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## MULTIPLE-DECISION SELECTION AND RANKING PROCEDURES

Robert E. Bechhofer

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Cornell University

Prepared for:

Army Research Office-Durham

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# MULTIPLE-DECISION SELECTION AND RANKING PROCEDURES

FINAL REPORT

by

Robert E. Bechhofer

August 27, 1973

U.S. ARMY RESEARCH OFFICE-DURHAM

Contract DA-31-124-ARO-D-474

Department of Operations Research College of Engineering Cornell University Ithaca, New York 14850

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#### FINAL REPORT ON CONTRACT DA-31-124-ARO-D-474

This is the final report or Contrac+ DA-31-124-ARO-D-474 entitled "Multiple-Decision Selection and Ranking Procedures." The initial contract covered a three-year period starting September 15, 1966; the contract was renewed for a second three-year period starting September 15, 1969; a no-cost extension was given until January 31, 1973 and a second such extension until June 30, 1973.

The following pages list the technical reports and published papers (and those accepted for or submitted for publication) which were written with the full or partial support of the contract; the contents of these reports and papers have already been described in the semi-annual progress reports. Also included is a list of the scientific personnel supported by the contract, and the advanced degrees earned by them while supported by the contract.

Most of the papers deal with research on the subject of "Statistical Multiple Decision Ranking Procedures," a statistical methodology pioneered by the Principal Investigator and several colleagues; some of the papers deal with related statistical techniques, and a few with new probabilistic developments.

Some of the many results obtained on this contract were reported on at the meetings of professional societies. Past results and future plans were outlined at the Chief Investigators Conference and Review of the Military Theme "OPERAFIONS RESEARCH" held at Aberdeen Proving Ground, July 18-19, 1972. The Principal Investigator has been a regular participant in the annual Design of Experiments Conferences sponsored by ARO-D.

The mission of this contract is being continued under a new contract, ARMY DANCG4-73-C-0008. The Principal Investigator is deeply indebted to the Army Research Office-Durham for its strong support of this activity.

### Summary of Research Completed on the Contract

2

Technical reports, the research for which was supported in whole or in part by ARO Contract DA-31-124-ARO-D-474.

- Bechhofer, Robert E.: <u>Single-stage procedures for ranking multiply-classified</u> <u>variances of normal populations</u>, Technical report No. 41 dated February 1968.
- Bechhofer, Robert E.: <u>Multiple comparisons with a control for multiply-</u> <u>classified variances of normal populations</u>, Technical report No. 42 dated February 1968.
- Higgins, James E.: <u>Bernoulli sampling plans which approximately minimize the</u> <u>maximum expected sample size subject to certain probability requirements</u>, Technical report No. 65 dated February 1969.

Ramberg, John S.: <u>A multiple-decision approach to the selection of the best set</u> of predictor variates, Technical report No. 79 dated July 1969.

- Bawa, Vijay S.: <u>Asymptotically optimal ranking and selection procedures</u>, Technical report No. 102 dated March 1970.
- Nocturne, D.J.M.: Asymptotic efficiency of the maximum likelihood estimators for the parameters of certain stochastic processes, Technical report No. 105 dated March 1970.
- Bechhofer, Robert E. and Nocturne, D.J.M.: <u>Optimal allocation of observations</u> when comparing several treatments with a control, II: 2-sided comparisons, Technical report No. 110 dated May 1970.
- Bawa, Vijay S.: <u>Asymptotic afficiency of one multifactor experiment relative to</u> <u>several one-factor experiments for selecting the normal population with the</u> largest mean, Tachnical report No. 121 dated August 1970.
- Bechhofer, Robert E. and Turnbull, Bruce W.: <u>Optimal allocation of observations</u> when comparing several treatments with a control, III: globally best <u>one-sided intervals for unequal variances</u>, Technical report No. 129 dated May 1971.
- Turnbull, Bruce W.: Bounds and otpimal strategies for stochastic systems, Technical report No. 134 dated July 1971.
- Fushimi, Massnori: An improved version of a Sobel-Weiss play-the-winner procedure for selecting the better of two binomial populations, Technical report No. 170 dated January 1973.

Frischtak, Ricardo: <u>Statistical multiple-decision procedures for some multivari-</u> <u>ate selection problems</u>, Technical report No. 187 dated July 1973.

Fushimi, Masanori: <u>A non-symmetric sequential procedure for selecting the better</u> of two binomial populations, Technical report No. 189 dated August 1973. Papers (published), the research for which was supported in whole or in part by ARO contract DA-31-124-ARO-D-474.

- Bawa, V.S.: "Asymptotic efficiency of one R-factor experiment relative to R one-factor experiments for selecting the best normal population," <u>Journal of</u> the American Statistical Association, Vol. 67 (1972), pp. 660-661.
- Bechhofer, R.E.: "Single-stage procedures for ranking multiply-classified variances of normal populations," <u>Technometrics</u>, Vol. 10, No. 4 (1968), pp. 693-714.
- Bechhofer, R.E.: "Multiple comparisons with a control for multiply-classified variances of normal populations," <u>Technometrics</u>, Vol. 10, No. 4 (1968), pp. 715-718.
- Bechhofer, R.E.: "Designing factorial experiments to rank variances," <u>Trans-</u> actions of the Twenty-Se and Annual Technical Conference of the American Society for Quality Control, May 1968, pp. 69-73.
- Bechhofer, R.E.: "Optimal allocation of observations when comparing several treatments with a control," <u>Multivariate Analysis</u>, Vol. 2, Academic Press, Inc., New York 1969, pp. 463-473.
- Bechhofer, R.E.: "On ranking the players in a 3-player tournament," <u>Nonpara-</u> <u>metric Techniques in Statistical Inference</u> (ed. by M.L. Puri), Cambridge University Press, September 1970, pp. 545-559.
- Bechhofer, R.E. and Turnbull, B.: "Cptimal allocation of observations when comparing several treatments with a control (III): globally best one-sided intervals for unequal variances," <u>Statistical Decision Theory and Related</u> <u>Topics</u> (ed. by S.S. Gupta and J. Yackel), Academic Press, Inc., 1971, pp. 41-77.
- Bechhofer, R.E. and Nocturne, D.J.M.: "Optimal allocation of observations when comparing several treatments with a control (II): 2-sided comparisons," <u>Technometrics</u>, Vol. 14, No. 2 (1972), pp. 423-436.
- Hooke, J.: "On some limit theorems for the GI/G/1 queue," Journal of Applied Probability, Vol. 7 (1970), pp. 634-640.
- Hooke, J.: "A priority queue with low priority arrivals general," Journal of the Operations Research Society of America, Vol. 20 (1972), pp. 373-380.
- Hooke, J.: "Some heavy traffic limit theorems for a priority queue with general arrivals," <u>Journal of the Operations Research Society of America</u>, Vol. 20 (1972), pp. 381-388.
- Ramberg, J.: "Selection sample size approximations," <u>Annals of Mathematical</u> Statistics, Vol. 43, No. 6 (1972), pp. 1977-1980.
- Turnbull, B.W.: "Chebyshev-like inequalities for dam models," Journal of Applied Probability, Vol. 9 (1972), pp. 617-629.

Turnbull, B.W.: "Inequalities for branching processes," Annals of Probability, Vol. 1, No. 3 (1973), pp. 457-474.

Turnbull, B.W.: "Inequalities for multitype branching processes," <u>Annals of</u> <u>Probability</u>, Vol. 1, No. 3 (1973), pp. 475-479.

Paper (accepted for publication), the research for which was supported in whole or in part by ARO contract DA-31-124-ARO-D-474.

Fushimi, M.: "An improved version of a Sobel-Weiss play-the-winner procedure for selecting the better of two binomial populations." Accepted for publication in <u>Biometrika</u>.

Papers (submitted for publication), the research for which was supported in whole or in part by ARO contract DA-31-124-ARO-D-474.

- Fushimi, M.: "A non-symmetric sequential procedure for selecting the better of two binomial populations." Submitted for publication to Biometrika.
- Nocturne, D.: "Asymptotic efficiency of the maximum likelihood estimator for the parameters of certain stochastic processes." Submitted for publication to the Annals of Statistics.

#### Graduate students supported by ARO contract DA-31-124-ARO-D-474.

Prakash Awate Vijay S. Bawa Ricardo M. Frischtak James E. Higgins John Hooke Prasadarao V. Kakumanu Jose Kreimerman

Vijay Marathe

Dominique Nocturne Jayvivek Prabhu John Ramberg Yvonne (Kramer) Resnick Ajit Tamhane Bruce Turnbull Alan N. Unger

Research Associate supported by ARO contract DA-31-124-ARO-D-474.

Masanori Fushimi

Ph.D. dissertations and M.S. theses which were supported in whole or in part by ARO contract DA-31-124-ARO-D-474.

- Bawa, Vijay S.: (Ph.D. dissertation) "Asymptotically optimal ranking and selection procedures." June 1970.
- Frischtak, Ricardo M.: (Ph.D. dissertation) "Statistical multiple-decision procedures for some multivariate selection problems." August 1973.
- Higgins, James E.: (M.S. theris) "Bernoulli sampling plans which approximately minimize the maximum expected sample size." February 1969.
- Hooke, John: (Ph.D. dissertation) "Some limit theorems for priority queues." January 1970.
- Kakumanu, Prasadarao V.: (Ph.D. dissertation) "Continuous time Markov decision models with applications to optimization problems." September 1969.

Marathe, Vijay: (Ph.D. dissertation) "Priority queuing systems with simultaneous server requirements." May 1972.

Nocturne, Dominique: (Ph.D. dissertation) "Asymptotic efficiency of the maximum likelihood estimators for the parameters of certain stochastic processes." June 1970.

Ramberg, John S. (Ph.D. dissertation) "A multiple-decision approach to the selection of the best set of predictor variates." February 1969.

Resnick, Mrs. "vonne (Kramer): (M.S. thesis) "Hedging procedure for estimation of (k+1) quantiles for a population with unknown mean." September 1969.

Turnbull, Bruce W.: (Ph.D. dissertation) "Bounds and optimal strategles for stochastic systems." September 1971.