lomonosov. It encouraged many engineers, probabilists and statisticians to start working on different aspects of reliability theory. Many of these were people working on queuing theory and operations research. Gnedenko himself and many of his colleagues and students were constant speakers in this seminar. Among these were Belyayev, Chepurin, Kovolyuk Kovalenko, Kozlov, Kashtanov, Kalashnikov, Solovyev, Schnepps, Tomko, Ushakov and many others. This seminar produced many fundamental papers over a period of more than 10 years. These papers were published in local journals as well as in the proceedings of annual summar schools of probability and statistics. These schools were held in several cities of the Soviet Union such as Vilnius, Tashkent, Kiev and cities of the East-block countries, Sophia, Varna, Warsaw and others.

The first book by Barlow and Proschan, *Mathematical Theory of Reliability* (1965), perhaps the first mathematically rigorous book in reliability theory, was translated and published in the Soviet Union in 1969. However, Gnedenko, Belyayev and Solovyev also published their book *Mathematical Methods in the Theory of Reliability* in 1965 and the English translation appeared in 1969. This book was perhaps more of a general statistics text than a book on reliability theory per se. The 1965 Barlow and Proschan book had a great impact on Soviet contributions in reliability theory. (The second book by Barlow and Proschan (1975) mentioned by Rukhin and Hsieh was not published in Russian translation until 1984.)

The Gnedenko school of reliability has produced many scholars working on different aspects of the theory. Within the Soviet Union many of these are established scholars in many research institutes of Moscow, in the universities of the Ukraine, the universities of the Baltic states, in Central Asia and Soviet Georgia. Outside the Soviet Union many of these scholars work in the research institutes and universities of Bulgaria, East Germany, Egypt, Algeria and many other places. The authors in these countries have numerous results in reliability theory published locally and internationally. Among these are Mahmoud, Senoussi-Bereksi, Fahim, Barakat and many others.

Gnedenko's (1964a, 1964b) papers on standby redundancy have led to many contributions by his students over the late sixties and all of the seventies. Specifically, papers were published on various standby systems where Laplace-Stieltjes transforms of systems lifetime distributions were derived and important limit theorems were established. Also, relatively recent papers on random sums of independent random variables and their limiting behavior known as "transfer type theorems" have wide applicability in reliability theory because a large number of reliability problems are described by probability models involving summation of a random number of random variables.

The references to Soviet and non-Soviet authors is very limited both in Parts I and II. Many East and West European authors have contributed as well as Japanese, Egyptian and Indian authors. In the early 1960s, the series "Selected Translations in Probability and Mathematical Statistics" appeared. This series, published jointly by the Institute of Mathematical Statistics and the American Mathematical Society, contained several translated papers by Soviet researchers and guest researchers to the Soviet Union. Many of these papers are original contributions to reliability theory.

As Rukhin and Hsieh have noted, Soviet research in statistical inference is limited at best. Of the Soviet school, Belyayev seems to be one of those most interested in the Bayesian approach in statistical inference. However, on the whole, the Gnedenko school has not been enthusiastic about the Bayesian approach.

It is our impression that reliability theory research in the Soviet Union is more organized than is the case in the U. S. Also, the gap between university investigators and reliability engineers may be wider in the U. S. than in the Soviet Union. Information flow in reliability research, vis-à-vis U. S. and Soviet work, seems to be largely one way—toward the Soviet Union. This may be in part because of secrecy in the Soviet Union as well as the language, which may be more of a barrier for U. S. researchers than for the Soviets. On the other hand, there are many instances where similar research discoveries seem to have taken place almost at the same time without either party being aware of the other. The reference to the paper by Zhegalov (1986) (actually published in the Soviet Union in 1985) may be a case in point. His result that k out of n system reliability when components have different reliabilities may be computed in $O(n^2)$ running time was published in the *IEEE Transactions on Reliability* in 1984 (pages 322–323). (However, in this case, the result was no doubt long known to complexity theorists in this country.) In terms of the review by Rukhin and Hsieh, it would seem that they may be behind in computational complexity research relative to network reliability (cf. the August 1986 network reliability survey issue of the *IEEE Transactions on Reliability*).

ADDITIONAL REFERENCES

BARLOW, R. E. and PROSCHAN, F. (1965). *Mathematical Theory of Reliability*. Wiley, New York.

BROWN, M. (1987). Inequalities for distributions with increasing failure rate. In *Contributions to the Theory and Application of Statistics* (A. E. Gelfand, ed.). Academic, Orlando, Fla.

BROWN, M. and GE, G. (1984). Exponential approximations for two classes of aging distributions. *Ann. Probab.* **12** 869–875.

KEILSON, J. (1979). *Markov Chain Models—Rarity and Exponentiality*. Springer, Berlin.

KEILSON, J. (1986). The Markov approach to calculating system reliability: Computational problems. In *Theory of Reliability* (A. Serra and R. E. Barlow, eds.). North-Holland, Amsterdam.

Comment

Nozer D. Singpurwalla

This paper provides valuable service to those interested in reliability theory and its applications. The material in this paper, together with a cursory reading of some of its references leads me to conclude that:

1. Any serious student of reliability (and also biometry) cannot afford to overlook the *Soviet Journal of Computer and System Sciences* or its predecessor *Engineering Cybernetics*.

2. Soviet researchers appear to be more knowledgable about the developments in reliability in the West than their Western counterparts, particularly those in the United States, and that this is true even when it pertains to the work of such distinguished scholars as Gnedenko, Belyayev, Solovyev, Ushakov, Kordonskiy and Kartashov. The above is particularly disturbing—I too am guilty of it—because English language translations of *Engineering Cybernetics* and the *Soviet Journal of Computer and System Sciences* have been available for quite some time.

3. The unclassified Soviet research in reliability attempts to address technically difficult problems with a tendency to emphasize mathematical detail, many times at the cost of relevance and sometimes at the cost of elegance.

4. Unlike what is currently happening in Great Britain, Western Europe and the United States, the conspicuous and noteworthy absence of a Bayesian perspective on reliability has left the Soviet researchers working in a frame of reference that is reminiscent of an era prevalent in the midseventies and before. Thus for example, it should be the theory of extreme values for *exchangeable* random variables that should be used for system reliability modeling rather than Gnedenko's development for independent and identically distributed (iid) random variables. With Belyayev's venture into an investigation of the behavior of posterior densities of parameters in reliability models, a welcome thaw in the above state of affairs appears to be looming on the horizon. However, given Belyayev's orientation, this work emphasizes the mathematics of weak convergence of stochastic processes and in so doing loses some of its pragmatic appeal.

5. That there seems to be a dearth of Soviet literature addressing the important topics of *component dependencies* in multicomponent systems, the reliability of *multistate systems* and *measures of importance* of coherent systems. The latter appear to be widely used in the nuclear reactor industry (cf. Barlow, Fussell and Singpurwalla, 1975), and the former two are a challenge to all researchers in reliability. Given the Soviet engineer's affinity for Zadeh's (1965, 1973) *possibility theory* and *fuzzy logic*, it is surprising that the above concepts have not been explored by them for application in multistate reliability theory.

Rukhin and Hsieh's claim that the Soviet literature on reliability emphasizes probability modeling over inference has truth to it; however, this is also the case in the West, wherein the number of papers in the former overwhelms those in the latter. To appreciate this point, one has simply to scan journals such as the *IEEE Transactions in Reliability*, the *Journal of Applied Probability*, *Operations Research*, *Stochastic Processes and Their Applications* and the *Naval Research Logistics Quarterly*. The fortunate situation in the West is that journals that are predominantly statistical in orientation, such as the *Journal of the American Statistical Association*, *The Annals of Statistics*, the *Journal of the Royal Statistical Society*, *Biometrika* and *The American Statistician*, recognizing the importance of the role of statistical inference in reliability problems, have been receptive and supportive of papers in reliability. It is my hope that *Statistical Science* will also continue to uphold this fine tradition. A possible reason for the above sense

Nozer D. Singpurwalla is Professor of Operations Research and of Statistics, The George Washington University, Washington, D.C. 20052.