

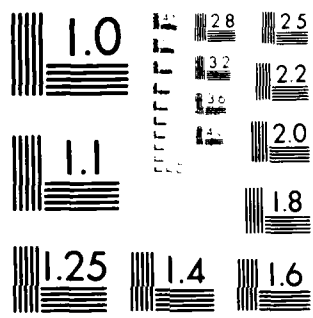
AD-A128 536 REPORT ON SPONSORED RESEARCH ON ALGORITHMIC METHODS IN 1/1
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REPORT ON SPONSORED RESEARCH ON
ALGORITHMIC METHODS IN PROBABILITY

Submitted by

Final

MARCEL F. NEUTS
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DEPARTMENT OF MATHEMATICAL SCIENCES
UNIVERSITY OF DELAWARE
NEWARK DE 19711

to

THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

for

GRANT No. AFOSR-77-3236

PERIOD COVERED: 1 JUNE 1982 - 31 MAY 1983

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report covers the period 1 June 1981 - 31 May 1982 for Grant AFOSR-77-3236. The development of algorithmic procedures for the study of stochastic processes and queues, in particular, has continued at a very high level of intensity at the University of Delaware. This was a period where several works of longer duration and effort were completed and published. The principal ones among these are the book on Matrix-Geometric Solutions in Stochastic Models by Professor M.F. Neuts, and the Ph.D. dissertation of Dr. D.M. Lucantoni. (CONTINUED)		

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ITEM #20, CONTINUED:

The report submitted for the preceding year listed a large number of papers, which were at that time submitted or accepted for publication. Most of these papers have now appeared and seem to have a seminal influence on the research on the algorithmic approach to probability and its applications, which is being initiated at more and more centers in Europe and Asia.

This research effort has, we believe, contributed significantly to the much needed task of bringing the findings and methodology of the theory of stochastic models closer to its genuine applications in technology. It has done so by the elaboration of mathematical methods that lead to implementable algorithms and to detailed numerical results, whose interpretation yields insight into the stochastic behavior of queues and related stochastic models.

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1. INTRODUCTION

THIS REPORT COVERS THE PERIOD 1 JUNE 1981 - 31 MAY 1982 FOR GRANT No. AFOSR-77-3236. THE DEVELOPMENT OF ALGORITHMIC PROCEDURES FOR THE STUDY OF STOCHASTIC PROCESSES AND QUEUES, IN PARTICULAR, HAS CONTINUED AT A VERY HIGH LEVEL OF INTENSITY AT THE UNIVERSITY OF DELAWARE. THIS WAS A PERIOD WHERE SEVERAL WORKS OF LONGER DURATION AND EFFORT WERE COMPLETED AND PUBLISHED. THE PRINCIPAL ONES AMONG THESE ARE THE BOOK ON MATRIX-GEOMETRIC SOLUTIONS IN STOCHASTIC MODELS BY PROF. M. F. NEUTS AND THE PH.D. DISSERTATION OF DR. D. M. LUCANTONI.

THE REPORT SUBMITTED FOR THE PRECEDING YEAR LISTED A LARGE NUMBER OF PAPERS, WHICH WERE AT THAT TIME SUBMITTED OR ACCEPTED FOR PUBLICATION. MOST OF THESE PAPERS HAVE NOW APPEARED AND SEEM TO HAVE A SEMINAL INFLUENCE ON THE RESEARCH ON THE ALGORITHMIC APPROACH TO PROBABILITY AND ITS APPLICATIONS, WHICH IS BEING INITIATED AT MORE AND MORE CENTERS IN EUROPE AND ASIA.

THE RESEARCH PROGRAM SPONSORED BY THE AIR FORCE OF SCIENTIFIC RESEARCH SINCE 1977 HAS, WE BELIEVE, CONTRIBUTED SIGNIFICANTLY TO THE MUCH NEEDED TASK OF BRINGING THE FINDINGS AND METHODOLOGY OF THE THEORY OF STOCHASTIC MODELS CLOSER TO ITS GENUINE APPLICATIONS IN TECHNOLOGY. IT HAS DONE SO BY THE ELABORATION OF MATHEMATICAL METHODS THAT LEAD TO IMPLEMENTABLE ALGORITHMS AND TO DETAILED NUMERICAL RESULTS, WHOSE INTERPRETATION YIELDS INSIGHT INTO THE STOCHASTIC BEHAVIOR OF QUEUES AND RELATED STOCHASTIC MODELS.

IT HAS DONE THIS THROUGH THE FOLLOWING MEANS:

a. THE EXTENSIVE RECORD OF PUBLICATION, LECTURING AND INDUSTRIAL CONSULTING OF THE PRINCIPAL INVESTIGATOR.

b. THE VISITS OF A STEADY STREAM OF FACULTY MEMBERS, WHO COME TO THE UNIVERSITY OF DELAWARE TO SHARE IN THE ACTIVITIES OF THE LIVELY GROUP OF INDIVIDUALS AROUND M. F. NEUTS WHO THINK ABOUT PROBABILITY MODELS IN DYNAMIC, ALGORITHMIC TERMS. WHILE THE GRANT DID NOT PROVIDE DIRECT SUPPORT FOR THIS PART OF THE EFFORT, THE UNIVERSITY HAS UNRELENTINGLY ENCOURAGED AND SUPPORTED SUCH VISITS. WITH VERY LIMITED MEANS, MUCH HAS BEEN ACCOMPLISHED THEREBY.

c. THE EDUCATION OF GRADUATE STUDENTS TO THE SUCCESSFUL COMPLETION OF M. SC. AND PH.D. DEGREES. THE THREE M. SC. AND ONE PH.D. STUDENTS WHO HAVE CONCENTRATED ON THIS AREA AND HAVE WORKED UNDER THE SUPERVISION OF PROF. NEUTS, HAVE ALL FOUND ATTRACTIVE AND CHALLENGING POSITIONS IN MAJOR INDUSTRIAL FIRMS IN THE UNITED STATES. THE COMBINATION OF A STRONG ACADEMIC PROGRAM WITH A DIRECT CONCERN FOR RELEVANCE AND APPLICABILITY MAKES THEM ATTRACTIVE TO AND APPRECIATED BY THEIR EMPLOYERS.

THE SUPPORT OF AFOSR HAS ENDED WITH THE TERMINATION OF THE PERIOD COVERED BY THIS REPORT. THANKS TO THE APPROVAL OF A THREE-YEAR RENEWABLE GRANT FROM THE NATIONAL SCIENCE FOUNDATION IN SEPTEMBER 1982, THIS HAS NOT SIGNIFIED THE END OF THE RESEARCH SUPPORT FOR THIS GENUINE GROUP EFFORT. IT HAS, HOWEVER, PRECLUDED ANY FURTHER EXPANSION AT THIS TIME. WITH THE POOL OF YOUNGER ACADEMIC MATHEMATICIANS IN THE UNITED STATES, WHO WORK ON (REAL) APPLIED PROBABILITY, ALMOST BONE DRY, IT IS A PITY TO SEE AN EFFORT THAT PROVIDED SEVERAL WITH AN EDUCATION OF HIGH QUALITY INHIBITED IN ITS FURTHER GROWTH.

THE THREE CURRENT DOCTORAL STUDENTS OF PROF. NEUTS SHOULD COMPLETE THEIR DISSERTATIONS. TWO BY THE SUMMER 1983, THE THIRD BY THE END OF 1984. WITH THE SABBATICAL LEAVE OF THE PRINCIPAL INVESTIGATOR DURING THE ACADEMIC YEAR 1983-84, THE RESEARCH PROGRAM WILL SOON COME TO A WATERSHED.

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Chief, Technical Information Division

THE ACCOMPLISHMENTS OF THE RESEARCH SUPPORTED BY THE GRANT ARE BEST DOCUMENTED BY THE ACCOMPANYING LISTS OF TECHNICAL REPORTS, PUBLISHED PAPERS AND PROFESSIONAL RECOGNITIONS OF THE INDIVIDUALS INVOLVED. RATHER THAN GOING OVER THE SAME GROUND IN THE NARRATIVE PORTION OF THIS REPORT, IT APPEARS TO BE DESIRABLE TO LOOK AT THE POSSIBILITIES AND CHALLENGES OF THE COMING YEARS.

AFTER YEARS OF A SEVERE SHORTAGE OF GRADUATE STUDENTS AND OF A NEARLY EXCLUSIVE DEVELOPMENT OF ABSTRACT PROBABILITY, THERE IS AT THE PRESENT A GROWING INTEREST ON THE PART OF YOUNG PERSONS IN ADVANCED STUDY IN THE AREAS OF PROBABILITY, OPERATIONS RESEARCH AND STATISTICS THAT CONTRIBUTE DIRECTLY TO THE TECHNOLOGICAL STRENGTH OF OUR COUNTRY. THE RECORD SHOWS THAT THE EFFORT SUPERVISED BY PROF. NEUTS IS AIMED STRONGLY AT THE DEVELOPMENT OF SUCH GRADUATE CAREERS. THAT EFFORT IS ALSO ONE OF A SMALL NUMBER REMAINING IN THE MATHEMATICAL DEPARTMENTS IN THE COUNTRY.

IF THE EFFORT IS TO CONTINUE AND TO GROW, IT IS ESSENTIAL THAT IT BE EXPANDED BY JUNIOR FACULTY MEMBERS, SO THAT THE GRADUATE STUDENTS OF TALENT WE APPEAR TO ATTRACT MAY BE EDUCATED IN LARGER NUMBERS AND IN A WIDER VARIETY OF SUBDISCIPLINES THAN ONE SENIOR FACULTY MEMBER CAN MEANINGFULLY HANDLE. THIS IS INDEED A PLEA FOR RENEWED RESEARCH SUPPORT FOR THE PERIOD AFTER PROF. NEUTS' SABBATICAL LEAVE WHICH ENDS LATE IN 1984. WITH THE ABSORPTION - FOR QUITE OBVIOUS REASONS - OF NEARLY ALL THE BEST APPLIED PROBABILISTS BELOW THE AGE OF THIRTY-FIVE INTO INDUSTRIAL RESEARCH, A PLEA FOR SUPPORT ON THE PART OF A STRONGLY ACTIVE AND SENIOR ONE IS NOT SELF-SERVING. IT COMES FROM THE RECOGNITION THAT THE GRADUATE STUDENTS WHO WISH TO SPECIALIZE IN THAT ESSENTIAL AREA MAY NOT BE ABLE TO DO SO IN FUTURE YEARS, BECAUSE THERE WILL BE SO FEW APPLIED PROBABILISTS REMAINING TO SUPERVISE THEIR THESES.

TWO STUDIES, UNDERTAKEN WITH PARTIAL SUPPORT OF THE GRANT, ARE NOW CLOSE TO COMPLETION. THESE ARE THE PH.D. DISSERTATIONS OF MESSRS. S. CHAKRAVARTHY AND S. KUMAR. THE WORK OF S. CHAKRAVARTHY DEALS WITH THE OPTIMAL DUPLICATION, SUBJECT TO VARIOUS CONSTRAINTS, OF TOOLS IN A COMMON TOOL MAGAZINE SHARED BY TWO MACHINES. THIS STOCHASTIC AND COMBINATORIAL OPTIMIZATION PROBLEM HAS VARIOUS OTHER APPLICATIONS. THE WORK OF S. KUMAR IS THE SIMULATION STUDY OF A MESSAGE NETWORK IN WHICH THE MESSAGES DESTINED FOR A COMMON DESTINATION MUST CONTENTEND FOR ACCESS TO THEIR RECEIVING NODES.

IT IS ANTICIPATED THAT BOTH DISSERTATIONS WILL BE COMPLETED BY THE SUMMER 1983. COPIES OF THE RESULTING TECHNICAL REPORTS WILL BE SUBMITTED TO THE AFOSR, AS SOON AS THEY BECOME AVAILABLE.

THE WORK OF THE FOLLOWING PERSONS WAS SUPPORTED THROUGH THE GRANT:

PROF. MARCEL F. NEUTS - PRINCIPAL INVESTIGATOR

MR. S. CHAKRAVARTHY - GRADUATE ASSISTANT

MR. S. KUMAR - GRADUATE ASSISTANT.

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2. ITEMS PUBLISHED

A. BOOK

MATRIX-GEOMETRIC SOLUTIONS IN STOCHASTIC MODELS - AN

ALGORITHMIC APPROACH

MARCEL F. NEUTS

THE JOHNS HOPKINS UNIVERSITY PRESS, BALTIMORE,
MARYLAND 1981.

B. JOURNAL ARTICLES

1. ALGORITHMIC ANALYSIS OF A MULTIPROGRAMMING-MULTIPROCESSOR
COMPUTER SYSTEM
GUY LATOUCHE
TECHNICAL REPORT: 78/13 - JULY 1978 -
JOURNAL: JOURNAL OF THE A.C.M. (1981), 28, 662-679
2. ALGORITHMIC METHODS FOR MULTI-SERVER QUEUES WITH GROUP
ARRIVALS AND EXPONENTIAL SERVERS
DAVID E. BAILY AND MARCEL F. NEUTS
TECHNICAL REPORT: 78/14 - JUNE 1978 -
JOURNAL: EURO. JOURN. OF OPER. RES. (1981), 8, 184-196
3. A GI/M/c QUEUE WITH A DIFFERENT SERVICE RATE FOR CUSTOMERS
WHO NEED NOT WAIT - AN ALGORITHMIC SOLUTION -
DAVID M. LUCANTONI
TECHNICAL REPORT: 48B - MAY 1979 -
JOURNAL: CAHIERS DU CENTRE DE RECHERCHE OPERATIONNELLE,
(1982), 24, 5-20.
4. A SINGLE SERVER QUEUE WITH PLATOONED ARRIVALS AND PHASE
TYPE SERVICES
MARCEL F. NEUTS AND S. CHAKRAVARTHY
TECHNICAL REPORT: 50B - APRIL 1980 -
JOURNAL: EURO. J. OF OPER. RES. (1981), 8, 379-389.
5. ALGORITHMIC SOLUTION OF SOME QUEUES WITH OVERFLOWS
MARCEL F. NEUTS AND S. KUMAR
TECHNICAL REPORT: 51B - APRIL 1980 -
JOURNAL: MANAGEMENT SCIENCE, (1982), 28, 925-935.
6. EXPLICIT STEADY-STATE SOLUTIONS TO SOME ELEMENTARY QUEUEING
MODELS
MARCEL F. NEUTS
TECHNICAL REPORT: 53B - MARCH 1980 -
JOURNAL: OPERATIONS RESEARCH (1982), 30, 480-489.
7. STATIONARY WAITING TIME DISTRIBUTIONS IN THE GI/PH/1 QUEUE
MARCEL F. NEUTS
TECHNICAL REPORT: 55P - APRIL 1980 -
JOURNAL: JOURNAL OF APPLIED PROBABILITY (1981), 18, 901-912.

8. A PHASE-TYPE SEMI-MARKOV POINT PROCESS
GUY LATOUCHE
TECHNICAL REPORT: 56B - APRIL 1980 -
JOURNAL: SIAM JOURNAL ON ALGEBRAIC AND DISCRETE METHODS,
(1982), 3, 77-90
9. ASYMPTOTIC BEHAVIOR OF THE STATIONARY DISTRIBUTIONS IN THE
GI/PH/C QUEUE WITH HETEROGENEOUS SERVERS
MARCEL F. NEUTS AND YUKIO TAKAHASHI
TECHNICAL REPORT: 57B - MAY 1980 -
JOURNAL: ZEITSCHRIFT FUR WAHRSCHEINLICHKEITSTHEORIE (1981),
57, 441-452
10. A MULTI-SERVER QUEUE WITH THRESHOLDS FOR THE ACCEPTANCE
OF CUSTOMERS INTO SERVICE
MARCEL F. NEUTS AND R. NADARAJAN
TECHNICAL REPORT: 59B - JUNE 1980 -
JOURNAL: OPERATIONS RESEARCH (1982), 30, 948-60
11. AN ILLUSTRATIVE PROBLEM IN COMPUTATIONAL PROBABILITY
MARCEL F. NEUTS
TECHNICAL REPORT: 60B - JUNE 1980 -
JOURNAL: OPSEARCH (1981), 18, 171-177.
12. SHOCK MODELS WITH PHASE TYPE SURVIVAL AND SHOCK RESISTANCE
MARCEL F. NEUTS AND MANISH C. BHATTACHARJEE
TECHNICAL REPORT: 61B - AUGUST 1980 -
JOURNAL: NAVAL RESEARCH LOGISTICS QUARTERLY (1981),
28, 213-219.
13. ON THE USE OF PHASE TYPE DISTRIBUTIONS IN RELIABILITY
MODELLING OF SYSTEMS WITH TWO COMPONENTS
MARCEL F. NEUTS AND KATHLEEN S. MEIER
TECHNICAL REPORT: 62B - JULY 1980 -
JOURNAL: O. R. SPEKTRUM (1981), 2, 227-234.
14. A NUMERICAL PROCEDURE FOR THE SELECTION OF THE CONSTANT
INTERARRIVAL TIME TO A SINGLE SERVER QUEUE
CARL GEISZLER
TECHNICAL REPORT: 63B - JULY 1980
JOURNAL: COMPUTERS AND MATHEMATICS WITH APPLICATIONS,
(1981), 7, 537-546.
15. THE C-SERVER QUEUE WITH CONSTANT SERVICE TIMES AND A
VERSATILE MARKOVIAN ARRIVAL PROCESS
MARCEL F. NEUTS
TECHNICAL REPORT: 65B - OCTOBER 1980
JOURNAL: APPLIED PROBABILITY - COMPUTER SCIENCE: THE INTERFACE,
PROC. CONF. BOCA RATON, FLORIDA, JANUARY 1981, R. L. DISNEY AND
T. J. OTT (eds.), 1, 31-70, 1982.
16. OPERATOR-GEOMETRIC STATIONARY DISTRIBUTIONS FOR MARKOV
CHAINS WITH APPLICATION TO QUEUEING MODELS
RICHARD L. TWEEDIE
TECHNICAL REPORT: 68B - DECEMBER 1980 -
JOURNAL: ADVANCES IN APPLIED PROBABILITY, 14, 368-391, 1982.

17. ON THE COEFFICIENT OF VARIATION OF MIXTURES OF PROBABILITY DISTRIBUTIONS
MARCEL F. NEUTS
TECHNICAL REPORT: 69B - DECEMBER 1980 -
JOURNAL: COMMUNICATIONS IN STATISTICS, B 11, 649-657, 1982.
18. ALGORITHMIC ANALYSIS OF A DYNAMIC PRIORITY QUEUE - I
V. RAMASWAMI AND DAVID M. LUCANTONI
TECHNICAL REPORT: 70B - FEBRUARY 1981
JOURNAL: APPLIED PROBABILITY - COMPUTER SCIENCE: THE INTERFACE,
PROC. CONF. BOCA RATON, FLORIDA, JANUARY 1981, R. L. DISNEY AND
T. J. OTT (eds.), II, 157-206, 1982.
19. LAWS OF LARGE NUMBERS FOR SUMS OF EXTREME VALUES
DAVID M. MASON
TECHNICAL REPORT: 71B - FEBRUARY 1981 -
JOURNAL: ANNALS OF PROBABILITY, (1982), 10, 754-764.
20. GENERATING RANDOM VARIATES FROM A DISTRIBUTION OF PHASE TYPE
MARCEL F. NEUTS AND MIRIAM E. PAGANO
TECHNICAL REPORT: 73B - JULY 1981
JOURNAL: 1981 WINTER SIMULATION CONFERENCE PROCEEDINGS,
T. I. OREN, C. M. DELFOSSE, C. M. SHUB (EDS.), 381-387.

3. ITEMS ACCEPTED FOR PUBLICATION

A. MONOGRAPH

AN ALGORITHMIC ANALYSIS OF A COMMUNICATION MODEL WITH
RETRANSMISSION OF FLAWED MESSAGES

DAVID M. LUCANTONI

MONOGRAPH: PITMAN RESEARCH NOTES IN MATHEMATICS No. 81, 1983.
160 PAGES.

B. JOURNAL ARTICLES

1. A SERVICE MODEL IN WHICH THE SERVER IS REQUIRED TO SEARCH
FOR CUSTOMERS
MARCEL F. NEUTS AND M. F. RAMALHOTO
TECHNICAL REPORT: 75B - DECEMBER 1981
JOURNAL: JOURNAL OF APPLIED PROBABILITY
2. SHORTER QUEUE PROBLEM: A NUMERICAL STUDY USING MATRIX-GEOMETRIC
SOLUTION AND INVESTIGATION OF THE SPECTRAL RADIUS OF THE MATRIX R
ILYA GERTSBAKH
TECHNICAL REPORT: 77B - FEBRUARY 1982
JOURNAL: EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
3. RELIABILITY ANALYSIS OF A PARALLEL SYSTEM WITH EXPONENTIAL LIFE
TIMES AND PHASE TYPE REPAIRS
S. CHAKRAVARTHY
TECHNICAL REPORT: 76B - MARCH 1982
JOURNAL: O. R. SPEKTRUM

4. ITEMS SUBMITTED FOR PUBLICATION

1. ASYMPTOTIC METHODS IN RELIABILITY THEORY A REVIEW
ILYA B. GERTSBAKH
TECHNICAL REPORT: 80B - SEPTEMBER 1982

5. OTHER ITEMS OF INTEREST

LARGELY ON THE STRENGTH OF THE BOOK ON MATRIX-GEOMETRIC METHODS, PROF. NEUTS RECEIVED AN ALEXANDER VON HUMBOLDT SENIOR U.S. SCIENTIST AWARD, WHICH WILL ENABLE HIM TO SPEND THE FIRST SIX MONTHS OF HIS UPCOMING SABBATICAL LEAVE AT THE UNIVERSITY OF STUTTGART. THERE, HE PLANS TO WORK WITH THE GROUP SUPERVISED BY PROF. PAUL KUHN ON PROBLEMS ARISING IN THE METHODOLOGY OF DATA PROCESSING AND TELECOMMUNICATIONS.

FROM MARCH 1984 TO MID-JULY OF THAT YEAR, HE WILL VISIT THE SCHOOL OF INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH AT TECHNION IN HAIFA, ISRAEL.

PROF. NEUTS WAS APPOINTED TO COLLABORATING EDITOR FOR THE JOURNAL OF APPLIED PROBABILITY, WITH SPECIAL RESPONSIBILITY FOR THE PAPERS DEALING WITH STOCHASTIC MODELS ARISING IN TECHNOLOGY.

DURING THE PERIOD COVERED BY THIS REPORT, HE ALSO GAVE A LARGE NUMBER OF LECTURES AT UNIVERSITIES AND INDUSTRIAL RESEARCH CENTERS IN THE UNITED STATES. DURING THE MONTH OF JANUARY, HE VISITED BELL LABORATORIES AND STUDIED QUEUEING PROBLEMS ARISING IN ELECTRONIC MESSAGE SWITCHES. THE DOCTORAL THESIS OF MR. S. KUMAR, WHICH IS NOW IN PREPARATION, IS LARGELY AN OUTGROWTH OF THAT VISIT.

THE PH.D. DISSERTATION OF DAVID M. LUCANTONI WAS SELECTED FOR THE ALLAN P. COLBURN AWARD AT THE UNIVERSITY OF DELAWARE. A REVISED AND EDITED VERSION OF DR. LUCANTONI'S THESIS IS TO BE PUBLISHED AS A MONOGRAPH IN THE PITMAN SERIES, EARLY IN 1983.

MS. MIRIAM PAGANO, WHOSE M.SC. THESIS WAS SUBMITTED TO THE AFOSR AS A TECHNICAL REPORT, HAS JOINED THE FEDERAL SYSTEMS DIVISION OF THE I.B.M. CORPORATION

DURING THE PERIOD OF THE GRANT, THE UNIVERSITY RECEIVED EXTENDED VISITS FROM PROF. ILYA B. GERTSBAKH OF THE UNIVERSITY OF THE NEGEV, BEERSHEVA, ISRAEL AND FROM PROF. MARIA-FERNANDA RAMALHOTO OF THE CENTRE FOR STATISTICS AND APPLICATIONS IN LISBON, PORTUGAL. PROF. OSMAN M. E. ALI OF THE MILITARY ACADEMY, CAIRO, EGYPT IS CURRENTLY SPENDING A STUDY LEAVE AT THE UNIVERSITY. ALL THREE PERSONS CAME TO THE UNIVERSITY OF DELAWARE TO PARTICIPATE IN ITS RESEARCH PROGRAM IN APPLIED PROBABILITY

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