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THE ADOPTION OF OPERATIONS RESEARCH TECHNIQUES BY MANUFACTURING ORGANIZATIONS: A REGIONAL EXAMINATION AND ANALYSIS

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NORMAN GAITHER

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THE ADOPTION OF OPERATIONS RESEARCH TECHNIQUES BY MANUFACTURING ORGANIZATIONS: A REGIONAL EXAMINATION AND ANALYSIS

APPROVED BY

L. A. Bishop

Robert A. Ford

William Holmes

W. Borg

Jack A. Fuller

DISSERTATION COMMITTEE

To

Lynda, Mark, Paul and Adam

and

the memory of my father: Clifford A. Gaither

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CHAPTER I

THE PROBLEM

Quantitative methods are presently a predominant part of the subject material in production/operations management curricula in colleges and universities. Some of the factors which contributed to this development are the following: (1) the scientific management movement, (2) the operations research movement, and (3) the development of the computer industry.

The scientific management movement principally resulted from the writings and work of Frederick Winslow Taylor in the early 1900's. Although Taylor built on the earlier work of Charles Babbage, Henry Towne, and others, the credit must go to Taylor, his associates, and successors for popularizing the methods of the scientific management movement in this country and in Europe. Utilization of the scientific management methods was enhanced by the industrial buildup in the World War I period.[1] Those techniques of Taylor, Taylor's followers, and others who sought to rationalize the production process during the early 1900's contributed to the body of knowledge of production management which was to be the predominant subject matter in production management writings until the early 1960's.[2]

The European Campaign of World War II brought into play immense quantities of resources that had to be efficiently rationalized. Interdisciplinary teams of scientists combined to study operational problems with the goal of providing the top military leadership with recommendations concerning operational decisions. The first such study concerned the effective utilization of radar resources in optimizing the sighting, identification, and reporting of enemy planes. These studies were so successful that operations research teams were spread throughout the campaigns of World War II.[3] After World War II, many operations research team members found their way back to universities and private industry. They returned with valuable experience in operations research.

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[1] Charles D. Flagle, William H. Huggins, and Robert H. Ray, Operations Research and Systems Engineering (Baltimore: The Johns Hopkins Press, 1960), p. 15.

[2] Richard I. Levin, *et al.*, Production/Operations Management: Contemporary Policy for Managing Operating Systems (New York: McGraw-Hill Book Company, 1972), p. 10.

[3] Joseph F. McCloskey and Florence N. Trefethen, Operations Research for Management (Baltimore: The Johns Hopkins Press, 1954), p. 6.

During the next decade, a series of events proved to be crucial in the development and expansion of the private sector operations research activity:

1. Establishment of operations research-management science curricula in colleges and universities.
2. Establishment of consulting firms specializing in operations research-management science techniques.
3. Organization of operations research-management science societies, which publish journals exhibiting a continuing refinement of quantitative methods.
4. Conferences on operations research-management science topics.
5. Launching of the 1958 Russian Sputnik, and the realization that this country was being overtaken technologically by competing nations.
6. Publication of the 1959 Gordon-Howell and Pierson reports, which emphasized the need for problem solving through scientific methods and quantitative analysis in business colleges.[4]
7. Development and growth of the computer industry.

The first UNIVAC computer was installed at the Bureau of the Census in 1951. The first business installation of computers was in 1954 at the General Electric

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[4]R. A. Gordon and J. E. Howell, Higher Education for Business (New York: Columbia University Press, 1959, pp. 179-182. F. C. Pierson, The Education of American Businessmen: A Study of University-College Programs in Business Administration (New York: McGraw-Hill Book Co., 1959).

Appliance Park in Louisville, Kentucky. These first-generation computers in the 1950's evolved into second- and third-generation computers in the 1960's. This development facilitated operational studies previously infeasible because of the sheer magnitude of the calculations.[5]

Statement of the Problem

In the late 1950's and early 1960's, optimism reigned supreme concerning the future role of operations research, model building, and computers in organizations. In a landmark article in 1958, Leavitt and Whisler predicted that as a result of operations research, model building, the computer and related technology, the practice and structure of management would change enormously.

> The horizontal slice of the current organization chart that we call middle management will break in two, with the larger portion shrinking and shrinking and sinking into a more highly programmed state and the smaller portion proliferating and rising to a level where more creative thinking is needed.[6]

The implications that model building and the computer would: (1) routinize many of the traditional functions of middle management, (2) eliminate many middle-management positions, and (3) result in a "quantitative elite" top corporate management, are found in the writings of Herbert

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[5]Gordon B. Davis, Computer Data Processing (New York: McGraw-Hill Book Company, 1969), p. 62.

[6]Harold J. Leavitt and Thomas L. Whisler, "Management in the 1980's," Harvard Business Review, November-December, 1958, pp. 41-48.

Simon during this period.[7]

Our higher educational system has responded to the prediction that future managers would need quantitative tools of analysis with academic programs giving the students training in courses such as Quantitative Methods, Computer Simulation, Model Building, Computer Programming, Mathematical Programming, and Queueing Theory.

In 1961, Buffa offered one of the first quantitatively-oriented production management textbooks.[8] Since the early 1960's, Buffa's book has undergone four editions. At the same time, there has been a great proliferation of other quantitatively-oriented production management textbooks and a general decline in the number of traditional descriptive management textbooks.

What is the stage of development of business organizations in utilizing these quantitative techniques? More specifically, since manufacturing processes tend to be more rational or programmable than other processes found in other business organizations, to what extent are manufacturing organizations using operations research techniques?

Review of the Pertinent Research

Any researcher who investigates the extent of

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[7]Herbert A. Simon, The New Science of Management Decision (New York: Harper and Row Publishers, 1960), p. 34.

[8]Elwood S. Buffa, Modern Production Management (New York: John Wiley & Sons, Inc., 1961).

adoption of operations research techniques by manufacturing organizations is confronted with the scarcity of published results of such efforts. Although a growing body of literature recognizes the need for such research, there remains a scarcity of published work in the field.

One of the first pieces of research in the area was conducted by Arthur Anderson and Company for the American Management Association in 1957. This mail survey sought to determine the extent of the utilization of operations research among (1) the industry members of Operations Research Society of America (ORSA), (2) the industry members of The Institute of Management Sciences (TIMS), (3) attendees of American Management Association conferences on operations research, and (4) presidents of 2700 U.S. companies with more than 1000 employees. The study utilized a sample size of 631 and generally sought to determine: (1) the percentage of firms in each industry classification using operations research at the time of the study and their future plans, (2) the size of operations research groups in each industry, (3) the educational backgrounds of operations research personnel by industry, and (4) in what functional areas of the organization was operations research being applied. The results of the study indicated that 51.4% of the respondents was using operations research, 22.8% of the respondents intended to use operations research, and 25.8% of the respondents did not intend to use operations research in the future.[9]

In 1958, Hovey and Wagner at Stanford University essentially followed the same procedure as the 1957 AMA report.[10] The study utilized a sample size of 90 and surveyed firms which were: (1) company affiliates of an author of an article appearing in Operations Research or Management Science (1956 and 1957), or (2) a member of Operations Research Society of America or The Institute of Management Sciences and a company listed in the 1958 College Placement Annual as employing mathematicians and engineers. The 1957 AMA questionnaire was used and the results of the study indicated that 68% of the respondents was currently using operations research.

In 1964, Schumacher and Smith conducted a survey similar to the AMA and Hovey and Wagner reports.[11] This study essentially sought to update the earlier studies in the area. The sample size of 65 was utilized to survey firms which were cross-indexed between the "Fortune Top 500" industrial corporations with firms listed in the College Placement Annual as seeking engineers and mathematicians.

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[9] Operations Research Reconsidered (New York: American Management Association, Inc., 1957), Report No. 10, p. 25.

[10] Ronald W. Hovey and Harvey M. Wagner, "A Sample Survey of Industrial Operations-Research Activities," Operations Research, VI (November-December, 1958), pp. 876-79.

[11] Charles C. Schumacher and Barnard E. Smith, "A Sample Survey of Industrial Operations-Research Activities, II," Operations Research, XIII (December, 1965), pp. 1023-27.

The firm size ranged from 2000 to 500,000 employees, with 15,000 employees being the median. The study indicated that 75% of the respondents reported engagement in operations research activities.

Buffa cites these three research studies as a factual basis for concluding that there has been a rapid development in the use of operations research in production and operations management (refer to Table 1).[12]

TABLE 1

THE USE OF OPERATIONS RESEARCH IN PRODUCTION AS A PERCENTAGE OF N

Researcher(s)	Year	N	Percent
AMA	1957	631	24
Hovey and Wagner	1958	90	32
Schumacher and Smith	1964	65	68

Buffa's conclusions concerning the rapid development of the operations research in production is inappropriate in this researcher's view because of the following:

1. No inferences can be made from any one study to manufacturing industries at large because the populations surveyed are known to be biased toward the use of operations research.
2. No inferences can be made between the studies as each

[12] Buffa, Modern Production Management, pp. 697-98.

sample came from a different population. All three populations are biased toward the use of operations research, but not uniformly so.

3. No study is made in any of the research cited above of the non-responses to determine the representativeness of the samples.

These early studies appear to be deficient in the researcher's view for other reasons:

1. No effort is made to define "operations research" so that a common understanding of the term is shared by all of the respondents.
2. Each respondent indicates only that he is or is not using operations research; hence, no measure of the extent of usage of operations research is made. Respondents who use a wide variety of operations research techniques routinely are equated with those using only a few techniques on very rare occasions. To know which operations research techniques are used more frequently than others would be desirable.

During the 1967-1971 period, Elmer H. Burack, of the Illinois Institute of Technology, studied companies with formal operations research groups.[13] The key issues under examination by Burack were the identification of the

[13]Robert Bomi D. Batlivala and Elmer H. Burack, "Operations Research: Recent Changes and Future Expectations in Business Organizations," Business Perspectives, IX, No. 1 (Fall, 1972), pp. 15-22.

factors of major importance in the success or failure of operations research groups and the position and movement of these groups in their organization structures. Although these studies indicate that formal operations research groups were experiencing only limited growth, more and more operations research techniques were being adopted by other functional groups in the organization. These studies utilized as respondents the operations research and management personnel of 49 major U.S. corporations, 12 industrial consultants engaged in operations research work, and 34 academicians with operations research interests.

In 1970, Radnor and Neal surveyed 108 large U.S. corporations. This study sought to analyze the progress of operations research activities in these firms. This study is helpful in identifying the types of personnel performing and leading operations research activities, the organizational location of operations research and the project-portfolio characteristics. This study speculates that the following factors are important in encouraging operations research activities: (1) large organizations, (2) continuous process industries, and (3) capital intensive industries.[14]

In summary, all of these studies utilized samples which were known to be biased to firms utilizing operations

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[14]Michael Radnor and Rodney D. Neal, "The Progress of Management-Science Activities in Large U.S. Industrial Corporations," Operations Research, XXI, No. 2 (March-April, 1973), pp. 427-450.

research techniques. To make inferences from these studies to the universe of manufacturing organizations concerning the extent of adoption of operations research techniques would be inappropriate. These studies leave unanswered a large number of questions concerning the use of operations research techniques in manufacturing organizations.

Research Questions

Descriptive statistical analysis and tabular data displays were used to provide information to answer these five research questions:

1. What is the overall extent of usage of operations research techniques in manufacturing firms?
2. What organizational units and how many operations research personnel administer these operations research techniques in each strata of manufacturing firms?
3. What types of manufacturing problems are analyzed with operations research techniques in manufacturing firms?
4. In the opinion of the manufacturing executive in charge, what overall results have operations research personnel achieved while using operations research techniques in manufacturing firms?
5. What problems are encountered in using operations research techniques in manufacturing firms?

Hypotheses

Inferential statistical analysis was used to test eight hypotheses in this study. These are stated in the positive form as follows:

1. There is a significant relationship between the Firm Size (number of employees) Class and the extent of usage of operations research techniques in manufacturing firms.
2. There is a significant relationship between the Industry Group (investment per employee) Class and the extent of usage of operations research techniques in manufacturing firms.
3. There is a significant relationship between the Education (top manufacturing executive) Class and the extent of usage of operations research techniques in manufacturing firms.
4. There is a significant relationship between the cross effects of the Firm Size (number of employees) Class, Industry Group (investment per employee) Class and the Education (top manufacturing executive) Class, and the extent of usage of operations research techniques in manufacturing firms.
5. There is a significant relationship between the Firm Size (number of employees) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.

6. There is a significant relationship between the Industry Group (investment per employee) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.
7. There is a significant relationship between the Education (top manufacturing executive) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.
8. There is a significant relationship between the cross effects of Firm Size (number of employees) Class, Industry Group (investment per employee) Class and the Education (top manufacturing executive) Class, and the extent of usage of <u>each</u> operations research technique in manufacturing firms.

Significance and Need for the Study

Educators need to know what skills are required in today's business environment. In order for business college graduates to be socially and individually productive they must survive and develop in the present and short-term future. This requires that courses of study reflect the present and short-term future business environment's needs, particularly in Bachelor's and Master's degree programs.

One role of the university is to expand knowledge through research applicable to the future. There is no way to accurately predict the future, but predictions are vastly improved if we know where we are in the present. This study seeks to provide guidance for future academic program planning and research activity. Academic researchers in operations management need to know which operations research techniques are used more extensively and which operations research techniques need to be made more useful in today's business environment.

The writings of Grayson and Wagner emphasize the need to examine industry's use of operations research and for academicians to endeavor to bridge the gap between the university and the business environments.[15] This same cry for relevance comes from students, the business community and legislators. This study seeks to respond to these cries for relevance.

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[15]C. Jackson Grayson, Jr., "Management Science and Business Practice," Harvard Business Review, LI, No. 4 (July-August, 1973), pp. 41-48; Harvey M. Wagner, "ABC's of Operations Research," Operations Research, XIX (October, 1971), pp. 1259-81.

CHAPTER II

THE ORIGINS AND HISTORICAL DEVELOPMENT OF OPERATIONS RESEARCH-MANAGEMENT SCIENCE (OR-MS)

Operations Research-Management Science (Operations Research, Operational Research, Management Science and Decision Analysis) has been described as (1) a profession, (2) a discipline, (3) a field of study, (4) a science, and (5) a natural extension of the quantitative school of management thought.

While there is a wide divergence of opinion on the status and lineage of OR-MS, there is general agreement about the function of OR-MS, as illustrated in the following definitions:

1. A scientific approach to problem solving for executive management.[1]

2. The application of scientific methods, techniques and tools to problems involving the operation of a system so as to provide those in control of the system with optimum solutions to the problems.[2]

3. The application of a theory of the reasoning process at all group levels from world wide and national down to the individual. The prediction

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[1]Harvey M. Wagner, Principles of Management Science (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969), p. 17.

[2]C. West Churchman, Russell L. Ackoff and E. Leonard Arnoff, Introduction to Operations Research (New York: John Wiley & Sons, Inc., 1957), p. 5.

and comparison of values, effectiveness, and costs of a set of proposed alternative courses of action involving man-machine systems.[3]

4. An activity that can and does bring new attitudes, new concepts and new techniques of research into the service of management. It helps management solve complex problems and make major decisions.[4]

5. It consists of bringing the knowledge of various disciplines to bear on the study and effective solution of managerial problems. A scientific method utilizing all pertinent scientific tools for providing a quantitative basis for managerial decisions.[5]

Likewise, there is general agreement on the characteristics of Operations Research-Management Science. The characteristics most often noted are:

1. OR-MS approaches problem-solving and decision-making from the total system's perspective.
2. OR-MS is interdisciplinary; it draws on techniques from sciences such as biology, physics, chemistry, mathematics, and economics, and applies the appropriate techniques from each field to the system being studied.
3. OR-MS does not experiment with the system itself but constructs a model of the system upon which to conduct experiments.
4. Model building and mathematical manipulation provide

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[3] Randolph W. Cabell, Basic Operations Research Methods for Management (Baltimore: The Johns Hopkins Press, 1956), p. 2.

[4] Joseph F. McCloskey and Florence N. Trefethen, Operations Research Management (Baltimore: The Johns Hopkins Press, 1954), p. xi.

[5] Patrick Rivett, An Introduction to Operations Research (New York: Basic Books, Inc., 1968), p. 6.

the methodology which has been the key contribution of OR-MS.

5. The primary focus is on decision-making.
6. The electronic computer is used extensively.

The above characteristics are important in establishing the fact that OR-MS has something new to contribute to management that its predecessors did not; and foremost among those additions are the systems approach, complex interdisciplinary techniques and the electronic computer.

OR-MS is said to have started during the late 1930's in Britain, just prior to the start of World War II. Interdisciplinary teams were brought together to apply scientific methods to the problems of leaders of military organizations. However, the fact that scientific methods were employed to solve these problems is not enough to set OR-MS apart as a new field of study. Military science has long applied the scientific method to strategy and tactics, and documents on this subject can be found dating back to Thucydides and the Greek battle against the Persians.[6] One of the best known instances of the use of the scientific method in ancient history occurred in 212 B.C. when Hieron, King of Syracuse, employed Archimedes to devise a means for breaking the Roman

[6]C. West Churchman, Proceedings of the Symposium on Operations in Business and Industry--History and Prospects for Operations Research (Kansas City: Midwest Research Institute, April 8-9, 1954), p. 2.

naval siege of his city.[7] Even Napoleon made use of the scientific method when he employed scientists to conduct trajectory studies for artillery operations.

Political science may be included in the broadest definition of OR-MS as it is concerned with research. Plato's Republic presents the idea that the rulers of a state should be persons who are scientifically trained for their jobs because the administration of the state requires the highest degree of scientific training. Aristotle's Politics contains another statement on the application of the scientific method to problems confronting the executive, and Machiavelli argued in The Prince for certain scientific principles governing the executive actions of the Prince in municipalities. In the 19th century Jeremy Bentham tried to develop a science of social policy, in which he stressed the calculus of pleasure and pain. Bentham's idea was for an executive to use such a calculus in deciding the best courses of action.[8]

In the field of economics, Ricardo, Mill and later economists all tried to develop a scientific approach to problems of economics and the application of the science of economics to specific decisions made by governments and industrial executives. In addition, Frederick Taylor and

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[7]Claude S. George, Jr., The History of Management Thought (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968), p. 150.

[8]Churchman, Proceedings of the Symposium, p. 2.

his followers attempted to develop a science of industrial management.

All of these attempts to employ the scientific method occurred before the term "operations research" appeared. The first use of the term was in the late 1930's when it referred to the employment of scientific teams to study military operations. Many operations research teams subsequently were set up in military establishments both in Great Britain and in the U.S.[9]

What distinguishes operations research from these and other past and contemporary efforts to apply scientific methods to research into problems concerning the executive? Is operations research essentially different from scientific activities in military science, political science, the science of social policies or the science of industrial management? Or is operations research merely a new name for something that has been going on continuously in industry, government and other groups?

Perhaps the distinguishing characteristic which sets OR-MS apart from other attempts to apply scientific methods to research problems concerning the executive is the complex problem-solving techniques which are employed, such as the use of mathematical programming, queueing theory, inventory theory, and mathematical models. Just as Frederick Taylor

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[9] Charles D. Flagle, William H. Huggins and Robert H. Ray, Operations Research and Systems Engineering (Baltimore: The Johns Hopkins Press, 1960), p. 15.

did not invent many of the techniques which he employed, OR-MS came into existence long after many of these complex problem-solving techniques were developed. It could hardly be argued that Taylor invented time-study, for Charles Babbage in the 1830's developed great skill in employing time study, specialization of labor, and rigid investigations in production management. In addition, in the late 1800's Henry R. Towne developed a means of incentive pay which was similar to Taylor's work in piece-rate compensation.

Although OR-MS, like scientific management, may be best known for its techniques, it cannot claim the origination of the techniques which it employs. For example, A. K. Erlang had already established the basis for modern queueing theory in 1917 with his work at the Copenhagen Telephone Company. In the late 1930's when operations research began, Erlang's work formed the basis for the state of the art.[10]

Mathematical programming models were advanced by economists Quesnay (1759) and Walras (1874); more sophisticated economic models of a similar nature were proposed by Von Neuman (1937) and Kantorvich (1939). The mathematical basis for linear models was established near the turn of the 19th century by Jordan (1873), Minkowski (1896), and Farkas (1903). Innovative suggestions for economical inventory control were published by Harris in various business

[10]Thomas L. Saatz, "A. K. Erlang," Operations Research, Vol. V (April 1957), p. 293.

and industrial engineering journals during the 1920's. These models were the basis for inventory theory in the late 1930's when the concept of operations research came into existence.[11]

Thus, the origins of Operation Research-Management Science cannot be tied to the development of a set of complex techniques, for those teams which pioneered in this field during the early days of World War II merely utilized the body of knowledge in the various disciplines to attack management problems. Further development and sophistication of these techniques did not occur until after World War II, for example, the development of the second and third generation of various mathematical programming techniques such as the simplex machine, the dual method, dynamic programming, and integer programming. It is an interesting paradox that OR-MS is perhaps best known for its complex techniques but that most of these techniques were developed and used prior to the inception of OR-MS.

Although Operations Research-Management Science exhibits the characteristic of utilizing the mixed or multidiscipline team concept, OR-MS was not the first discipline to do so. Taylor had at least twelve colleagues in his metal-working studies who had various academic and experience backgrounds. Maunsel White was an accomplished metallurgist; Gantt was best known for his managerial abilities;

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[11]Wagner, Principles, p. 7.

and Carl Barth was a mathematician.[12] Although OR-MS may have developed this concept more completely, the multidiscipline team concept cannot establish OR-MS as a new discipline or field of study.

Frederick Taylor, in his approach to scientific management, developed the concept of the formation of an organization for research on operations. In fact, the organizational relationships and the organization mission of Taylor and his associates were the same in concept as those used in operations research today.[13] In this respect, then, the conclusion might be reached that OR-MS is continuing the tradition established by scientific management.

Those characteristics which tend to make OR-MS different from its predecessors are (1) the total systems approach or perspective, (2) a higher degree of development and utilization of complex, interdisciplinary techniques, and (3) the utilization of the electronic computer.

Although these characteristics differentiate OR-MS from scientific management and/or other areas of the quantitative stream of management, OR-MS can still be considered a natural extension of these previous efforts through the evolution of time and circumstances.

Scientific management emerged during the late 1800's and early 1900's after a period of great resource accumulation when production was the key problem facing industrial

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[12]Flagle, Systems Engineering, p. 17.

[13]Ibid., p. 15.

organizations. Industrial management saw scientific management as a means of solving particular organizational problems, i.e., production and the rationalization of resources which had been accumulated in an earlier period.[14] Scientific management provided industrial organizations with a means of increasing output to meet the needs of World War I, and it was popularized as a concept both in the U.S. and Europe.

At the end of the 1930's depression, renewal of resource accumulation occurred through the World War II period. This accumulation again created the need for a new resource rationalization. During the period prior to World War II in the U.S., it is difficult to identify the efforts in industry as either scientific management or operations research. Various kinds of production problems were being solved, such as stocking the proper level of inventories, scheduling production, manufacturing in economical batches, quality control, capital acquisition, and other physical resource problems.[15] During this transition period many of the techniques that were to be used later by operations research were being employed by industrial organizations. They were, however, being used in more "micro" or suboptimizing applications than those for which OR-MS groups

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[14] Daniel A. Wren, The Evaluation of Management Thought (New York: The Ronald Press Company, 1972), p. 474.

[15] Flagle, Systems Engineering, pp. 474-75.

would eventually utilize them. In other words, the concept of the total systems approach does not appear to have been utilized during this pre-World War II period.

With the advent of World War II both in the U.S. and in Europe, organizations (i.e., military, government and industrial) grew to immense proportions. These organizations were not only larger in number, but also they were attempting to solve complex problems in a more dynamic environment than had been previously experienced. The European Campaign of World War II brought into play immense quantities of resources that had to be rationalized in efficient ways in order to accomplish a specific set of objectives. It seems natural that the body of knowledge and techniques emerging from this environment would be directed in a more "macro" or systems approach. Never before had organizations faced such complex management, executive or leadership decisions. These organizational situations created the need for a problem-solving approach aimed at solving top management's problems (i.e., top of the organizational perspective). Because of this complexity, interdisciplinary teams were formed that utilized many of the disciplines in existence at that time. The concept of the total systems approach and the interdisciplinary utilization of complex mathematical techniques evolved as a result of these conditions. Thus, the hectic and chaotic conditions existing in the huge organizations involved in World War II prompted the need for and development of Operations Research-Management Science.

It should be noted that there were early attempts at operations research during World War I, in which military operations on both sides of the Atlantic were analyzed mathematically. In England this work was undertaken as a hobby by F. W. Lanchester, whose papers on the relationship of victory, numerical superiority, and the superiority of firepower appeared in 1914 and 1915. His efforts to express military operations as equations, however, had no effect on the operations in World War I. In America Thomas Edison made studies of antisubmarine warfare for the Naval Consultant Board. His work included the compilation of statistics to be used in determining the best methods for evading and destroying submarines, the use of a tactical game board for avoiding submarine attack and an analysis of the value of "zig-zagging" as a method of protecting merchant shipping. Like Lanchester's work, Edison's studies had no actual effect on operations but were a prelude to similar work in World War II.[16]

The World War II Period

British Operational Research

At the outbreak of the war in 1939, there was already a nucleus of a British operational research

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[16] McCloskey, Operations Research for Management, p. 5.

organization in existence at Bawdsey Research Station under the direction of A. P. Rowe. The Bawdsey Research Station was employing groups of physical scientists to study the interference of radio reception by low-flying aircraft. It was found that this was due to the reflection of radio waves from the aircraft, and this discovery led to the applied research which resulted in the development of radar. It was then this group's task to train military personnel in the operational use of radar, and these trainees were called Radar Operational Research Teams to distinguish them from the Radar Research Team from which they had stemmed. In time the word "radar" was dropped, and "operational research" remained.[17]

The study and operational use of radar evolved into a project which attempted to integrate the developing early warning system against enemy air attack with the older system of operational control based principally on observer corps whose members were trained in the sighting, identification, and reporting of planes. This latter study, which occurred just prior to the war, involved the total efficiency of the communications system and examined it from the position of the executive officer responsible for the entire control network. This first development of the systems approach became a distinguishing characteristic of

[17] Patrick Rivett, An Introduction to Operations Research (New York: Basic Books, Inc., 1968), pp. 5-6.

operational research.

Royal Air Force

The Bawdsey Research Station, later called the Tele-Communications Research Establishment, sent a small group of scientists under the leadership of Mr. H. Larnder, Dr. E. C. Williams, and Mr. G. A. Roberts to form a research section at the headquarters of the Royal Air Force Fighter Command at Stanmore when the war began. It was this group, under the direction of Wing Commander R. Hart, who conducted an extended comprehensive analysis of all phases of night operations, and the report which resulted became the pattern on which other operational research sections based their analysis of operations. Thus, the RAF was a forerunner in the use of operational research in Britain during World War II.[18]

British Army

In August 1940 General Pile, Commander-in-Chief of the Anti-aircraft Command, requested assistance from higher command in solving problems with newly installed radar equipment at gun sites. This equipment gave the slant, range and bearing of an attacking bomber and possessed some newly developed apparatus which provided a reading for its elevation. Professor P.M.S. Blackett of the University of Manchester, a Fellow of the Royal Society, a Nobel Laureate

[18] McCloskey, Operations Research for Management, p. 6.

and formerly a naval officer, was recommended to study the problem. The new equipment did not perform on the gun sites as it did at the testing stations, a discrepancy which indicated the need for extensive on-site observation during actual operations. For this work Blackett collected men who were scientifically trained but who were not necessarily radar specialists. The anti-aircraft command research group which he assembled included three physiologists, two mathematical physicists, one astrophysicist, one army officer, one surveyor, one general physicist and two mathematicians. "Blackett's Circus," as the group was called, was soon able to demonstrate the value of the mixed-team approach to operational problems.[19]

Blackett is probably the earliest name associated with the literature of operational research. His two papers, "Scientists at the Operational Level" (1941) and "A Note on Certain Aspects of the Methodology of Operational Research" (1943), were published as an addendum to his article, "Operational Research," which appeared in the Advancement of Science in 1948.[20]

In May 1941 the Coastal Command Research Group became known as the Operational Research Group of the Air Defense Research and Development Establishment (Ministry of Supply). They later became a separate establishment known as the Army Operational Research Group.

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[19] Ibid.

[20] P. M. S. Blackett, "Operational Research," Advancement of Science, V, No. 17 (April, 1948), pp. 114-136.

British Navy

In March 1941 Blackett and members of his group moved from the Anti-aircraft Command to the Coastal Command. They became involved in problems concerning the detection of ships and submarines by the use of radar equipment in airplanes. This type of investigation brought Blackett close to the Admiralty's antisubmarine warfare problems, and in December 1941 he became Director of the Naval Operational Research at the Admiralty. He was replaced at Coastal Command by E. J. Williams.

Thus, after the beginning of the war, all three of Britain's military services formally established operational research groups. Later in the war, similar groups were organized in Canada and Australia.[21]

Civilian Defense

Civilian defense activities also had the benefits of operational research analysis. J. D. Bernal, as a member of the Ministry of Home Securities and the Civil Defense Research Committee at Prince's Risborough, began a comprehensive collection and analysis of damage statistics during the period when Britain was experiencing heavy bombing. The group assembled for this work included several Americans who later became involved in operations analysis for the U.S. Air Force.[22]

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[21] *Ibid.*, p. 7.

[22] *Ibid.*

Scope of Operational Research

The number of persons engaged in the various British operational research activities continued to increase throughout the course of the war. For example, in 1942 the Army set itself the goal of eventually placing 36 officers in research units in the combat theaters; by the end of the war, however, some 120 officers had been attached to these sections. Before V-E Day a total of 365 scientists had engaged in operational research for the British Army.[23]

Examples of Operational Research

During the winter of 1941-42, a project under the direction of E. J. Williams of the Coastal Command was conducted with the goal of improving antisubmarine actions. Investigations showed that depth charges were being set to explode at 100 feet while only on rare occasions did an enemy sub reach the danger depth in time for detonation. After extensive studies Professor Williams recommended that charges be set to explode at 20 to 25 feet. The magnitude of increase in the destruction of submarines was estimated at 400 percent by the Royal Navy and 700 percent by the RAF. So many enemy submarines were destroyed that German crews were reporting that new and more powerful bombs were being used against them.

In 1942 the Admiralty wanted information about the size of merchant convoys which would be most effective in

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[23] *Ibid.*, p. 8.

terms of both minimum losses from submarine action and a minimum of escort requirements. It was suggested that more escort protection would reduce losses, but neither planes nor additional escort vessels were available. Therefore, the only variable with which the research team could experiment was the size of the convoy. The result of the study was a recommendation that the size of the convoy be substantially increased; subsequently, shipping losses were significantly reduced.

The Fighter Command conducted research activities in the detection of enemy aircraft and was highly successful. It was estimated that the introduction of radar increased the probability of intercepting enemy aircraft by a factor of ten; in addition, the small operational research teams' efforts increased the probability by a factor of two.[24]

It is obvious from the previous examples that British operational research was originally developed to improve defensive operations since at that time the government was faced with the problem of effectively using relatively small numbers of men and machines to withstand the superior forces of the enemy. As the war progressed, however, the data collected and the techniques employed in solving problems related to defense were used for increasing

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[24]*Ibid.*, p. 10.

the effectiveness of offensive actions against the enemy. For example, the information gained from the study of convoy losses contributed directly to the strategy of employing larger plane formations in the bombing raids over Germany which, in turn, resulted in a smaller percentage of losses. These findings resulted in the first 1,000-plane RAF raid over Germany in 1942.[25]

The total systems approach to problem solving necessitated the study of additional operationally related problems and was probably the one achievement which most clearly distinguished World War II operational research from earlier research activities.[26] Mr. G. A. Roberts of the Bawdsey Research Station, Tele-Communications Research Establishment, and later a member of the Operational Research Group at Fighter Command, the RAF Command at Stanmore, was largely responsible for this expanded approach in England. He was asked to solve a radar problem primarily because of his experience in communications. In the process of the problem's solution, however, he went far beyond the limits of communications and into many other aspects of the operation of the warning network.

In the latter stages of the war, the various military operational research groups were organized into both field units and central office units. The purpose of the central

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[25] *Ibid.*

[26] *Ibid.*, p. 11.

office unit was to maintain contact with such administrative centers as the War Office and the Ministry of Supply, to serve as a planning and data processing headquarters and to act as a training and recruiting depot. The field units were to attach themselves to operating elements in order to make those direct observations and measurements essential to the thorough study of operational problems.[27]

Operations Research in the United States

Britain had been at war two years before the U.S. became involved in the conflict. The British activities in operations research from 1939 to 1941 had a profound impact on the establishment and development of operations research sections by the U.S. military establishment, which is evidenced by the almost universal adoption of the term "operations research," derived from the British use of the term "operational research" during the period.

Two Americans, Dr. James B. Conant and Dr. Vannevar Bush, were instrumental in the development of operations research in the U.S. during World War II. Dr. Conant was Chairman of the National Defense Research Committee and Dr. Bush was Chairman of the Committee on New Weapons and Equipment of the Joint Chiefs-of-Staff. These men had observed such groups in England in 1940 and 1942, respectively.[28]

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[27] Ibid., p. 10.

[28] George, History, p. 154.

Navy

In 1941 Dr. Ellis A. Johnson, head of the countermeasures section of the Naval Ordinance Laboratory (NOL), established a group composed of some 50 senior members of mine warfare--strategic, tactical and technological. This group used the techniques of game theory to develop models of alternative operations and then "tested" various tactics and weapons.[29] These studies involving mine warfare were apparently successful enough to warrant the establishment of the NOL Operational Research Group on March 1, 1942. Initially, Dr. Walter Michels headed the group and was assisted by Dr. Thorton L. Page and Dr. Lawrence E. Hoisington. During the war the group was transferred to the Bureau of Ordinance and then to the Office of the Chief of Naval Operations. Dr. Francis Bitter, Dr. John Von Neumann and Dr. J. L. Doob were among those who served with this organization.[30] This group directed the aerial mining of the Japanese-controlled waters from Singapore to the home islands. Approximately 5.7 percent of the 21st Bomber Command's effort was devoted to mining the home islands, and this effort is estimated to have been comparable to the high explosive and incendiary bombings that accounted for the remainder of the Command's effort. Japanese industrialists

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[29] McCloskey, Operations Research for Management, p. 15.

[30] Ibid.

are reported to have told the military that the economic strangulation brought about by the mines made the war effort impossible to be supported.[31]

The work done by the NOL Group in offensive mine warfare was the high-water mark in American operations research during the World War II period. This project deserves special attention, because the project was not only concerned with achieving optimum results with existing systems and equipment, but the results that were expected from adopting proposed courses of action were precisely predicted in advance. These predictions were then used as guidelines for the development of future strategies, tactics, and weapons. The predictive nature of this project greatly influenced future operations research studies.[32]

In April 1942 during the early days of intensified antisubmarine warfare, the Commanding Officer of the Atlantic Fleet Antisubmarine Warfare Unit asked the coordinator of research and development to form a group to analyze the antisubmarine operations. This request was forwarded to the National Defense Research Committee, and on May 1, 1942, a group of seven researchers, recruited by Columbia University, was formed with Dr. Phillip M. Morse of M.I.T. as the leader. "This unit set about immediately to analyze sea and air attacks against German U-boats and to study means for

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[31]Ibid., p. 14.

[32]Ibid., p. 17.

improving the efficiency of both the Navy and Army forces engaged in these operations."[33]

In July 1943 the group under the direction of Morse, with approximately 40 operations researchers, was transferred to the staff of the Tenth Fleet as the Anti-submarine Warfare Operations Research Group. In 1944 it was transferred to the Readiness Division of the CominCh Headquarters and renamed Operations Research Group.

> At the war's end, the group consisted of 73 scientists who represented a diversity of backgrounds. They functioned as a single, coherent, central unit attached to the top operational command in Washington; at any time, however, from one fourth to one third of the men were on rotation in the field, attached to Theater Fleet or Sea Frontier Commanders.[34]

(This group was known as the Operations Evaluation Group after the war.)

Army Air Force

Just as in Britain, the American operations research activities for the Air Force grew up around problems arising from new radar equipment. There were many parallel factors or events which were occurring simultaneously within the Air Force that eventually culminated in the establishment of operations analysis groups. Some of these were:

1. Secretary of War Stimson traveled to Panama to inspect the air radar defenses. While he was in Panama, General Andrews suggested to him that a

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[33] *Ibid.*, p. 14.

[34] *Ibid.*

group of civilian analysts might be of value in coordinating radar equipment with other defenses of the Canal Zone; shortly thereafter several scientists were dispatched to Panama.

2. As a result of Vannevar Bush's description of operational research teams with the RAF, two scientists, Dr. Ward S. Davidson and Major W. B. Leach, were asked by the Committee on New Weapons and Equipment, of which Dr. Bush was chairman, to investigate the situation in Britain and any similar activities within the U.S. War and Navy Departments. They submitted their report on August 15, 1942.

3. In late 1941 or early 1942, General Eaker put in a request to General Spaatz, Commanding General of the Eighth Air Force stationed in England, to establish an operation analysis group. General Spaatz passed on the request to General Arnold, Commanding General of the Air Force.[35]

As a result of these and other events, General Arnold dispatched a letter to all Commanding Generals of the Air Force recommending that they include operations research teams in their staffs. There is further evidence that other requests for establishing operations research teams had previously been submitted since the October 1942 letter from General Arnold produced favorable responses from several commands which indicated that they had earlier requested the assignment of such sections.[36]

The first of the operations research sections was established in October 1942 and was attached to the Eighth Bomber Command in England (later designated as the Eighth Air Force). It served as a prototype for similar groups

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[35] Ibid., p. 12.

[36] Ibid., p. 13.

attached to other commands.

> By V-J Day a total of 26 Operations Analysis Groups had been established at Air Force Headquarters, including every combat air force and a number of ZI headquarters. Some 400 officers, enlisted men, analysts and civilians on loan from other agencies engaged in operations research for the Air Force for the course of the war.[37]

The average Operations Analysis Section consisted of about ten analysts working on the problems of the command to which the section was attached.

On December 31, 1942, Leach, now a Colonel, established the Operations Analysis Division reporting to Brigadier General Byron E. Gates (on the Air Staff) of the Office of Management Control. The Operations Analysis Division of Washington served largely as a training and recruiting headquarters in support of the Field Operations Research Group.[38]

Army Ground Forces

The Army Ground Forces did not make as much use of operations research as the Air Force or the Navy, but by the end of the war they did have a few evaluation groups who were using similar techniques in their operations in the Pacific. In late 1943 after learning of the accomplishments of operations research groups in the Air Force, General George Marshall sent a message to all Theater Commanders suggesting that similar analysis teams be formed to study

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[37] *Ibid.*

[38] *Ibid.*, p. 17.

amphibious and ground operations.[39]

Examples of Operations Research

The Navy's Operations Research Group conducted studies which enabled a pattern of planned, controlled search operations to be substituted for the more general "catch-as-can" searching activity which was previously used. This revised method allowed the number of search planes required to patrol a given area to be reduced while the area was more thoroughly covered. In January 1944 this new patrol system was used in the South Atlantic, and the subsequent seizure of enemy ships and their cargoes of raw materials was a valuable gain for the allies.

During the last months of the Pacific War, allied ships were being exposed to Kamikaze attacks. Commanders could not decide whether a ship under attack should maneuver violently to avoid being hit or keep straight to better aim with its anti-aircraft guns. Through extensive investigation the Navy's Operations Research Group concluded that a large ship should maneuver violently but that a small ship should change course slowly. Those ships under attack that observed the recommendations of the operations research group were hit 29 percent of the time while other ships were hit 47 percent of the time.

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[39] Ibid.

The Operations Analysis Section attached to the Fifteenth Air Force in Bari, Italy, studied the problem of destroying the Vienna-Lobau underground oil storage depot. Intelligence reports indicated that the oil storage was invulnerable since it was covered by seven feet of concrete and ten feet of earth. The Operations Analysis Section concluded that it was not feasible, from an engineering standpoint, to have that extent of concrete protection. Reconnaissance photographs were carefully pieced together, and with the use of other intelligence information, it was conceived that there was no concrete protection whatsoever. The Operations Analysis Group recommended the type of bomb and the bombing pattern with which to attack the Vienna-Lobau storage depot.

The Operations Analysis Section (OAS), Eighth Bomber Command and later the Eighth Air Force in England, was the first OAS Group in the Air Force, and it was probably the most successful, at least in terms of publicity. "The bombing-accuracy studies alone did much both to insure the success of the aerial campaign against Germany and to enlarge the scope of the Operations Research Method."[40] During 1943 and 1944 a three-man team of William J. Youden, Phillip C. Scott and James A. Clarkson developed a plan

[40]*Ibid.*, p. 19.

utilizing B-17's equipped with Norden bomb sights, which improved the accuracy of placing bombs within 1,000 feet of the aiming point by 300 percent. Their plan called for each individual bomber to sight on the group leaders instead of the squadron leader or for individual bombers to sight on the target.[41]

World War II Period Summary

There is no way of knowing or measuring the total impact that operations research had upon the Allies' final victory in World War II. It is interesting to note, however, that operations research was peculiar to the Allies and seems to have had no counterpart within the organization of the enemy forces. "It presented, in effect, a view of war that was antithetical to Hitler's, bringing measurement, control and analysis of complex operations into play against the more romantic and 'inspired' moves of the Axis forces."[42]

Postwar Operations Research Developments 1945-Present

Postwar operations research developments can be categorized as follows: (1) electronic computer development, (2) military operations research, and (3) nonmilitary operations research.

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[41] *Ibid.*

[42] *Ibid.*, p. 20.

Electronic Computer Development

It must be remembered that the glowing examples of operations research during World War II were accomplished without the aid of electronic computers. Many of the OR efforts of the military during World War II now appear very rudimentary in their methods of solution, but when it is noted that they lacked present-day data processing capability, those accomplishments become much more respectable.

In the 1830's Charles Babbage developed the concept of the digital computer, but it was not until 1937 that Howard Aiken of Harvard actually designed and built a machine that could prepare mathematical tables by automatically performing a set of arithmetic equations. The machine was mechanical instead of electronic, and the program of instructions consisted of switch-settings, wire controlled boards and punched paper tape. Data were represented by patterns of open and closed mechanical relays. The Mark I, as it was called, was completed in 1944 and is historically important because it was the immediate predecessor of the electronic computer and contained many features of operation now associated with computers, such as pre-established programs.[43]

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[43]Gordon B. Davis, Computer Data Processing (New York: McGraw-Hill Book Company, 1969), p. 62.

ENIAC

The ENIAC (Electronic Numerical Integrater and Calculator), designed by J. Presper Eckert and John W. Mauchly of the Moore School of Engineering at the University of Pennsylvania, was an electronic version of the Mark I. The ENIAC was completed in 1945 and used electronic components instead of mechanical relays and was therefore much faster than the Mark I. It was programmed by switches, used plug-in connections and electronic components and was used mainly for calculating mathematical tables.[44] The ENIAC is often identified as the first electronic computer.

Edvac, Edsac and IAS

After the Eniac many research laboratories, most of them connected with universities, began to construct computers. One of the most active of these research groups continued to be the Moore School of Engineering. Eckert and Mauchly designed the EDVAC (Electronic, Discrete, Variable, Automatic Computer), which differed from the ENIAC in two ways: the use of binary numbers and the internal storage of instructions written in digital form. Because completion of the EDVAC was delayed until 1952, another computer, the EDSAC, built at the University of Manchester in England, became the first stored program electronic computer.

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[44]*Ibid.*, p. 63.

John Von Neumann, a mathematician at the Institute for Advanced Studies at Princeton University, participated in a joint project with Eckert and Mauchly of the Moore School to construct the IAS computer (named for the Institute for Ad vanced Studies). The IAS, completed in 1952, is historically important because of the innovations in its design. The binary system and parallel arithmetic were utilized which provided the basis for subsequent parallel binary computers. The EDVAC, on the other hand, is the prototype of serial computers.[45]

UNIVAC I

The UNIVAC I (Universal Automatic Computer) is historically important because it was the first commercially available computer. The UNIVAC I was built by the Ekert and Mauchly Computer Company, founded in 1946 by J. Presper Ekert and J. W. Mauchly. The company was purchased by Remington Rand in 1949 and subsequently became the UNIVAC Division of the Sperry Rand Corporation.

The first UNIVAC I computer was installed at the U.S. Bureau of Census in 1951. In 1964 this UNIVAC was given to the Smithsonian Institute for its historical value, indicating the importance of the obsolescence factor in computer models. The first business use of the computer was in 1954 at the General Electric Appliance Park in Louisville, Kentucky. The successful use of computers in business opened an entirely

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[45] Ibid.

new field and became an important factor in the growth of the computer industry.[46]

Computers Since the UNIVAC I

All computers built during the period between 1951 and 1959 are referred to as "first-generation" computers. The characteristic which differentiates them from later models is the fact that they utilized vacuum tubes. International Business Machines Corporation (IBM) entered the computer business with the IBM 701 in 1953. Late in 1954 IBM installed the first of the IBM 650 Computers. This small to medium capacity computer was the most popular during the period of 1954 to 1959. It is interesting to note that although IBM was a latecomer into the computer market, it dominated the computer field during this 1954-1959 period by servicing more than two-thirds of the market.[47]

"Second-generation" computers are identified by the use of transistors instead of vacuum tubes. The transistor is smaller, less expensive, generates almost no heat, and requires little power. Consequently, "second-generation" computers were substantially reduced in size, required less power, needed little or no air-conditioning, and were more reliable than the "first-generation" equipment. The popular "second-generation" computers were the

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[46] Ibid.

[47] Ibid., p. 64.

IBM small to medium capacity, business-oriented 1401 Computer; and the small, scientific-oriented 1620 Computer. IBM's 7090-7094 series dominated the large-scale computer market.[48]

The "third generation" of computers is characterized by miniaturized circuits, the integration of hardware and software (programming and operating aids), an orientation to data communication, and the handling of more than one operation simultaneously. The speeds of the "third-generation" equipment are faster, and the prices are generally lower. The transition to "third-generation" computers began in 1963-1964, but the major transition was in 1965 when IBM began deliveries of its "third-generation" System/360.[49]

The computer industry is still in the "third-generation" stage of manufacturing computers. The more recent developments primarily involve the availability of computer service to almost any customer at a reasonable price. Since the use of the first computer in a business in Louisville, Kentucky, in 1954, installations have increased at an increasing rate.

Colleges and universities throughout the U.S. have incorporated in their curricula computer science courses which include computer languages, computer systems operation,

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[48] Ibid.

[49] Ibid.

and the applications of computers. Consequently, many employees have a background in computers when they are hired. It is not surprising that these employees are more comfortable with the computer, tend to use the computer more, and aid in expanding the applications of the computer in business. There is evidence that top executives today are closely tied to the computer center in their organization.[50]

If the use of computers in operations research is traced historically, it is evident that there has been a time lag between the general acceptance of computers in business and the actual use of computers in performing operations research studies. In general, computers were reasonably common in industrial organizations by the late 1950's and early 1960's. It is estimated that the average company uses a computer for five years before any extensive operations research studies are conducted utilizing the equipment. Thus, it is estimated that computer usage in operations research was a significant factor from about 1965 to the present.[51] It is also interesting to note that companies which have computer centers and operations research sections are using their computers for operations

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[50] N. J. Dean, "Computer Comes of Age," Harvard Business Review, Vol. XLVI (January, 1968), p. 84.

[51] Ibid., p. 89.

research increasingly as a percentage of total computer time.[52]

The impact of computers on operations research is immeasurable. This development made possible studies which were previously infeasible because of the sheer magnitude of the manual calculations. In addition, mathematical models emerged as "the" methodology to be used in operations research. Although during World War II many experiments were carried out literally utilizing the operation being studied, today this approach is almost nonexistent. The advent of computerized operations research models provided an economical means of experimenting with mathematical models which simulate the "real world" situation. When fast answers were required in the past, the operations research approach was infeasible because of the long timelag required for the systematic analysis. However, the computer significantly reduces the time involved in these studies so that new applications of operations research are possible.

In addition, computers have made the education of the operations researchers more streamlined. For example, it is no longer absolutely necessary that each operations research trainee know the intricate details of the various OR-MS techniques because there are numerous "canned" programs which perform the required calculations,

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[52] Ibid.

such as the standard programs available for linear programming problems. The computer facilitated the use of technicians to manipulate computer programs rather than the employment of teams of Ph.D.'s, such as those utilized during World War II.

Military Operations Research

At the end of the war military operations research groups on both sides of the Atlantic were flourishing. Operations research activity was considered to be so valuable by the military leaders that such functions were not discontinued at the end of the war.[53] Both British and American Armed Forces, however, were faced with the problem of providing for the continuation of operations research.

Britain

There is evidence that as early as 1942 the British Army was considering postwar plans for operational research. At the meeting of the Weapons Development Committee in August 1942 Sir Charles Darwin suggested that suitable officers be drawn from engineering services and thoroughly trained so that they might form a nucleus for later operational research work in the Army. Such a pool was established, and a comprehensive training program was conducted throughout the balance of the war in the Army's six wartime

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[53]George, History, p. 154.

Operational Research Sections (ORS).

In November 1945 the War Offices' Military Operational Research Unit was functioning with the Ministry of Supplies' Army Operational Research Group, which was composed predominantly of civilian scientists. These groups eventually were consolidated as the Army Operations Research Group (A.O.R.G.). Thus, the British had executed a plan which systematically transformed the operational research units from wartime to peacetime organizations.

Most of the postwar operational research activities of the British military are under tight security classification, and very little information is available. One interesting trend, however, is the increasing emphasis on men as opposed to the past emphasis on machines. This may indicate that operations research is continuing to expand its horizons in terms of the systems approach in recognizing the larger man-machine system.[54]

United States

The 1947 Security Act indicated the need for an impartial evaluation of weapons and weapons systems at the level of the Joint-Chiefs-of-Staff. Both the Hoover Commission and a special committee appointed by Secretary Forrestal recommended the establishment of a body which

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[54] McCloskey, Operations Research for Management, p. 21.

would perform this function. In the directive, dated December 11, 1948, Forrestal authorized the Weapons System Evaluation Group (WSEG), which was to serve the Joint-Chiefs-of-Staff. Shortly thereafter, Lt. General John E. Hull, Commanding General of the U.S. Army, Pacific, and overall Commander for the Eniwetok, atomic bomb tests, was appointed director of the new group. Dr. Phillip Morse was its first technical director. The staff was composed of Armed Services officers, civilian scientists, and other technicians. WSEG received reports developed by the Army, Air Force, and Navy Operations Research Groups and endeavored to work toward total system optimization.[55]

Navy

The Navy's Operations Research Group under the direction of Phillip M. Morse received approval from the Secretary of Navy to continue the organization after the war. In 1947 it became the Operations Evaluations Group (OEG); Morse (M.I.T.) continued as its director, and his responsibilities were outlined in a contract drawn up between the Office of Naval Research and M.I.T. The group is still in existence and includes about 50 scientists who advise the staff of the Chief of Naval Operations and various field commands, such as those in Hawaii, Tokyo and the Mediterranean. Their mission is to conduct research in

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[55]*Ibid*.

antisubmarine warfare, guided missiles, radar and atomic energy warfare.[56]

Air Force

In October 1946 operations analysis in the peacetime Air Forces was established by a regulation which authorized an Operations Analysis Section (OAS) to each command in which the commanding general desired one. After the establishment of the U.S. Air Force as a separate service, operations analysis underwent various organizational changes. The centralized organization for operations research in the Air Force became the Operations Analysis Division (OAD) within the Office of the Deputy Chief of Staff/Operations. In addition, various Operations Analysis Section (OAS) offices were assigned to many Air Force Commands.[57]

In 1946 General Arnold, Commanding General of the U.S. Air Force, sensed the need for an organization which would provide scientific assistance in formulating Air Force decisions with respect to research and development. Donald Douglas of Douglas Aircraft was engaged to manage Project RAND (Research and Development), and the Air Force provided $10 million to finance this project. The original nucleus of the staff was drawn from industry but was soon

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[56] Ibid.

[57] Ibid.

augmented by academic research people who were first physical scientists and later social scientists. "Postwar operations research for the Air Force was, from the beginning, more closely allied to industrial than were operations research activities for the other services, possibly because the Air Force is unique among the services in having most of its procurement problems concentrated within one industry.[58]

Army

In April 1948 Major General McAuliffe, the Army's Deputy Director of Logistics for Research and Development, selected the Johns Hopkins University to administer a research group performing operations research activities. In September 1948 the General Research Office (GRO) was established at Fort Leslie J. McNair, Washington, D.C., with Ellis A. Johnson as Director. Three months later GRO was renamed Operations Research Office (ORO), and in 1951 ORO moved to the former Chevy Chase Jr. College in Chevy Chase, Maryland.[59]

In summary, the Army and Navy each have under contract a research group administered by a university plus operations research groups at central headquarters and field offices. The Air Force is served by the Operations

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[58] Ibid., p. 22.

[59] Ibid., p. 23.

Analysis Division (OAD) at headquarters. The Operations Analysis Office (OAO) is attached to various Air Force Commands, and the RAND Project reports to the Deputy Chief-of-Staff/Development. In addition, the Joint Chiefs-of-Staff have a research group of civilian scientists and military officers (WSEG) to conduct the same sort of analysis used by the services, which is applied to inter-service problems and leads toward the formulation of coordinated plans for war.

Examples of Operations Research

Much of the operations research activity which took place in the United States shortly after the war until the early 1950's was concerned with documenting the data gathered in Europe and Asia during the World War II period. The goal of this activity was to develop source data that could be used in models to predict American performance in future hypothetical wars. World War II data, however, became less and less useful with the passage of time and the development of newer weapons systems.

Much of the activity involving operations research within the various military branches is under tight security, particularly the activities which have occurred in recent times. Some information is available, however, on activities during the Korean War, for example:

1. The Operations Analysis Section of the Fifth Air Force worked on the selection of targets and weapons. They examined the effectiveness of attacks and suggested improvements in operations. They also predicted the success of untried equipment in combat prior to the Korean hostilities.[60]
2. The RAND Corporation (the RAND project eventually became the RAND Corporation, a nonprofit organization) conducted cost-effectiveness studies involving various bombing systems for the Air Force during the Korean Conflict. These studies continued past the Korean Conflict and involved future weapons, tactics, and strategies. Factors such as the social effects of bombing the enemy, Russian capabilities, and particularly the prediction of future capabilities were taken into account. The emphasis on human factors in military operations resulted in bringing social scientists into the operations research activity. The RAND Corporation and the Operations Research Office (ORO) also have utilized psychologists, social scientists, economists, political scientists, and anthropologists.[61]
3. A Navy Operations Evaluations Group (OEG-M.I.T.) conducted studies during the Korean Conflict of seaports

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[60] _Ibid._, p. 25.

[61] _Ibid._, p. 26.

heavily taxed by the demands of war. These studies revealed that a large system could operate closer to its capacity before running into the risk of tie-ups than a small system. The research results indicated that it was possible to predict the length of time that a given seaport would be tied up.[62]

4. The flight logs and photographic histories of hundreds of airplane fights, many of which included hits from anti-aircraft fire in dog fights with enemy planes, were subjected to analysis so that less vulnerable planes could be designed and so that pilots could learn where to expect the most danger to themselves and how to do the most damage to enemy planes.[63]

5. The Army's Operations Research Offices (ORO) conducted studies to discover ways in which the Air Force could do the most damage to enemy front-line infantry troops. The results of these studies indicated the desirability of having strategic bombers (B-29's) take on the job of tactical bombing as close air support for infantry operations.[64]

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[62] Ibid.

[63] Ibid.

[64] Ibid., p. 27.

Although it is undocumented, WSEG is said to have conducted studies involving a historical analysis beginning with B-17 and B-29 bombing data from World War II up to present planes in order to form a comprehensive study of strategic bombing, which resulted in predicting results from various strategic bombing programs and weapons systems.[65]

Although military security has attempted to prevent public knowledge of the activities of WSEG since it was established in 1948, military operations research organizations are still in existence and appear to be functioning at a high level of activity.

Nonmilitary Operations Research

At the end of the war, the economic climate in America and Britain was favorable for the introduction of operations research into the private sectors. Some of the secrecy previously associated with military applications of operations research was beginning to disappear; military personnel involved in operations research activities were being released to the private sector; and industry needed to revamp production organizations back to peacetime

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[65] *Ibid.*

needs quickly.

The mathematicians and physicists who had worked on operational problems during the war began to develop mathematical solutions for extremely complex problems in industry. Once the war was over, many of these men began work in nonmilitary operations research, bringing with them both their wartime experience and their highly specialized mathematical abilities.

In Britain the nationalization of basic industries provided an opportunity for experimentation with operations research techniques in industries as a whole. Today operations research groups exist in Britain for the iron and steel, coal, road and rail transport, textile, agriculture, brickmaking, and shoe industries, with most but not all under civil service sponsorship.[66]

In the U.S. the application of OR-MS techniques to business operations was somewhat slower. Although it is likely that a limited amount of operations research had already been conducted in industry by management consultants, specialists in quality control, time and motion experts, marketing analysts, design engineers, and industrial engineers, most executives simply did not know how to use operations research techniques. The competitive factor decreased the exchange of information between companies because each individual company did not want to aid

[66]George, <u>History</u>, p. 155.

a competitor by releasing results of OR-MS studies. In Britain this problem was reduced to some degree because of nationalization.[67]

Pre-World War II private sector operations research activity in Britain was practically nonexistent. In general, postwar nonmilitary operations research in Britain came directly from wartime experience and did not stem from related business activity of prewar years.[68] The American industrial manager, however, probably had previous experience with management consultants and efficiency experts of all types and was reluctant to accept another "form of Industrial Engineering." Because of this resistance, American nonmilitary operations research got off to a slow start after the war.

About two dozen firms were drawn into the operations research activity by undertaking operations research contracts for military departments, and several business enterprises, including such large companies as the U.S. Rubber Company and the Sun Oil Company, established their own groups.[69] During the next decade a series of events occurred which proved to be crucial in the development and expansion of private sector OR-MS activities. These were:

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[67] Ibid., p. 156.

[68] McCloskey, Operations Research for Management, p. 30.

[69] Ibid.

1. The introduction of Operations Research-Management Science in colleges and universities.
2. The development of consulting firms in Operations Research-Management Science.
3. The formation of Operations Research-Management Science societies.
4. The organization of conferences on Operations Research-Management Science.

OR-MS in Colleges and Universities

In 1948 the Massachusetts Institute of Technology (M.I.T.) established the first course in nonmilitary applications of operations research, and in the spring of 1952, Columbia University presented its first course in operations research.[70] These early efforts were largely exploratory because the status of operations research in relation to other disciplines was in dispute. The Case Institute of Technology was the first institution of higher learning to offer a curriculum in operations research, which led to the degree of Master of Science. This development of the operations research curriculum at U.S. colleges and universities has not been duplicated in Great Britain. Courses and seminars have been offered in British universities, such as those at University College, London, in the autumn of 1949 and at Birmingham University in July 1950, but there is no

[70]George, History, p. 156.

counterpart of the advanced degree programs offered by institutions such as Case, M.I.T., Michigan, Johns Hopkins, Stanford and others.

The interest in developing curricula in operations research has become controversial at several colleges and universities. Some regard operations research as a new discipline for which a specialized course of training can and should be developed; others prefer a combination of existing disciplines and recommend specialized training in one branch of science or mathematics supplemented by operations research indoctrination.[71] In any event, U.S. colleges and universities have been instrumental in preparing college graduates in operations research techniques and applications and in conducting research which has extended the theoretical base of the operations research techniques.

Consulting Firms in OR-MS

Because of the strength of operations research groups in Great Britain shortly after the war, the civil service nature of the groups and the cross-fertilization of ideas between and within industries, there was much less development of consulting firms in Britain than in the U.S. In the U.S. such firms as Arthur D. Little, Inc., Booz, Allen and Hamilton, and Haskins and Sells were

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[71] Ibid.

instrumental in bringing the knowledge of operations research techniques and applications to large American industries.[72] Through the efforts of these firms, many OR-MS departments were organized in the various client companies.

OR-MS Societies

In order to provide a clearinghouse for the exchange of information, operations research societies were established both in Britain and the United States. In April 1948 a few scientists in London who had been active in operational research during the war years formed the Operational Research Club, now known as the Operational Research Society. This society publishes the Operational Research Quarterly, which was the first periodical in the field.[73]

In 1949 the National Research Council formed a committee on operations research with Dr. Horace C. Levinson as Chairman. The purpose of the committee was to foster interest in nonmilitary operations research and to disseminate information about it. In April 1951 the committee published Operations Research with Special Reference to Non-Military Applications, which briefly described operations research, its problems, and its personnel requirements.

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[72]Flagle, Systems Engineering, p. 21.

[73]McCloskey, Operations Research for Management, p. 34.

At Columbia University in May 1950, the Operations Research Society of America was formally established, with its own constitution and officers and with Dr. Phillip M. Morse as President. The Society began publishing the Journal of the Operations Research Society of America in November 1952.[74] At a meeting at Columbia University in December 1953, The Institute of Management Sciences (TIMS) was formally organized. This society began publishing the Journal of Management Science in January 1955.

A great deal of credit must go to these societies for extending Operations Research-Management Science, for without this outlet much of the second- and third-generation improvements in the OR-MS techniques could not have been published. The publication of articles, the interpretation of results, and the exchange of information between universities and industries has accelerated the extension of the state of the art in Operations Research-Management Science techniques.[75]

Conferences in OR-MS

During the late 1940's and early 1950's various conferences were conducted in this country and Europe which resulted in the exchange of information on Operations

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[74] *Ibid.*, p. 35.

[75] Martin Kenneth Star, *Executive Readings in Management Science* (New York: The Macmillan Company, 1965), p. 41.

Research-Management Science. Some of the conferences were:

1. The Case Institute of Technology Conference, Cleveland, Ohio, November 1951--conference on the application of operations research to the problems of business and industry.[76]
2. The Decennial Conference of Operations Research, Chief-of-Naval Operations, May 1952--"A wide variety of backgrounds and organizations were represented by speakers and the wide area covered by their papers made this conference an important episode in the history of Operations Research."[77]
3. The Midwest Institute, April 8-9, 1954, Kansas City, Missouri--symposium on operations research in business and industry.[78]
4. The First International Conference on Operations Research, Oxford, England, 1957--Operational Research Society of the United Kingdom, Operations Research Society of America and the Institute of Management Science.[79]
5. The Second International Conference on Operations Research, University of Aix, Marseille in Aix-en-Province, France, September 1960--attended by 350

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[76]McCloskey, Operations Research for Management, p. 33.

[77]George, History, p. 157.

[78]Churchman, Proceedings of the Symposium, p. 15.

[79]George, History, p. 157.

delegates from 22 countries.[80]

Chapter Summary

Operations Research-Management Science is viewed here as a natural extension of the quantitative school of management thought. During the World War II period, OR-MS was best known for its interdisciplinary teams which were formed to provide problem-solving support to top management. During the post-war era, OR-MS was chiefly characterized by its quantitative techniques which are mathematical models manipulatable on computers. While most operations researchers today will insist that OR-MS is more than just quantitative techniques, most will agree that quantitative techniques will always be present if operations research is used by business firms.

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[80] Ibid.

CHAPTER III

RESEARCH METHODOLOGY

The conduct of this study is described and explained in this chapter and in the appendices. The scope of this chapter includes details, descriptions, and explanations of (1) the population, (2) data collection procedures, (3) instrument design and testing, (4) statistical procedures, and (5) nonresponse study. A chapter summary establishes the basis for the analysis and interpretation of the results presented in Chapter IV.

The Population

The population studied in this research is comprised of the manufacturing executives in charge of all manufacturing firms with 250 or more employees in Arkansas, Colorado, Kansas, Missouri, New Mexico, Oklahoma, and Texas.

The research questions and hypotheses developed in Chapter I require the population to be stratified according to (1) firm size (number of employees), (2) industry group (investment per employee), and (3) education of the top manufacturing executive in charge. Data on the quantitative training of the executive in charge were not available in any of the sources used to identify the population in this study; consequently, this information was deduced from the questionnaires of the respondents to the mail survey. The population was stratified according to the firm size and the industry group from the sources utilized for population data in this study. Firm Size (number of employees) in this study refers to the firm size at each location in the geographical area. This distinction is necessary as a few firms in the sample are branch locations of a common parent company.

Sources of Population Data

State registers of manufacturers were utilized to provide data on all the firms included in the population. Table 2 shows the state, the title of the publication, and the date of publication of these sources. Each citation in these publications gives (1) the name of the firm, (2) the geographical location, (3) the products manufactured, (4) the mailing address, (5) the telephone number, (6) the manager in charge, (7) the manager's title, (8) the total number of employees at that location, (9) the standard industrial classification code, and (10) the products manufactured. These data sources provided information which was ideally suited for a mail survey.

Firm Size Classification

Five of the seven data sources listed below in Table 2 utilized a common classification scheme for the number of employees in each firm. Data from two of the sources had to be reclassified because the exact number of employees per firm was listed. With this slight modification of the data, information was available for the following

TABLE 2

STATE REGISTERS OF MANUFACTURERS

State	Title	Date
Arkansas	Directory of Industries	1973
Colorado	Directory of Colorado Manufacturers	1973-74
Kansas	Kansas Manufacturers and Products	1972-73
Missouri	Missouri Directory of Manufacturing and Mining	1973
New Mexico	Directory of New Mexico Manufacturing and Mining	1972
Oklahoma	Oklahoma Directory of Manufacturers	1972
Texas	Texas Manufacturers	1973

common firm size classification: (1) 250-499 employees, (2) 500-999 employees, (3) 1,000-4,999 employees, and (4) 5,000+ employees.

Table 3 classifies the population according to state and firm size. Approximately two-thirds of the firms included in the population are in the states of Missouri and Texas, while approximately one-third of the firms are in the other five states of the geographical region under examination. The distribution of firms among the firm size classifications shows a substantial skewedness toward the 250-499 employee classification: 60.7% of the firms in the population are found to have 250-499 employees, whereas only 1.6% of the population's firms have 5,000+ employees.

TABLE 3

THE POPULATION CLASSIFIED TO STATE AND FIRM SIZE

State	Number of Firms in Each Employee Size Class				
	250-499 (A_1)	500-999 (A_2)	1000-4999 (A_3)	5000+ (A_4)	Total
Arkansas	120	36	24	--	180
Colorado	48	17	17	2	84
Kansas	49	24	16	1	90
Missouri	235	71	35	6	347
New Mexico	7	6	2	--	15
Oklahoma	60	30	15	3	108
Texas	328	144	90	12	574
Totals	847	328	199	24	1398
Percent of Total	60.7	23.5	14.2	1.6	100.0

Industry Group Classification

Authors doing research on the applications of operations research in industry have speculated that (1) the degree of capital intensity, (2) the rates of growth, (3) the size of the firms (as reflected in the number of employees and/or capital investment), and (4) the type of manufacturing processes (intermittent or continuous) are industry factors which affect the degree of adoption of operations research techniques by industries.[1]

[1]Robert Bomi D. Batlivala and Elmer H. Burack, "Operations Research: Recent Changes and Future Expectations

This study utilized the new investment per employee as a single measure to reflect the degrees of capital intensity, the rates of growth, and the types of manufacturing processes for each industry Standard Industrial Classification (SIC) major group.[2]

Table 4 shows the computations for the new investment per employee for each Standard Industrial Classification. The two most recent Census of Manufacturers publications from the Bureau of the Census were used to develop these data. The 1963 new capital expenditures was added to the 1967 new capital expenditures for each Standard Industrial Classification. This total was then divided by the number of employees in each Standard Industrial Classification. Table 4 shows that for the period under consideration, the capital expenditures per employee range from a low of $246 for apparel to $6710 for petroleum.

Table 5 clusters and ranks the Standard Industrial Classifications according to the new investment per employee computed in Table 4. Six industry groups are identified in Table 5 ranging in size from 163 firms in Group B_4 to 264 firms in Group B_1.

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in Business Organizations," Business Perspectives, Vol. IX, No. 1 (Fall, 1972), p. 16; Rodney D. Neal and Michael Radnor, "The Progress of Management Science Activities in Large U.S. Industrial Corporations," Operations Research, Vol. XXI, No. 2 (March & April, 1973), pp. 447-448.

[2]Executive Office of the President--Office of Management and Budget, Standard Industrial Classification Manual (Washington, D.C.: Statistical Policy Division, 1972).

TABLE 4

CAPITAL EXPENDITURES IN 1963 AND 1967 PER EMPLOYEE FOR EACH STANDARD INDUSTRIAL CLASSIFICATION (SIC) MAJOR GROUP

SIC Code	SIC Title	1963 New Investment ($000,000)	1967 New Investment ($000,000)	Total 1963 & 1967 New Investment ($000,000)	Number of 1967 Employees (000)	1963 & 1967 New Investment per 1967 Employee
19	Ordinance	88.2	200.0	288.2	341.3	846
20	Food	1249.2	1730.1	2979.3	1725.9	1727
21	Tobacco	53.8	52.9	106.7	83.1	1282
22	Textile Mills	382.4	733.1	1115.5	954.0	1170
23	Apparel	128.6	208.3	336.9	1372.9	246
24	Wood	394.7	426.0	820.7	561.7	1460
25	Furniture	110.2	198.0	308.2	430.0	717
26	Paper	708.5	1585.3	2293.8	670.7	3420
27	Printing	463.9	788.1	1252.0	1052.1	1190
28	Chemicals	1545.7	2936.1	4481.8	982.7	4560
29	Petroleum	413.7	999.3	1413.0	210.7	6710
30	Rubber & Plastics	343.4	677.2	1020.6	531.0	1925
31	Leather	34.6	62.1	96.7	336.6	287
32	Stone, Clay, Glass	607.6	820.9	1428.5	620.6	2300
33	Primary Metals	1446.3	3131.1	4577.4	1329.1	3450
34	Fabricated Metals	610.2	1118.4	1728.6	1375.1	1257
35	Machinery	783.1	1868.1	2651.2	1929.4	1375
36	Electrical Machinery	701.9	1537.2	2239.1	1980.6	1130
37	Transportation Equipment	981.1	1822.4	2803.5	1935.5	1450
38	Professional, Scientific, Optical	191.9	392.2	584.1	406.6	1435
39	Miscellaneous	131.0	213.5	344.5	490.3	703

Source: "1963 Census of Manufacturers," U.S. Department of Commerce, Bureau of the Census and "1967 Census of Manufacturers," U.S. Department of Commerce, Bureau of the Census.

TABLE 5

RANKING AND GROUPING STANDARD INDUSTRIAL CLASSIFICATIONS INTO INDUSTRY GROUPS BY 1963 AND 1967 NEW INVESTMENT PER EMPLOYEE

SIC Code	SIC Title	New Investment per Employee ($)	Number of Firms in SIC Class	Number of Firms in Industry Group	Industry Group Code
23	Apparel	246	136		
31	Leather	287	70	264	B_1
39	Miscellaneous	703	22		
25	Furniture	717	36		
36	Electrical Machinery	1130	119		
22	Textiles	1170	20	213	B_2
27	Printing	1190	74		
34	Fabricated Metals	1257	112	261	B_3
35	Machinery	1375	149		
38	Professional, Sci, Optical	1435	36		
37	Transportation	1450	95	163	B_4
24	Wood	1460	32		
20	Food	1727	168		
30	Rubber & Plastics	1925	35	250	B_5
32	Stone, Clay & Glass	2300	47		
26	Paper	3420	33		
33	Primary Metals	3450	63	247	B_6
28	Chemicals	4560	99		
29	Petroleum	6710	52		

Table 6 shows a cross-classification of the population between industry group and firm size.

The data displayed in Tables 3 through 6 provide the basis for a final characterization of the population according to firm size and industry group.

TABLE 6

THE POPULATION CLASSIFIED TO INDUSTRY GROUP AND FIRM SIZE

Industry Group	Number of Firms in Each Employee Size Class				Total
	250-499 (A_1)	500-999 (A_2)	1000-4999 (A_3)	5000+ (A_4)	
B_1	207	39	18	-	264
B_2	114	52	38	9	213
B_3	155	72	34	-	261
B_4	78	43	33	9	163
B_5	175	46	28	1	250
B_6	118	76	48	5	247
Total	847	328	199	24	1398

Characterization of the Population

Table 7 shows the stratification of the population into two strata: firm size and industry group. The firms in the population were divided according to the firm size to form the first stratum. Each of these cells was further divided according to industry group to form the second stratum. Each of the cells contained in the industry group

TABLE 7

STRATIFICATION OF THE POPULATION TO FIRM SIZE AND INDUSTRY GROUP

Number of Firms in Unclassified Population	Firm Size Class Codes (Number of Employees)	Number of Firms in Each Firm Size Class	Industry Group Class Codes	Number of Firms in Each Firm Size and Ind. Group Class
1398	A_1 (250-499)	847	A_1B_1	207
			A_1B_2	114
			A_1B_3	155
			A_1B_4	78
			A_1B_5	175
			A_1B_6	118
	A_2 (500-999)	328	A_2B_1	39
			A_2B_2	52
			A_2B_3	72
			A_2B_4	43
			A_2B_5	46
			A_2B_6	76
	A_3 (1000-4999)	199	A_3B_1	18
			A_3B_2	38
			A_3B_3	34
			A_3B_4	33
			A_3B_5	28
			A_3B_6	48
	A_4 (5000+)	24	A_4B_1	--
			A_4B_2	9
			A_4B_3	--
			A_4B_4	9
			A_4B_5	1
			A_4B_6	5
Totals		1398		1398

stratum provides the basis for a stratified sample to be used in the mail survey.

Data Collection Procedures

The data required for the analysis of the research questions and hypotheses of this study were obtained from a mail survey of 515 of the total 1398 firms in the population.

Mail Survey

Table 8 shows the events and their associated dates of the mail survey. Examples of the advance letter, the first wave cover letter, and the second wave cover letter are contained in Appendices E-1, E-2, and E-3. The advance letter was intended to introduce the recipient to the study and to stress the importance of his response. The first wave arrived approximately one week after the receipt of the advance letter. Three to four days later the reminder postal card arrived, and if the recipients had not responded, they received a second wave approximately three weeks after the reminder postcard.

A computer program was written and utilized to select randomly 500 recipients from the 1398 firms of the population. Table 9 shows the number of firms in all the possible firm size and industry group combinations in the A_iB_i cells. Index numbers were assigned to the firms in each cell, and 28 percent were selected randomly to receive the mail survey (500/1398 = 28%). The computer program

TABLE 8

MAILING SCHEDULE

Event Number	Event	Date
1.	Mail advance letter	October 31, 1973
2.	Mail first wave of cover letter, questionnaire and return envelope	November 5, 1973
3.	Mail reminder postcard	November 9, 1973
4.	Mail second wave of cover letter, questionnaire and return envelope	November 27, 1973
5.	Close survey	December 22, 1973

TABLE 9

THE NUMBER OF RECIPIENTS AND RESPONDENTS IN THE MAIL SURVEY FROM EACH POPULATION CELL*

Population Cell Codes (A_iB_i)	Number of Firms in Each Population Cell	Number of Recipients to Yield 500 Total Mailings	Actual Number of Recipients per Cell	Number of Respondents per Cell	Rate of Response per Cell
A_1B_1	207	74	74	38	51
A_1B_2	114	41	41	21	51
A_1B_3	155	55	55	31	56
A_1B_4	78	28	28	15	54
A_1B_5	175	62	62	40	64
A_1B_6	118	42	42	22	52
A_2B_1	39	14	14	7	50
A_2B_2	52	18	18	11	61
A_2B_3	72	26	26	14	54
A_2B_4	43	16	16	8	50
A_2B_5	46	17	17	9	53
A_2B_6	76	27	27	14	52
A_3B_1	18	7	7	4	57
A_3B_2	38	13	13	5	39
A_3B_3	34	12	12	7	58
A_3B_4	33	12	12	7	58
A_3B_5	28	10	10	7	70
A_3B_6	48	17	17	10	59
A_4B_1	--	--	--	--	
A_4B_2	9	3	9	5	56
A_4B_3	--	--	--	--	
A_4B_4	9	3	9	3	33
A_4B_5	1	1	1	--	
A_4B_6	5	2	5	2	40
Totals	1398	500	515	280	

*Note: A_i, i = 1, ..., 4 represents the firm size (number of employees class) and B_i, i = 1, ..., 6 represents the industry group.

utilized the subroutine RANDU from IBM's Scientific Subroutine package to randomly select the index numbers identifying the recipient firms.

Table 9 shows that a total of 280 of the recipients responded with usable completed questionnaires. Because of void A_4B_i cells in the population, the small number of total firms in these cells (24) in the population, and the use of a nonproportional mailing schema for these cells, the A_4B_i responses were reduced to proportionality and consolidated with A_3B_i responses.

Consolidation of A_3B_i and A_4B_i Responses

The population contained a total of 24 firms with 5000 or more employees in the geographical area under consideration. If these A_4B_i cells were sampled proportionally as the other A_iB_i cells, a total of nine mailings would have been made to firms in the A_4B_i cells; however, because of the small number of firms in these cells, mailings were sent to all firms in the A_4B_i cells of the population. This nonproportional mailing was considered necessary in order to insure an adequate response rate from these cells.

For the purpose of correlation analysis only, the respondents from the A_4B_i (5000+ employees) cells were combined with the respondents of the A_3B_i (1000-4999 employees) cells. Table 10 shows that five of the ten responses in the A_4B_i cells were removed from the sample. This was done by writing and utilizing a computer program which randomly selected three, one, and one respondents from the three A_4B_i cells. This resulted in only three firm size groups for the purposes of correlation analysis: 250-499 employees, 500-999 employees and 1000+ employees; although, four A_i classes were utilized in the descriptive statistical analysis section of Chapter IV.

Instrument Design and Testing

Paul L. Erdos, a noted authority on questionnaire design and mail surveys, was the principal source followed in preparing the questionnaire for this study.[3] The principles of effective questionnaire design outlined by Mr. Erdos were utilized in designing the initial questionnaire to be used in a pilot test (see Appendix A-1).

On-site interviews were conducted at six manufacturing plants in the Oklahoma City area. The six manufacturing executives who participated are: Mr. G. L. Bryant, Honeywell, Inc.; Mr. Charles Casebeer, Star Manufacturing Company; Mr. Bruce Firetag, Fife Corporation; Dr. Clem B. LePak, Western Electric Company, Inc.; Mr. William Petty, Westinghouse Electric Corporation; and Mr. Ronald Williams, Wilson and Company, Inc. Each of the participating manufacturing

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[3]Paul L. Erdos, Professional Mail Survey (New York: McGraw-Hill Book Company, 1970).

TABLE 10

CONSOLIDATION OF FIRM SIZE CLASSES 3 AND 4

Population Cell Codes (A_iB_i)	Number of Firms in Each Population Cell	Number of Respondents per Cell	Reduction of Class A_4 for Correct Weight	Adjusted and Combined Respondents per Cell	Response Rate per Cell
A_3B_1	18	4		4	4/7 =57
A_3B_2	38	5		7	7/16=44
A_3B_3	34	7		7	7/12=58
A_3B_4	33	7		9	9/15=60
A_3B_5	28	7		7	7/10=70
A_3B_6	48	10		11	11/19=58
A_4B_1	--	--	--	--	
A_4B_2	9	5	-3	--	
A_4B_3	--	--	--	--	
A_4B_4	9	3	-1	--	
A_4B_5	1	--	--	--	
A_4B_6	5	2	-1	--	
Totals	223	50	-5*	45	

*Note: The A_4B_i group received a disproportionate number of the mail surveys since all firms in the population were recipients. A proportionate mailing schema would have been 0, 3, 0, 3, 1, 2 instead of 0, 9, 0, 9, 1, 5. With a response rate comparable to the overall average of the other A_iB_i groups (50-55%) the appropriate weighted response is 0, 2, 0, 2, 0, 1.

executives filled out the questionnaire in this researcher's presence and offered comments and observations concerning the questionnaire design, the terminology, and observations about the use of operations research techniques in their firms in general.

The experience gained in these on-site interviews with the use of the pilot test questionnaire provided information concerning terminology, questionnaire format, respondent instructions, and other problem areas in the design of the questionnaire. This information was incorporated into the revised questionnaire contained in Appendix A-2. This improved version of the questionnaire was reproduced and utilized in the mail survey.

Statistical Procedures

Percentages, frequency distributions, rankings, means, ranges, and standard deviations were used in the descriptive statistical analysis to answer the research questions stated in Chapter I of this report.

Parametric statistical analysis was used to test the hypotheses of this study. Multiple and partial correlation analyses were used to test the relationships between firm size (number of employees), industry group, (investment per employee), and education of the top manufacturing executive, and the extent of usage of operations research techniques. The Chi-Square test was used to test the difference between the distributions of the respondents and nonrespondents.

No nonparametric test of significance is available to examine the significance of the correlation coefficients developed in this study. Appendix B contains a review of some of the literature on the use of parametric tests of significance when ordinal data are utilized or the assumptions of equinormality of the parametric tests are violated, an explanation of the computation of the correlation coefficients used in this study, an explanation of the statistical tests of significance used in this study, and the power of the statistical tests used in this study.

Non-Response Study

The respondents in a mail survey must be statistically equivalent to the nonrespondents along the measured dimensions of the study if the sample is to be considered representative. Two kinds of bias can generally be introduced into the study if the respondents are not representative of the population: (1) the class of respondents is not representative of the classes included in the population, and (2) the type of responses is not representative of the universe of responses contained in the population. The first type of non-representativeness becomes a much reduced concern when the sample is stratified along all the dimensions that are required or desired to be represented in the sample, allowing the researcher some degree of control over the type of respondent that is represented in the sample.

The second kind of non-representativeness becomes much less of a concern as the response rate in the mail survey increases. As the response rate increases, the probability increases that all types of responses present in the population are present in the sample.

This study experienced a 55 percent (275/500) response rate. Although most mail survey researchers consider this response rate substantial, a nonresponse study was conducted to compare the attributes of the nonrespondents with the respondents.

Table 11 shows the number of respondents, nonrespondents, and recipients of the nonresponse study in each cell of the population. A computer program utilizing IBM's RANDU subroutine was used for randomly selecting a recipient for the nonresponse study in each cell of the population. The randomly selected code number identified the recipient of the nonresponse study among the preassigned code numbers of the nonrespondents.

A telephone interview was conducted with the executive in charge of the selected firms in the nonresponse study. In a few cases the executive in charge had either been replaced or was away on extended leave. In these cases the executive's replacement or his assistant was interviewed. Section A and Questions I and II of Section B of the questionnaire were completed (see Appendix A-2).

TABLE 11

RECIPIENTS OF THE NON-RESPONSE STUDY

Population Cell Codes (A_iB_i)	Respondents per Cell	Non-Respondents per Cell	Recipients of Non-Response Study per Cell
A_1B_1	38	36	1
A_1B_2	21	20	1
A_1B_3	31	24	1
A_1B_4	15	13	1
A_1B_5	40	22	1
A_1B_6	22	20	1
A_2B_1	7	7	1
A_2B_2	11	7	1
A_2B_3	14	12	1
A_2B_4	8	8	1
A_2B_5	9	8	1
A_2B_6	14	13	1
A_3B_1	4	3	1
A_3B_2	7	9	1
A_3B_3	7	5	1
A_3B_4	9	6	1
A_3B_5	7	4	1
A_3B_6	11	8	1
Totals	275	225*	18

*Note: There were 515 recipients of the mail survey: 280 responded and 235 did not. When cells A_4B_i (firms with 5000+ employees) were adjusted and combined with cells A_3B_i, the effective number of recipients was reduced to 500 since cells A_4B_i were reduced from 24 to 9. The effective number of respondents was reduced from 10 to 5 to yield an effective number of responses of 275. 500 recipients and 275 respondents yields 225 non-respondents.

This identified the degree of quantitative training of the executive in charge and the extent of the adoption of operations research techniques in that firm. Finally, the interview sought to determine the reason for nonresponse.

The results of the nonresponse study are found in Chapter IV.

Chapter Summary

This study is a regional analysis of manufacturing firms with over 250 employees in Oklahoma and all states with common borders with Oklahoma. The study is primarily concerned with ascertaining the extent of usage of operations research techniques in these firms.

Five research questions were formulated and stated in Chapter I. Descriptive statistics provide the basis for answering these research questions in Chapter IV.

Eight hypotheses were formulated and stated in substantive positive form in Chapter I. These hypotheses are restated here in the null form, as tested in this study:

1. There is no significant relationship between the Firm Size (number of employees) Class and the extent of usage of operations research techniques in manufacturing firms.
2. There is no significant relationship between the Industry Group (investment per employee) Class and the extent of usage of operations research techniques in manufacturing firms.

3. There is no significant relationship between the Education (top manufacturing executive) Class and extent of usage of operations research techniques in manufacturing firms.
4. There is no significant relationship between the cross effects of the Firm Size (number of employees) Class, Industry Group (investment per employee) Class, and the Education (top manufacturing executive) Class, and the extent of usage of operations research techniques in manufacturing firms.
5. There is no significant relationship between the Firm Size (number of employees) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.
6. There is no significant relationship between the Industry Group (investment per employee) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.
7. There is no significant relationship between the Education (top manufacturing executive) Class and the extent of usage of <u>each</u> operations research technique in manufacturing firms.
8. There is no significant relationship between the cross-effects of the Firm Size (number of employees) Class, the Industry Group (investment per employee) Class, and the Education (top manufacturing executive) Class,

and the extent of usage of each operations research technique in manufacturing firms.

Computer programs were used to select a proportional stratified random sample from the population. The sample was stratified along two dimensions: firm size (number of employees) and new investment per employee industry group.

An initial questionnaire design was used in a pilot test which culminated in the questionnaire contained in Appendix A-2. This questionnaire was featured in a mail survey designed to provide data to answer the research questions and test the hypotheses. The sample size was 275 resulting from a proportional mailing of 500 from a population of 1398, yielding a response rate of 55 percent.

CHAPTER IV

ANALYSIS AND INTERPRETATION OF THE DATA

The results of the analysis of the data of this study are described and explained in the following sections and in the appendices. The scope of this chapter includes detailed descriptions and explanations of (1) the descriptive statistical analysis, (2) the inferential statistical analysis, and (3) results of the nonresponse study.

Descriptive Statistical Analysis

Five research questions were stated in Chapter I of this report. The purpose of these research questions was to provide information concerning the present state or nature of the practice of operations research in manufacturing organizations in one geographical area. Descriptive statistical analysis seeks to answer questions such as those of this study by describing and interpreting the collected data using statistics such as: means, percentages, distributions, ranges, standard deviations, and variances. Each research question of the study is discussed and analyzed in the following section.

Answering the Research Questions

Research Question 1: What is the overall extent of usage of operations research techniques in manufacturing firms?

This study provided data on each responding firm in the sample indicating the following:

1. Are any operations research techniques used in the firm?
2. How many operations research techniques are used in the firm?
3. How often is each operations research technique used in the firm?
4. How many operations research personnel are used to apply these techniques in the firm?

Table 12 shows that of the 275 firms included in the sample, 133 firms (referred to as using firms in this report) used one or more of the operations research techniques listed in the questionnaire (see Appendix A-2, Section B, Question 1). Nine general classes of operations research techniques and fourteen specific operations research techniques were found by this researcher to be the most common mentioned in the operations management literature. Those firms which use operations research techniques account for 48.4 percent of the firms included in the sample.

Table 13 shows the number of operations research techniques that were used by the firms in the sample.

TABLE 12

DO PERSONNEL OF THE RESPONDING FIRMS USE ANY OPERATIONS RESEARCH TECHNIQUES?

	No	Yes	Total
Number of Firms	142	133	275
Percentage	51.6	48.4	100.0

TABLE 13

NUMBER OF OPERATIONS RESEARCH TECHNIQUES USED BY THE RESPONDING FIRMS

Number of Techniques Used	Number of Firms	Percentage of Total Firms	Percentage of Using Firms
0	142	51.6	--
1	20	7.3	15.0
2	32	11.6	24.1
3	22	8.0	16.5
4	22	8.0	16.5
5	10	3.6	7.5
6	5	1.8	3.8
7	3	1.1	2.3
8	4	1.5	3.0
9	6	2.2	4.5
10	6	2.2	4.5
11	2	.7	1.5
12	0	.0	.0
13	1	.4	.8
14	0	.0	.0
Total	275	100.0	100.0

Note: Percentage of Using Firms (Column 4) means the percentage is based only on the number of using firms (133).

Over one-half of the firms in the sample which indicated the use of operations research techniques used fewer than four techniques per firm. The mean number of operations research techniques used per firm over all the firms in the sample is 1.89, and 3.91 for those firms indicating the use of operations research techniques.

Table 14 shows the number of firms, the percentage of total firms, and the percentage of using firms in the sample which used each operations research technique. Table 15 indicates the relative frequency with which each operations research technique was used by the firms in the sample. Frequency was measured on a three-point scale: Never, Occasionally, and Routinely. A Frequency Index Score (FIS) was computed for each technique. The FIS is a relative measure of the frequency of the use of each operations research technique.

Table 16 shows the operations research techniques ranked according to the percentage of using firms which used each technique and the Frequency Index Score (FIS) for each technique. More than one-half of the using firms indicated the use of the first five ranked operations research techniques: PERT, CPM, Linear Programming, Exponential Smoothing and Regression Analysis, and Computer Simulation. There is a great reduction in the percentage of using firms using each technique after these first five ranked techniques (from 51.9% for Computer Simulation to

TABLE 14

FIRMS USING EACH OPERATIONS RESEARCH TECHNIQUE

Operations Research Techniques	Number of Firms Using Each OR Technique	Percentage of Total Firms Using Each OR Technique	Percentage of Using Firms Using Each OR Technique
Linear Programming	76	27.6	57.2
Integer Programming	19	6.9	14.3
0,1 Programming	15	5.5	11.3
Nonlinear Programming	21	7.7	15.8
Stochastic Programming	13	4.7	9.8
PERT	92	36.4	69.2
CPM	89	32.4	66.9
Queueing Theory	39	14.2	29.3
Game Theory	3	1.1	2.3
Computer Simulation	69	25.0	51.9
Heuristic Programming	10	3.6	7.5
Exponential Smoothing & Regression Analysis	74	26.9	55.6
Direct Search Methods	10	3.6	7.5
Dynamic Programming	13	4.7	9.8

Note: Column 4 contains percentages based only on the number of using firms (133).

TABLE 15

HOW OFTEN IS EACH OPERATIONS RESEARCH TECHNIQUE USED BY THE RESPONDING FIRMS?

Operations Research Techniques	Number of Firms Which Use Each OR Technique in These Frequency Classes			Frequency Index Score
	Never (1 pt.)	Occasionally (2 pts.)	Routinely (3 pts.)	
Linear Programming	199	39	37	388
Integer Programming	256	17	2	296
0,1 Programming	260	9	6	296
Nonlinear Programming	254	14	7	303
Stochastic Programming	262	11	2	290
PERT	183	55	37	404
CPM	186	57	32	396
Queueing Theory	236	32	7	321
Game Theory	272	3	0	278
Computer Simulation	205	44	25	368
Heuristic P Programming	265	8	2	287
Exponential Smoothing & Regression Analysis	201	48	26	375
Direct Search Methods	265	8	2	287
Dynamic Programming	262	12	1	289

Note: The Frequency Index Score (column 5) is computed by multiplying the points in each frequency class (1, 2 & 3) by the number of firms in each frequency class for each OR technique and totaling these products for each OR technique. These Frequency Index Scores then reflect the relative frequency of use of each OR technique among the firms in the sample.

TABLE 16

OPERATIONS RESEARCH TECHNIQUES RANKED ACCORDING TO THE PERCENTAGE OF USING FIRMS WHICH USED THEM AND THE FREQUENCY INDEX SCORES (FIS)

Operations Research Technique	Percentage of Using Firms Using Each OR Technique	FIS
PERT	69.2	404
CPM	66.9	396
Linear Programming	57.2	388
Exponential Smoothing & Regression Analysis	55.6	375
Computer Simulation	51.9	368
Queueing Theory	29.3	321
Nonlinear Programming	15.8	303
Integer Programming	14.3	296
0,1 Programming	11.3	296
Stochastic Programming	9.8	290
Dynamic Programming	9.8	289
Direct Search Methods	7.5	287
Heuristic Programming	7.5	287
Game Theory	2.3	278

29.3% for Queueing Theory). Less than 10 percent of the using firms indicated the use of stochastic programming, dynamic programming, direct search methods, heuristic programming, and game theory.

The ranking of the techniques according to the Frequency Index Score is the same as the ranking of the techniques according to the percentage of using firms using each technique.

In summary, almost one-half of the firms in the sample indicated the use of one or more operations research techniques. Almost one-half of the using firms used four or more techniques per firm. Over one-half of the using firms used PERT, CPM, linear programming, exponential smoothing and regression analysis, and computer simulattion. Less than 10 percent of using firms used stochastic programming, dynamic programming, direct search methods, heuristic programming, and game theory. Nearly two-thirds of using firms used PERT and CPM.

The preceding summary indicates a moderately wide usage of five operations research techniques in the firms included in the sample. The total number of personnel in the firms who are applying operations research techniques to manufacturing problems is an additional measure of the extent of usage of operations research techniques: this information is provided in the analysis of research question #2.

Research Question 2: What organizational units and how many operations research personnel administer these operations research techniques in each strata of manufacturing firms?

Table 17 shows the total number of operations research personnel cross-classified between firm size and industry group. Operations research personnel, as used here, means college-trained personnel who devote the majority of their time to the use of operations research techniques. A total of 773 operations research personnel was employed by the 275 firms in the sample. Table 18 shows the total number of operations research personnel by firm size. Ninety-five firms, or approximately 35 percent of the firms in the sample, employed operations research personnel. The number of firms which employed operations research personnel tends to be heavily skewed toward the smaller firm: 47 firms in the firm size class of 250-499 employees and 5 firms with 5000+ employees. The total number of operations research personnel in each firm size class does not follow the same trend, however, as the number of personnel tends to be moderately uniform across the firm size classes. The mean number of operations research personnel per firm increases from 4.0 for firm

TABLE 17

TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL: A CROSS-CLASSIFICATION BETWEEN FIRM SIZE (NUMBER OF EMPLOYEES) AND INDUSTRY GROUP

Industry Group B_i	Firm Size (Number of Employees)				
	250-499 (A_1)	500-999 (A_2)	1000-4999 (A_3)	5000+ (A_4)	Total
B_1	9	12	18	0	39
B_2	43	42	0	36	121
B_3	28	73	32	0	133
B_4	7	9	7	88	111
B_6	30	5	12	0	47
B_6	73	61	166	22	322
Total	190	202	235	146	773

Note: Operations Research Personnel means college-trained personnel who devote the majority of their time to the use of operations research techniques.

TABLE 18

TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL: A CLASSIFICATION AND ANALYSIS BY FIRM SIZE (NUMBER OF EMPLOYEES)

	Firm Size (Number of Employees)				
	250-499 (A_1)	500-999 (A_2)	1000-4999 (A_3)	5000+ (A_4)	Total
Number of Firms with OR Personnel	47	28	15	5	95
Total Number of OR Personnel	190	202	235	146	773
Mean Number of OR Personnel per Firm	4.0	7.2	15.7	29.2	8.1
Range of Number of OR Personnel per Firm	1-29	1-23	2-55	1-79	1-79

size class A_1 progressively across the firm size classes to 29.2 for firm size class A_4. The mean number of operations research personnel per firm across all firms which employed operations research personnel is 8.1. The upper range of the number of operations research personnel per firm is seen to trend upward from 29 for firm size class A_1 to 79 for firm size class A_4.

Table 19 shows the total number of operations research personnel classified by industry group (investment per employee) classes. The number of firms with operations research personnel is moderately uniform with the exception of B_3 and B_6 (refer to Table 5 for description of the SIC's included in these B_i classes) which account for approximately half of the total firms employing operations research personnel among all industry group classes. The total number of operations research personnel is dominated by industry group class B_6 (paper, primary metals, chemicals and petroleum) which accounts for approximately 42 percent of the total operations research employees. There appears to be no discernible trend in the mean number of operations research personnel per firm across the industry group classes, except that industry group classes B_6, B_4, and B_2 tend to be substantially higher than industry group classes B_1, B_3, and B_5 by a factor of 2 or 3.

Table 20 displays nine of the firms from the sample with the largest number of operations research

TABLE 19

TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL: A CLASSIFICATION AND ANALYSIS BY INDUSTRY GROUP

	Industry Group						
	B_1	B_2	B_3	B_4	B_5	B_6	Total
Number of Firms with OR Personnel	10	13	23	11	14	24	95
Total Number of OR Personnel	39	121	133	111	47	322	773
Mean Number of OR Personnel per Firm	3.9	9.3	5.8	10.1	3.4	13.4	8.1
Range of Number of OR Personnel per Firm	1-10	2-27	1-17	1-79	1-8	1-55	1-79

personnel. Industry group class B_6 not only has the largest total number of operations research personnel, but, in addition, two-thirds of the firms with 20 or more operations research personnel are included in B_6 industry group class. Industry group class B_6, then, tends to dominate the other industry groups in terms of total number of operations research personnel and these personnel tend to be concentrated in a relatively few firms. One-fourth of the B_6 firms contains two-thirds of the operations research personnel in the B_6 industry group class.

Table 21 shows the total number of operations research personnel in manufacturing departments classified to firm size (number of employees). Over one-half (54.2 percent) of the operations research personnel included in the 275 firms in the sample, worked in line and staff groups with broader purposes than using operations research techniques to assist manufacturing. In other words, the majority of the operations research personnel in the sample were integrated into other line and staff departments within the manufacturing organization. Formal staff groups whose primary function is to assist manufacturing by using operations research techniques are ranked according to the total number of operations research personnel found in those departments as follows:

1. Systems analysis and data processing (142)
2. Process, product, and technical engineering (53)

TABLE 20

A DISPLAY OF ALL RESPONDING FIRMS WITH OVER 20 OPERATIONS RESEARCH PERSONNEL

Firm Name	Industry Group Class (B_i)	Total Number of Employees	Total Number of Operations Research Personnel
1. General Dynamics Corporation, Fort Worth, Texas	4	10,000	79
2. Continental Oil Company, Ponca City, Oklahoma	6	4,000	55
3. Mobil Oil Company, Beaumont, Texas	6	2,000	53
4. Cities Service Oil Company, Tulsa, Oklahoma	6	2,200	31
5. Celanese Corporation, Bay City, Texas	6	450	29
6. Texas Instruments, Inc., Dallas, Texas	2	12,000	27
7. Amoco Oil Company, Sugar Creek, Missouri	6	530	23
8. Phillips Petroleum Company, Bartlesville, Oklahoma	6	5,000	22
9. Armco Steel Corporation, Kansas City, Missouri	2	500	20
Total			339

TABLE 21

TOTAL OPERATIONS RESEARCH PERSONNEL IN MANUFACTURING DEPARTMENTS: A CLASSIFICATION AND ANALYSIS BY FIRM SIZE (NUMBER OF EMPLOYEES)

Formal Manufacturing Departments	Firm Size (Number of Employees)				Total
	250-499 (A_1)	500-999 (A_2)	1000-4999 (A_3)	5000+ (A_4)	
Production Planning, Scheduling and Control	10	16	10	0	36
Industrial Engineering	2	4	15	0	21
Operations Research/ Management Science	6	0	19	28	53
Quality Control	3	0	3	0	6
Manufacturing and Production Engineering	12	10	4	0	26
Maintenance and Project Planning	3	2	8	0	13
Systems Analysis and Data Processing	14	46	52	30	142
Process, Product and Technical Engineering	20	13	20	0	53
Other	3	0	1	0	4
Integrated Into Other Line and Staff Groups with Broader Purposes	117	111	103	88	419
Total	190	202	235	146	773
N (No. of Firms)	47	28	15	5	95

Note: Table 35 indicates the average number of operations research personnel per firm for each firm size class (A_i).

3. Operations research/management science (53)
4. Production planning, scheduling and control (36)
5. Manufacturing and production engineering (26)
6. Industrial engineering (21)

All other formal staff groups represent less than 3 percent of the total number of operations research personnel.

The dominant organization arrangement of operations research personnel is to integrate them into other line and staff groups with broader purposes. Systems analysis and data processing departments tend to be the most frequently used formal staff group for applying operations research techniques with process, product, and technical engineering and operations research/management science also showing moderate popularity among the sample firms.

No striking trends can be observed among the firm size classes in the popularity of manufacturing departments for applying operations research techniques. Operations research/management science departments tend to become more popular among larger firms as the percentage of operations research personnel in these departments increases from 3 percent in firm size class A_1 to over 19 percent in firm size class A_4.

Table 22 shows the total number of operations research personnel in manufacturing departments classified by industry group (investment per employee) classes. No discernible trend is observed in the popularity of

TABLE 22

TOTAL OPERATIONS RESEARCH PERSONNEL IN MANUFACTURING DEPARTMENTS: A CLASSIFICATION AND ANALYSIS BY INDUSTRY GROUP

Formal Manufacturing Departments	Industry Group						
	B_1	B_2	B_3	B_4	B_5	B_6	Total
Production Planning, Scheduling and Control	4	0	11	0	0	21	36
Industrial Engineering	4	2	2	0	4	9	21
Operations Research/ Management Science	0	12	0	5	0	36	53
Quality Control	0	0	2	0	0	4	6
Manufacturing and Production Engineering	0	0	10	0	1	15	26
Maintenance and Project Planning	0	0	2	0	0	11	13
Systems Analysis and Data Processing	16	26	12	30	5	53	142
Process, Product and Technical Engineering	0	10	16	0	0	27	53
Other	0	3	0	0	0	1	4
Integrated into Other Line and Staff Groups with Broader Purposes	15	68	78	76	37	145	419
Total	39	121	133	111	47	322	773

the manufacturing departments used to apply operations research techniques for industry group classes; except that the percentage of total operations research personnel integrated into other line and staff groups with broader purposes tends to increase progressively from industry group B_1 through industry group B_5 (38.5 percent to 78.7 percent). Industry group B_6 violates this trend by including a greater percentage of the total operations research personnel in formal staff groups. The staff groups in industry group B_6 which tends to become more popular are operations research/management science; process, product, and technical engineering; production planning, scheduling and control; and maintenance and project planning.

In summary, a total of 773 operations research personnel was employed in 95 firms included in the 275 firms of the sample. The mean number of operations research personnel in each using firm tends to increase substantially as the size of the firm increases. Industry group (investment per employee) B_6 (paper, primary metals, chemicals, and petroleum) dominates all other industry groups by employing 41.7 percent of the total operations research personnel in the sample; in addition, two-thirds of all the firms employing 20 or more operations research personnel are included in industry group B_6. The predominant organizational arrangement of operations research personnel across all firm size classes and industry group classes is to integrate the operations research personnel into other line and staff groups with broader purposes; with moderate popularity being shown for systems analysis and data processing; operations research/management science; process, product and technical engineering; and production planning, scheduling and control; formal staff groups.

Research Question 3: What types of manufacturing problems are analyzed with operations research techniques in manufacturing firms?

The on-site interviews used to test the initial instrument design indicated that the participants tended to be confused and unfamiliar with some of the operations research techniques listed in Section B, Question III (see Appendix A-1). The difficulty that the pilot test participants experienced in responding to the question "Which quantitative techniques are used to study the following types of manufacturing problems at your location?" suggested to this researcher the reduction of the number of technique classes to five in order to improve the quality of responses and the response rate on this question. The on-site interviews indicated that the applications of the following classes of techniques were the most commonly understood by the participants: linear or nonlinear programming, PERT and CPM, computer simulation, queueing theory, and exponential smoothing and regression analysis. These technique classes were then used on the final version of the questionnaire (see Appendix A-2) to investigate the type of operations research techniques that were being used in analyzing manufacturing problems in the population. Tables 14 and 15 indicate that these five classes of operations research techniques were indeed the most commonly used techniques and less than 15 percent of the using firms indicated that they were using the remainder of the techniques.

Table 23 shows the summary of the number of firms applying operations research techniques to manufacturing problems. The manufacturing problems are ranked according to the number of firms using any operations research technique in the analysis of that problem. The manufacturing problems are ranked as follows:

1. Production planning and control
2. Project planning and control
3. Inventory analysis and control

and grouped very closely in fourth, fifth, and sixth are quality control, analyzing capital investment projects, and maintenance planning. These rankings include all the firms in the sample indicating the use of operations research techniques. The totals of the columns in Table 23 indicate the number of manufacturing problems that were analyzed by each operations research technique in all the using firms of the sample. These totals give a relative measure of the degree of flexibility that each operations

TABLE 23

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: ALL FIRMS IN THE SAMPLE

Manufacturing Problems	Operations Research Techniques						
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	13	6	9	1	2	31	11
Line balancing	14	1	6	6	4	31	11
Chemical or Ingredient Blending	19	0	3	0	4	26	13
Reducing trim waste	6	0	2	0	0	8	21
Material allocation	19	1	14	0	4	38	9
Capacity allocation	29	0	13	2	2	46	7
Product mix	31	0	11	0	2	44	8
Logistics studies	13	2	5	2	1	23	14
Facilities layout	3	2	3	2	0	10	20
Production planning and control	41	40	25	7	23	136	1
Inventory analysis and control	20	5	29	8	22	84	3
Project planning and control	1	85	4	0	1	91	2

TABLE 23 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	3	11	0	14	18
System reliability	0	0	11	1	5	17	17
Equipment design analysis	4	2	21	1	4	32	10
Maintenance planning	8	33	5	2	3	51	6
Service crew size	2	0	8	10	0	20	16
Holding area size	4	0	6	4	0	14	18
Machines per operator	11	0	5	7	0	23	14
Analyzing capital investment projects	21	5	25	0	5	56	4
Quality control	1	2	12	0	27	56	4
Total	274	184	220	64	109		
Rank	1	3	2	5	4		

research technique exhibits in being applied to a wide variety of manufacturing problems. The operations research techniques are ranked accordingly as follows:

1. Linear or nonlinear programming
2. Computer simulation
3. PERT, CPM
4. Exponential smoothing and regression analysis
5. Queueing theory

This ranking is not, however, a ranking of the operations research techniques according to the number of firms which use them. The ranking does not indicate how widely the specific operations research technique is disseminated throughout the firms; but, the ranking does indicate the variety of manufacturing problems to which the operations research technique is applied.

Appendices D-1 through D-10 present a tabular analysis of the number of firms applying operations research techniques to manufacturing problems in the firm size classes and the industry group classes. Tables 24 and 25 are a summary of Appendices D-1 through D-10. Table 24 summarizes the ranking of manufacturing problems according to the frequency that all operations research techniques are applied for all firm size classes. The ranking in the last column for all firms (A_i) is the same as that included in Table 23. Production planning

TABLE 24

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: A SUMMARY OF THE RANKING OF MANUFACTURING PROBLEMS ACCORDING TO THE FREQUENCY THAT ALL OPERATIONS RESEARCH TECHNIQUES ARE APPLIED FOR ALL FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES (A_i)

Manufacturing Problems	Ranking of Manufacturing Problems				
	Firms with 250-499 Employees (A_1)	Firms with 500-999 Employees (A_2)	Firms with 1000-4999 Employees (A_3)	Firms with 5000+ Employees (A_4)	All Firms (A_i)
Facility location	11	10	10	18	11
Line balancing	10	12	8	15	11
Chemical or Ingredient Blending	13	16	10	12	13
Reducing trim waste	20	18	20	21	21
Material allocation	8	6	13	12	9
Capacity allocation	9	6	4	3	7
Product mix	5	10	8	12	8
Logistics studies	13	14	18	7	14
Facilities layout	21	21	14	20	20
Production planning and control	1	1	1	1	1
Inventory analysis and control	3	2	5	3	3
Project planning and control	2	3	2	5	2
Waiting lines	18	18	16	15	18
System reliability	15	15	21	7	17
Equipment design analysis	16	6	10	7	10
Maintenance planning	5	6	5	7	6
Service crew size	16	16	14	7	16
Holding area size	18	18	16	18	18
Machines per operator	11	12	18	15	14
Analyzing capital investment projects	4	4	7	5	4
Quality Control	7	4	3	1	4

TABLE 25

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: A SUMMARY OF THE RANKING OF OPERATIONS RESEARCH TECHNIQUES ACCORDING TO THE FREQUENCY OF APPLICATION TO THE VARIOUS MANUFACTURING PROBLEMS FOR ALL FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES (A_i)

	Ranking of Operations Research Techniques				
Operations Research Techniques	Firms with 250-499 Employees (A_1)	Firms with 500-999 Employees (A_2)	Firms with 1000-4999 Employees (A_3)	Firms with 5000+ Employees (A_4)	All Firms (A_i)
Linear or Nonlinear Programming	1	2	1	2	1
PERT, CPM	2	3	3	3	3
Computer Simulation	3	1	2	1	2
Queueing Theory	5	5	5	5	5
Exponential Smoothing & Regression Analysis	4	4	4	4	4

and control is seen to rank first among all of the firm size classes. The ranking of the manufacturing problems according to the total number of firms applying operations research techniques to the analysis of those problems indicates a moderately uniform ranking across all firm size classifications with two exceptions: (1) capacity allocation appears to become more important in the larger firms (A_3 and A_4) and (2) quality control appears to become more important in the larger firms (A_3 and A_4).

Table 25 shows a summary of the ranking of operations research techniques according to the frequency of application to the various manufacturing problems for all firm size classes. The ranking of the flexibility of the various operations research techniques in capability of being applied to a variety of manufacturing problems appears to be moderately uniform across all firm sizes; however, computer simulation tends to displace linear or nonlinear programming as being the most frequently applied operations research technique to a variety of manufacturing problems in firm size class A_2 and firm size class A_4.

Table 26 shows a summary of the ranking of manufacturing problems according to the frequency that all operations research techniques are applied for all industry groups. A few exceptions exist to a uniformly

TABLE 26

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: A SUMMARY OF THE RANKING OF MANUFACTURING PROBLEMS ACCORDING TO THE FREQUENCY THAT ALL OPERATIONS RESEARCH TECHNIQUES ARE APPLIED FOR ALL INDUSTRY GROUPS (INVESTMENT PER EMPLOYEE) (B_i)

Manufacturing Problems	Ranking of Manufacturing Problems						
	Firms in Industry Group B_1	Firms in Industry Group B_2	Firms in Industry Group B_3	Firms in Industry Group B_4	Firms in Industry Group B_5	Firms in Industry Group B_6	All Firms B_i
Facility location	13	19	6	11	6	11	11
Line balancing	7	12	9	16	10	11	11
Chemical or Ingredient Blending	17	18	20	16	10	8	13
Reducing trim waste	17	19	16	20	13	21	21
Material allocation	5	14	4	8	8	11	9
Capacity allocation	8	6	8	11	8	6	7
Product mix	13	12	11	8	4	6	8
Logistics studies	13	10	16	16	10	11	14
Facilities layout	13	19	16	20	16	17	20
Production planning and control	1	1	1	1	1	1	1

TABLE 26 (Continued)

Manufacturing Problems	Ranking of Manufacturing Problems						
	Firms in Industry Group B_1	Firms in Industry Group B_2	Firms in Industry Group B_3	Firms in Industry Group B_4	Firms in Industry Group B_5	Firms in Industry Group B_6	All Firms B_i
Inventory analysis and control	4	1	2	3	6	8	3
Project planning and control	2	3	3	2	2	2	2
Waiting lines	17	14	20	14	16	17	18
System reliability	17	10	16	16	16	16	17
Equipment design analysis	17	4	10	14	13	10	10
Maintenance planning	5	6	11	6	4	2	6
Service crew size	10	14	14	7	16	15	16
Holding area size	10	17	14	11	16	17	18
Machines per operator	10	6	11	10	13	17	14
Analyzing capital investment projects	8	5	6	3	3	5	4
Quality control	3	9	4	5	6	2	4

distributed ranking across all industry groups:

1. Product mix is ranked higher in industry groups B_5 (food; rubber and plastics; and stone, clay and glass), and B_6 (paper, primary metals, chemicals and petroleum).
2. Inventory analysis and control is ranked lower in these two industry group classes (B_5 and B_6).
3. Maintenance planning is ranked higher in these two industry groups (B_5 and B_6).
4. Quality control is ranked higher in industry groups B_6 and B_1 (apparel, leather, miscellaneous, and furniture).
5. Analyzing capital investment projects is ranked higher in industry groups B_4 (professional, scientific, optical, transportation, and wood) and industry group B_5.
6. Equipment design analysis is ranked higher in industry group B_2 (electrical machinery, textiles, and printing).

Table 27 shows a summary of the ranking of operations research techniques according to the frequency of application to the various manufacturing problems for all industry group classes. Linear and nonlinear programming, ranked first in flexibility of application to manufacturing problems, is displaced by computer simulation in industry groups B_3 (fabricated metals and machinery) and B_4 (professional, scientific, optical, transportation and wood). Industry group B_6 (paper, primary metals, chemicals and petroleum) ranks the forecasting techniques of

TABLE 27

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: A SUMMARY OF THE RANKING OF OPERATIONS RESEARCH TECHNIQUES ACCORDING TO THE FREQUENCY OF APPLICATION TO THE VARIOUS MANUFACTURING PROBLEMS FOR ALL INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES (B_i)

Operations Research Techniques	Firms in Industry Group B_1	Firms in Industry Group B_2	Firms in Industry Group B_3	Firms in Industry Group B_4	Firms in Industry Group B_5	Firms in Industry Group B_6	All Firms B_i
Linear and Nonlinear Programming	1	1	3	3	1	1	1
PERT, CPM	2	3	2	2	2	4	3
Computer Simulation	3	2	1	1	3	2	2
Queueing Theory	5	5	5	4	4	5	5
Exponential Smoothing and Regression Analysis	4	4	4	5	4	3	4

exponential smoothing and regression analysis ahead of PERT and CPM in contrast to the remainder of the groups.

In summary, the using firms in the sample ranked manufacturing problems analyzed by operations research techniques most frequently as follows:

1. Production planning and control
2. Project planning and control
3. Inventory analysis and control

and grouped very closely in fourth, fifth, and sixth, were quality control, analyzing capital investment projects, and maintenance planning. All the using firms in the sample ranked the operations research techniques as being most flexible in being applied to a variety of manufacturing problems as follows:

1. Linear or nonlinear programming
2. Computer simulation
3. PERT and CPM
4. Exponential smoothing and regression analysis
5. Queueing theory

Capacity allocation and quality control were analyzed more frequently in the larger firms. Product mix and maintenance planning tends to be analyzed more frequently in the continuous process industries, whereas inventory analysis and control tends to be analyzed less frequently. Quality control tends to be analyzed more at both poles of the intermittent to continuous industry groupings.

Analyzing capital investment projects tends to be analyzed more frequently in industry groups B_4 and B_5. Equipment design analysis tends to be analyzed more in the B_2 industry group. Computer simulation tends to be ranked higher in attacking a variety of manufacturing problems in the firm size classes A_2 and A_4 and the industry group classes of B_3 and B_4.

Research Question 4: In the opinion of the manufacturing executive in charge, what overall results have operations research personnel achieved while using operations research techniques in manufacturing firms?

Tables 28 and 29 show the overall results achieved by operations research personnel in firm size classes and industry group classes. In rating the results from operations research techniques, none of the respondents rated the results as poor. Almost half of the respondents rated the results as good, with 31.3 percent indicating very good results and 11.1 percent indicating excellent results. There appears to be a slight trend toward more favorable results from the smaller to the larger firms. No discernible trends are noted across the various classes of industry groups.

Ideally, the results indicated in Tables 28 and 29 should indicate overall satisfaction of top management with their investment in operations research techniques. There is some evidence, however, in this study, that the responsibility for completing the questionnaire tended to

TABLE 28

THE OVERALL RESULTS ACHIEVED BY OPERATIONS RESEARCH PERSONNEL IN ALL FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES (A_i)

Firm Size (Number of Employees)	Percentage of Firms						Number of Firms in Each Firm Size Class
	Degree of Results Achieved					Total	
	Poor	Fair	Good	Very Good	Excellent		
A_1 (250-499)	0.0	4.3	51.1	34.1	10.5	100.0	47
A_2 (500-999)	0.0	6.9	48.3	31.1	6.9	100.0	29
A_3 (1000-4999)	0.0	16.7	44.4	22.2	16.7	100.0	18
A_4 (5000+)	0.0	0.0	40.0	40.0	20.0	100.0	5
A_i (All Firm Classes)	0.0	9.1	48.5	31.3	11.1	100.0	99

TABLE 29

THE OVERALL RESULTS ACHIEVED BY OPERATIONS RESEARCH PERSONNEL IN ALL INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES (B_i)

Industry Group	Percentage of Firms						Number of Firms in Each Industry Group Class
	Degree of Results Achieved						
	Poor	Fair	Good	Very Good	Excellent	Total	
B_1	0.0	14.3	71.4	14.3	0.0	100.0	7
B_2	0.0	0.0	76.5	23.5	0.0	100.0	17
B_3	0.0	18.2	45.4	36.4	0.0	100.0	22
B_4	0.0	7.7	53.8	15.4	23.1	100.0	13
B_5	0.0	14.3	21.4	42.9	21.4	100.0	14
B_6	0.0	7.7	34.6	38.5	19.2	100.0	26
B_i (all firms)	0.0	9.1	48.5	31.3	11.1	100.0	99

be delegated to lower level managers, and, perhaps operations research personnel in the larger firms. This could have injected an upward bias in the overall ratings of the results of the use of operations research techniques.

Research Question 5: What problems are encountered in using operations research techniques in manufacturing firms?

Tables 30 and 31 show the problems that are encountered while using operations research techniques and summarize the ranking of the problems according to the number of firms experiencing problems for all industry groups and firm size classes. Across all of the using firms in the sample the following is the ranking of the problems encountered:

1. Production personnel are inadequately trained.
2. Competent personnel with quantitative training are scarce.
3. Staff personnel don't sell these solutions and approaches.
4. Returns from expenditures on these techniques are inadequate.
5. Data for these models are inadequate.
6. Staff personnel are reluctant to assist in the implementation of quantitative solutions.
7. Top management doesn't understand.
8. It takes too long to get answers.

The problem of "returns from expenditures from these

TABLE 30

PROBLEMS ENCOUNTERED WHILE USING OPERATIONS RESEARCH TECHNIQUES: A SUMMARY OF THE RANKING OF PROBLEMS ENCOUNTERED BY ALL FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES (A_i)

Problems Encountered	Firms with 250-499 Employees (A_1)		Firms with 500-999 Employees (A_2)		Firms with 1000-4999 Employees (A_3)		Firms with 5000+ Employees (A_4)		All Firms (A_i)	
	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank
1. Top Management doesn't understand	13	4	5	6	1	11	1	5	20	6
2. Production personnel are inadequately trained	28	1	17	1	8	1	1	5	54	1
3. The Computer is inadequate	11	6	1	11	1	10	0	9	13	9
4. Staff personnel don't sell these approaches and solutions	18	3	7	4	6	3	2	3	33	3
5. Returns from expenditures on these techniques are inadequate	13	4	9	3	4	5	0	9	26	4
6. The turnover of quantitative personnel is high	3	12	1	11	2	8	0	9	6	12
7. Quantitative personnel are too impractical	8	9	2	9	0	12	1	5	11	10
8. Staff personnel are reluctant to assist in the implementation of quantitative solutions	11	6	6	5	2	8	1	5	20	6

TABLE 30 (Continued)

Problems Encountered	Firms with 250-499 Employees (A_1)		Firms with 500-999 Employees (A_2)		Firms with 1000-4999 Employees (A_3)		Firms with 5000+ Employees (A_4)		All Firms (A_i)	
	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank
9. It takes too long to get answers	9	8	3	8	4	5	2	3	18	8
10. These models make too many unrealistic assumptions	4	11	2	9	4	5	0	9	10	11
11. Competent personnel with quantitative training are scarce	23	2	13	2	6	3	2	2	44	2
12. Data for these models is inadequate	7	10	4	7	8	1	3	1	22	5

TABLE 31

PROBLEMS ENCOUNTERED WHILE USING OPERATIONS RESEARCH TECHNIQUES: A SUMMARY OF THE RANKING OF PROBLEMS ENCOUNTERED BY ALL INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES (B_i)

Problems Encountered	Industry Group (Investment per Employee)												All Firms B_i	
	B_1		B_2		B_3		B_4		B_5		B_6			
	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank
1. Top Management doesn't understand	2	5	2	5	6	4	3	8	4	4	3	8	20	6
2. Production personnel are inadequately trained	7	1	7	2	18	1	6	1	10	1	6	3	54	1
3. The Computer is inadequate	2	5	2	5	2	9	3	8	0	11	4	7	13	9
4. Staff personnel don't sell these approaches and solutions	3	3	6	3	6	4	5	2	7	2	6	4	33	3
5. Returns from expenditures on these techniques are inadequate	3	3	2	5	7	3	5	2	4	4	5	5	26	4
6. The turnover of quantitative personnel is high	1	8	0	12	1	11	0	12	2	9	2	11	6	12
7. Quantitative personnel are too impractical	1	8	2	5	1	11	3	8	3	6	1	12	11	10

TABLE 31 (Continued)

Problems Encountered	Industry Group (Investment per Employee)												All Firms B_i	
	B_1		B_2		B_3		B_4		B_5		B_6			
	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank	Firms	Rank
8. Staff personnel are reluctant to assist in the implementation of quantitative solutions	0	11	4	4	6	4	4	5	3	6	3	8	20	6
9. It takes too long to get answers	2	5	2	5	2	9	4	5	3	6	5	5	18	8
10. These models make too many unrealistic assumptions	0	11	0	11	5	7	2	11	0	11	3	8	10	11
11. Competent personnel with quantitative training are scarce	7	1	8	1	8	2	5	2	7	2	9	1	44	2
12. Data for these models is inadequate	1	8	2	5	5	7	4	5	2	9	8	2	22	5

techniques are inadequate" tends to be ranked higher among the small firms. The problem of "it takes too long to get answers" tends to be ranked higher in the larger firms and "data for these models are inadequate" also is ranked higher in the larger firms. No discernible trends are noted in the ranking of problems encountered across the industry group classes.

As noted in Research Question No. 4, these data may reflect to some extent the viewpoints of the users of operations research techniques rather than top management, particularly in the larger firms of the sample.

Inferential Statistical Analysis

Inferential statistical analysis was used in this study to identify the relationships between the firm size, the industry group and the education of the top manufacturing executive and the use of operations research techniques in manufacturing firms. In the summary of Chapter III, eight hypotheses were stated in the null form. These hypotheses are tested for significance (whether the correlation coefficients equal 0) in the following sections.

Appendix B contains detailed discussions of the multiple correlation analysis, partial correlation analysis, and the test of significance and power of the test associated with each of these statistical analyses. The measure of the extent of usage of operations research techniques in the sample firms is a computed Frequency

Index Score (FIS). The FIS for each firm was calculated by determining the number of operations research techniques that were used never, occasionally, and routinely; all techniques which were used "never" were assigned a score of 1, all techniques that were used "occasionally" were assigned a score of 2, and all techniques which were used "routinely" were assigned a score of 3. The total score of all three classes determines the total FIS score for each firm. The FIS reflects the number of operations research techniques that are used and the frequency of use.

The FIS for the firms were then correlated with firm size classes, industry group classes, and education classes. The correlation coefficients were developed for each of the three factors and for all possible combinations of the factors with the FIS. The Student's t test was then used to test the significance of the partial correlation coefficients and the F test was used to test the significance of the multiple correlation coefficients.

Each of the hypotheses stated in the null form in the summary section of Chapter III is tested in the following sections.

Testing the Hypotheses

Hypothesis 1: There is no significant relationship between the firm size (number of employees) class and the extent of usage of operations research techniques in manufacturing firms.

$$H_{01}: \; r_{12 \cdot 34} = 0$$

$$H_{11}: \; r_{12 \cdot 34} \neq 0$$

In the above notational hypotheses the subscripts on the partial correlation coefficient, r, are defined as follows:

1 = FIS

2 = Firm size (number of employees) class

3 = Industry group (investment per employee) class

4 = Education (top manufacturing executive) class

$r_{12 \cdot 34}$ means, then, the partial correlation coefficient between the FIS and the firm size class screening out the effects of the industry group class and the education class statistically.

Table 32 shows the results of the correlation analysis. The partial correlation coefficient between the firm size and the FIS is .235. This is observed to be significant at a level less than .001. Statistically $r_{12 \cdot 34}$ is not equal to 0. The alternate hypothesis, H_{11}, is accepted and the null hypothesis, H_{01}, is rejected.

There is a positive relationship between the size of the firms and the extent to which the firms use operations research techniques. The sign of the partial correlation coefficient (PCC) indicates this conclusion. The magnitude of the PCC indicates that on a scale from 0 to 1.0 (no relationship to perfect relationship) there is a weak - moderate relationship between firm size and the use of operations research techniques.

A number of factors can be hidden in a correlation coefficient. An overall strong trend can be interrupted by one class, resulting in a much reduced correlation coefficient. There may be logical explanations why one class violates the trend. Much can be learned from examining the underlying distributions along the strata of the study. Table 33 shows the number and percentage of firms which use any operations research techniques. A progressively increasing percentage of firms does use operations research techniques as the firm size increases (from 41.3 percent to 100 percent). Table 34 shows the distribution of Frequency Index Scores (FIS) for each firm size class. The FIS is observed to increase progressively from the smaller to larger firms with a rather uniform standard deviation.

Table 35 shows a comparison of the total number of operations research personnel among the various firm size classes. The mean number of operations research personnel per firm is observed to increase progressively

TABLE 32

RELATIONSHIP BETWEEN FIRM SIZE (NUMBER OF EMPLOYEES) CLASS AND FREQUENCY INDEX SCORE (FIS)

Statistic Name	Statistic Value
Correlation Coefficient	.288
Partial Correlation Coefficient (PCC)	.235
Sample Size (N)	275
PCC Student t Value (t)	3.980
Significance Level	< .001

TABLE 33

NUMBER AND PERCENTAGE OF FIRMS WHICH USE <u>ANY</u> OPERATIONS RESEARCH TECHNIQUES: AN ANALYSIS BY FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES

Firm Size Classes (Number of Employees)	Number of Nonusing Firms	Number of Using Firms	Percentage of Using Firms
A_1 (250-499)	98	69	41.3
A_2 (500-999)	28	35	55.6
A_3 (1000-4999)	16	24	60.0
A_4 (5000+)	0	5	100.0
A_i (All Firms)	142	133	48.4

TABLE 34

A COMPARISON OF THE FREQUENCY INDEX SCORE (FIS) DISTRIBUTION FOR THE FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES

Firm Size Class (Number of Employees)	N	FIS Mean	FIS S.D.
A_1 (250-499)	167	15.639	4.256
A_2 (500-999)	63	17.095	4.043
A_3 (1000-4999)	40	18.175	4.706
A_4 (5000+)	5	27.400	3.131
A_i (All Firms)	275	16.558	4.592

TABLE 35

A COMPARISON OF THE TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL BETWEEN FIRM SIZE (NUMBER OF EMPLOYEES) CLASSES

Firm Size Class (Number of Employees)	Number of Operations Research Personnel per Class	Number of Firms per Class	Mean Operations Research Personnel per Firm
A_1 (250-499)	190	167	1.140
A_2 (500-999)	202	63	3.210
A_3 (1000-4999)	235	40	5.880
A_4 (5000+)	146	5	20.920
A_i (All Firms)	773	275	2.810

from the smaller to the larger firm classes.

H_{01} is rejected. The size of partial correlation coefficient, $r_{12\cdot34} = .235$, indicates a weak-moderate relationship between the firm size and the use of operations research techniques. The distributions showing the use of any operations research techniques; the frequency index scores; and the number of operations research personnel per firm for each firm size class indicates a progressive and uninterrupted increasing trend from the smaller to the larger firm size classes.

Hypothesis 2: There is no significant relationship between the industry group (investment per employee) class and the extent of usage of operations research techniques in manufacturing firms.

$$H_{02}: \; r_{13\cdot24} = 0$$

$$H_{12}: \; r_{13\cdot24} \neq \underline{0}$$

Table 36 shows the relationship between industry group and Frequency Index Score (FIS). The partial correlation coefficient, $r_{13\cdot24}$, is equal to .142. Using the Student's t test of the partial correlation coefficient, the PCC is observed to be significant at a level less than .02. The null hypothesis, H_{02}: $r_{13\cdot24} = 0$, is rejected, and the alternate hypothesis, H_{12}: $r_{13\cdot24} \neq 0$ is accepted. The size of the PCC indicates a weak relationship between the industry group class and the use of operations research techniques.

Table 37 shows the percentage of firms in the industry group classes which use any operations research techniques. Although there is a definite positive trend of increasing percentage of the use of any operations research techniques from B_1 through B_6 industry groups, industry groups B_4 and B_5 are observed to interrupt this positive trend as a lower percentage of the firms in these two industry group classes use operations research techniques.

Table 38 shows the distribution of the FIS means for the industry group classes. The FIS mean trend is upward from B_1 to B_6; however, industry group classes B_3, B_4 and B_5 are observed to interrupt this general trend. Table 39 shows the mean number of operations research personnel per firm for each industry group class. Although there is a general upward trend from industry group B_1 through B_6, industry groups B_3 and B_5 are observed to employ fewer operations research personnel per firm than the general trend would indicate.

H_{02} is rejected. The magnitude of the relationship between industry group classes and the use of operations research techniques is weak. This weak relationship can be observed in the magnitude of the PCC, the intermittent nature of the trends from industry group B_1 to industry group B_6 when considering the use of any operations research techniques, the frequency index scores, and the total mean number of operations research personnel per firm.

TABLE 36

RELATIONSHIP BETWEEN INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASS AND FREQUENCY INDEX SCORE (FIS)

Statistic Name	Statistic Value
Correlation Coefficient	.215
Partial Correlation Coefficient (PCC)	.142
Sample Size (N)	275
PCC Student t Value (t)	2.360[a]
Significance Level	< .02

TABLE 37

NUMBER AND PERCENTAGE OF FIRMS WHICH USE ANY OPERATIONS RESEARCH TECHNIQUES: AN ANALYSIS BY INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES

Industry Group	Number of Nonusing Firms	Number of Using Firms	Percentage of Using Firms
B_1	33	16	32.7
B_2	19	19	50.0
B_3	23	29	55.8
B_4	15	17	53.2
B_5	36	21	36.9
B_6	16	31	66.0
B_i (all firms)	142	133	48.4

TABLE 38

A COMPARISON OF THE FREQUENCY INDEX SCORE (FIS) DISTRIBUTIONS FOR THE INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES

Industry Group Class	N	FIS Mean	FIS S.D.
B_1	49	14.146	5.259
B_2	38	17.342	4.450
B_3	52	16.904	3.841
B_4	32	16.063	3.252
B_5	57	16.228	4.013
B_6	47	18.745	5.093
B_i (All Firms)	275	16.558	4.592

TABLE 39

A COMPARISON OF THE TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL BETWEEN INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES

Industry Group Class	Number of Operations Research Personnel per Class	Total Number of Firms per Classs	Mean Operations Research Personnel per Firm
B_1	39	49	.796
B_2	121	38	3.185
B_3	133	52	2.560
B_4	111	32	3.470
B_5	47	57	.825
B_6	322	47	6.850
B_i (All Firms)	773	275	2.810

Hypothesis 3: There is no significant relationship between the education (top manufacturing executive) class and the extent of usage of operations research techniques in manufacturing firms.

$$H_{03}: \; r_{14\cdot23} = 0$$

$$H_{13}: \; r_{14\cdot23} \neq 0$$

Table 40 shows the schema for the classification of the responding firms' top manufacturing executives. The reader will note that quantitative education and training is stressed in this schema. The data derived from Page 1 of the questionnaire (Appendix A-2) are reduced to a single class of education for each top manufacturing executive on a scale from 1 to 5. This was necessary to facilitate the correlation analysis of this section.

Table 41 shows the partial correlation coefficient, $r_{14\cdot23}$, to be .206. The Student t value for the PCC is observed to be significant at a level less than .001. The null hypothesis, H_{03}: $r_{14\cdot23} = 0$, is rejected, and the alternate hypothesis, H_{13}: $r_{14\cdot23} \neq 0$, is accepted. The magnitude of the PCC indicates a weak-moderate relationship between the education of the top manufacturing executives and the use of operations research techniques.

Table 42 shows a general upward trend in the percentage of firms using operations research techniques from the lower education classes to the higher education classes (C_1 to C_5); however, education class C_3 does interrupt this general upward trend.

TABLE 40

SCHEMA FOR CLASSIFICATION OF RESPONDENT'S QUANTITATIVE TRAINING*

Training Factors	Classes of Quantitative Training (C_1)	(C_2)	(C_3)	(C_4)	(C_5)
A. College Attendance	No	Yes	Yes	Yes	Yes
B. Years of College Attendance	0	Less than 4	4+	4+	4+
C. Highest College Degree Received	None	None	Bachelors	Bachelors	Masters or Doctors
D. Major Field of Study	--	All	Business, Social Sci., Law, or Other Non Quantitative	Engineering, Mathematics, Physics, or Other Quantitative	Engineering, Mathematics, Physics, or Other Quantitative

*Note: When the respondent has (1) attended seminars or training sessions on operations research techniques, (2) if the respondent majored in engineering, mathematics, business, or other quantitative field and attended college for two but less than four years and last attended college 1960-present, or (3) if the major was in business, social sciences or other non-quantitative field and an advanced degree was received, the score was improved a maximum of one class.

TABLE 41

RELATIONSHIP BETWEEN EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASS AND FREQUENCY INDEX SCORE (FIS)

Statistic Name	Statistic Value
Correlation Coefficient	.283
Partial Correlation Coefficient (PCC)	.206
Sample Size (N)	275
PCC Student t Value (t)	3.462[a]
Significance Level	< .001

TABLE 42

NUMBER AND PERCENTAGE OF FIRMS WHICH USE ANY OPERATIONS RESEARCH TECHNIQUES: AN ANALYSIS BY EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASSES

Education Class C_i	Number of Nonusing Firms	Number of Using Firms	Percentage of Using Firms
C_1	27	1	3.6
C_2	10	9	47.4
C_3	29	20	40.8
C_4	47	38	44.7
C_5	29	65	69.2
C_i (All Firms)	142	133	48.4

Table 43 shows the Frequency Index Scores for the education classes C_1 through C_5. The FIS is observed to develop an upward pattern from C_1 through C_5 with only C_3 interrupting the upward trend. Table 44 shows the mean number of operations research personnel per firm among the various education classes. The mean number of operations research personnel per firm is observed progressively to increase from C_1 through C_5.

Table 45 provides additional analysis of the number of operations research personnel in each education class. Education class C_5 (the highest quantitative training class) is observed to include 71.9 percent of the total operations research personnel in the sample. Although the mean number of operations research personnel per firm tends generally to increase from C_1 through C_5, slight interruptions are noted in the C_3 and C_4 classes.

In summary, H_{03} is rejected. The relationship between education class and the use of operations research techniques is observed to be weak-moderate. General upward trends are noted from education class C_1 through C_5 for the percentage of firms using operations research techniques, the FIS mean, and the total number of operations research personnel, with only slight interruptions to these trends. Education class C_5 (the highest quantitative training class) is observed to dominate the other classes in terms of the number of total operations research

TABLE 43

A COMPARISON OF THE FREQUENCY INDEX SCORE (FIS) DISTRIBUTIONS FOR THE EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASSES

Education Class	N	FIS Mean	FIS S.D.
C_1	28	14.556	1.311
C_2	19	16.211	3.120
C_3	49	14.755	6.353
C_4	85	16.153	3.190
C_5	94	18.511	4.754
C_i (All Firms)	275	16.558	4.592

TABLE 44

A COMPARISON OF THE TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL BETWEEN EDUCATION (TOP MANUFACTURING EXECUTIVES) CLASSES

Education Class	Number of Operations Research Personnel per Class	Number of Firms per Class	Mean Operations Research Personnel per Firm
C_1	6	28	.214
C_2	18	19	.947
C_3	66	49	1.347
C_4	127	85	1.495
C_5	556	94	5.920
C_i (All Firms)	773	275	2.810

TABLE 45

TOTAL NUMBER OF OPERATIONS RESEARCH PERSONNEL: A CLASSIFICATION AND ANALYSIS BY EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASS

	Education Class					Total
	C_1	C_2	C_3	C_4	C_5	C_i
Number of Firms with Operations Research Personnel	2	6	12	24	51	95
Total Number of Operations Research Personnel	6	18	66	12-7	556	773
Mean Number of Operations Research Personnel per Firm	3.0	3.1	5.5	5.3	10.9	8.1
Range of Number of Operations Research Personnel per Firm	2-4	1-6	1-22	1-20	1-79	1-79

personnel included in this class (556/773 = 71.9 percent).

Hypothesis 4: There is no significant relationship between the cross-effects of firm size (number of employees) class, industry group (investment per employee) class, and the education (top manufacturing executive) class and the extent of usage of operations research techniques in manufacturing firms.

$$
\begin{aligned}
H_{04}: \quad & R_{123} = 0 \\
& R_{124} = 0 \\
& R_{134} = 0 \\
& R_{1234} = 0 \\
H_{14}: \quad & R_{123} \neq 0 \\
& R_{124} \neq 0 \\
& R_{134} \neq 0 \\
& R_{1234} \neq 0
\end{aligned}
$$

Table 46 shows a correlation coefficient matrix between the firm size, industry group and education classes. These correlation coefficients are all positive and weak to moderate. These generally indicate that as a firm size increases we observe the education class to increase and, to a lesser extent, the industry group increases. As the industry group increases, the education group increases. This tends to indicate, as we begin to combine factors to examine cross-effects, that we would observe the multiple correlation coefficient of the group to be greater than the partial correlation coefficient of the individual factors in the group.

Table 47 shows the relationship between the

TABLE 46

THE RELATIONSHIPS BETWEEN THE FIRM SIZE (NUMBER OF EMPLOYEE) CLASSES, INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASSES AND THE EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASSES
(N = 275)

Correlation Coefficient Matrix

	Firm Size	Industry Group	Education
Firm Size	1.000		
Industry Group	.132	1.000	
Education	.206	.240	1.000

TABLE 47

RELATIONSHIPS BETWEEN FREQUENCY INDEX SCORE (FIS) AND COMBINATIONS OF FIRM SIZE (NUMBER OF EMPLOYEES) CLASS, INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASS AND EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASS
(N = 275)

Combination of Classes	Multiple Correlation Coefficient (MCC)	F* Value	Significance Level
Firm Size and Industry Group	.339	11.750	< .01
Firm Size and Education	.368	14.220	< .01
Industry Group and Education	.321	10.380	< .01
Firm Size, Industry Group and Education	.390	17.930	< .01

*Note: $P(F > 3.780) = .01$

Frequency Index Score (FIS) and all possible combinations of firm size, industry group, and education classes. The multiple correlation coefficients for the possible combinations of the factors are all positive and moderate. Each of them is significant below the .01 level. The null hypothesis, H_{04}, is rejected and the alternate hypothesis, H_{14}, is accepted. The strongest relationship between any pair of factors and the FIS is observed to be firm size and education. All three factors combined yield the strongest relationship to the FIS (.390 MCC).

Hypothesis 5: There is no significant relationship between the firm size (number of employees) class and the extent of usage of each operations research technique in manufacturing firms.

$$
\begin{array}{llll}
H_{05}: & r_{12\cdot3401} = 0 & H_{15}: & r_{12\cdot3401} \neq 0 \\
 & r_{12\cdot3402} = 0 & & r_{12\cdot3402} \neq 0 \\
 & r_{12\cdot3403} = 0 & & r_{12\cdot3403} \neq 0 \\
 & r_{12\cdot3404} = 0 & & r_{12\cdot3404} \neq 0 \\
 & r_{12\cdot3405} = 0 & & r_{12\cdot3405} \neq 0 \\
 & r_{12\cdot3406} = 0 & & r_{12\cdot3406} \neq 0 \\
 & r_{12\cdot3407} = 0 & & r_{12\cdot3407} \neq 0 \\
 & r_{12\cdot3408} = 0 & & r_{12\cdot3408} \neq 0 \\
 & r_{12\cdot3409} = 0 & & r_{12\cdot3409} \neq 0 \\
 & r_{12\cdot3410} = 0 & & r_{12\cdot3410} \neq 0 \\
 & r_{12\cdot3411} = 0 & & r_{12\cdot3411} \neq 0 \\
 & r_{12\cdot3412} = 0 & & r_{12\cdot3412} \neq 0 \\
 & r_{12\cdot3413} = 0 & & r_{12\cdot3413} \neq 0 \\
 & r_{12\cdot3414} = 0 & & r_{12\cdot3414} \neq 0
\end{array}
$$

Table 48 shows the relationship between the firm size class and the Frequency Index Scores for each operations research technique. The partial correlation coefficients for all of the 14 operations research techniques are observed to be positive. The Student t test was used to measure the significance of partial correlation coefficients for each operations research technique. Integer programming, nonlinear programming, game theory, and direct computer search methods were observed to be not significant. The infrequent use of these techniques by the firms in the sample results in low PCCs. Moderate relationships are observed for CPM, queueing theory, computer simulation and dynamic programming. Larger firms tend to use more of these techniques and smaller firms tend to use fewer relative to the other operations research techniques. Other techniques exhibited a weak-moderate relationship between the firm size and the usage of each operations research technique.

In summary, there is a general positive relationship between the firm size and the use of each operations research technique. However statistically, integer programming, nonlinear programming, game theory, and direct computer search methods are not significant. Therefore, the null hypothesis, as it relates to $r_{12\cdot3402}$, $r_{12\cdot3404}$, $r_{12\cdot3409}$, and $r_{12\cdot3413}$ is accepted. For all other operations research techniques, the null hypothesis is rejected

TABLE 48

THE RELATIONSHIP BETWEEN FIRM SIZE (NUMBER OF EMPLOYEES) CLASS AND THE FREQUENCY INDEX SCORE (FIS) FOR EACH OPERATIONS RESEARCH TECHNIQUE (N = 275)

Operations Research Techniques	Correlation Coefficient	Partial Correlation Coefficient (PCC)	Ranking (PCC)	Student t Value (PCC)	Significance Level
1. Linear Programming	.185	.129	10	2.142	< .05
2. Integer Programming	.100	.075	14	1.238	n.s.[a]
3. 0, 1 Programming (Binary)	.187	.157	7	2.619	< .01
4. Nonlinear Programming	.129	.096	12	1.536	n.s.
5. Stochastic Programming	.159	.133	9	2.210	< .05
6. PERT	.200	.160	6	2.670	< .01
7. Critical Path Method (CPM)	.254	.196	3	3.283	< .01
8. Queueing Theory	.231	.202	2	3.395	< .001
9. Game Theory	.107	.089	13	1.472	n.s.[a]
10. Computer Simulation	.270	.228	1	3.852	< .001
11. Heuristic Programming	.187	.156	8	2.605	< .01
12. Exponential Smoothing--Regression Analysis	.210	.168	5	2.802	< .01
13. Direct Computer Search Methods	.146	.113	11	1.872	n.s.[a]
14. Dynamic Programming	.185	.183	4	3.060	< .01

[a]Not significant at the .05 level.

and the alternate hypothesis is accepted.

Hypothesis 6: There is no significant relationship between the industry group (investment per employee) class and the extent of usage of each operations research technique in manufacturing firms.

H_{06}: $r_{13\cdot 2401} = 0$	H_{16}: $r_{13\cdot 2401} \neq 0$
$r_{13\cdot 2402} = 0$	$r_{13\cdot 2402} \neq 0$
$r_{13\cdot 2403} = 0$	$r_{13\cdot 2403} \neq 0$
$r_{13\cdot 2404} = 0$	$r_{13\cdot 2404} \neq 0$
$r_{13\cdot 2405} = 0$	$r_{13\cdot 2405} \neq 0$
$r_{13\cdot 2406} = 0$	$r_{13\cdot 2406} \neq 0$
$r_{13\cdot 2407} = 0$	$r_{13\cdot 2407} \neq 0$
$r_{13\cdot 2408} = 0$	$r_{13\cdot 2408} \neq 0$
$r_{13\cdot 2409} = 0$	$r_{13\cdot 2409} \neq 0$
$r_{13\cdot 2410} = 0$	$r_{13\cdot 2410} \neq 0$
$r_{13\cdot 2411} = 0$	$r_{13\cdot 2411} \neq 0$
$r_{13\cdot 2412} = 0$	$r_{13\cdot 2412} \neq 0$
$r_{13\cdot 2413} = 0$	$r_{13\cdot 2413} \neq 0$
$r_{13\cdot 2414} = 0$	$r_{13\cdot 2414} \neq 0$

Table 49 shows the relationship between the industry group class and the Frequency Index Score (FIS) for each operations research technique. Not all of the partial correlation coefficients for the operations research techniques are positive, as PERT and queueing theory are observed to be weakly negative. The null hypothesis is accepted for all of the partial correlation coefficients with the exception of linear programming and

TABLE 49

THE RELATIONSHIP BETWEEN INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASS AND THE FREQUENCY INDEX SCORE (FIS) FOR EACH OPERATIONS RESEARCH TECHNIQUE (N = 275)

Operations Research Techniques	Correlation Coefficient	Partial Correlation Coefficient (PCC)	Ranking (PCC)	Student t Value (PCC)	Significance Level
1. Linear Programming	.214	.154	1	2.565	< .02
2. Integer Programming	.098	.069	7	1.138	n.s.[a]
3. 0, 1 Programming (Binary)	.097	.051	9	.840	n.s.[a]
4. Nonlinear Programming	.148	.113	3	1.870	n.s.[a]
5. Stochastic Programming	.091	.053	8	.873	n.s.[a]
6. PERT	-.018	-.107	14	--	n.s.[a]
7. Critical Path Method (CPM)	.176	.094	5	1.552	n.s.[a]
8. Queueing Theory	.015	-.052	13	--	n.s.[a]
9. Game Theory	.066	.041	12	.676	n.s.[a]
10. Computer Simulation	.118	.045	10	.741	n.s.[a]
11. Heuristic Programming	.133	.092	6	1.520	n.s.[a]
12. Exponential Smoothing--Regression Analysis	.107	.043	11	.709	n.s.[a]
13. Direct Computer Search Methods	.142	.105	4	1.735	n.s.[a]
14. Dynamic Programming	.141	.136	2	2.260	< .05

[a]Not significant at the .05 level.

dynamic programming ($r_{13\cdot2401}$ and $r_{13\cdot2414}$). Linear programming and dynamic programming are found to be positively correlated and significant at the .05 level. For these two groups there is a weak - moderate relationship between industry group class and their use. All other operations research techniques are observed statistically to have no relationship between industry group class and the use of those techniques.

Hypothesis 7: There is no significant relationship between the education (top manufacturing executive) class and the extent of usage of each operations research technique in manufacturing firms.

H_{07}:	$r_{14\cdot2301} = 0$	H_{17}:	$r_{14\cdot2301} \neq 0$
	$r_{14\cdot2302} = 0$		$r_{14\cdot2302} \neq 0$
	$r_{14\cdot2303} = 0$		$r_{14\cdot2303} \neq 0$
	$r_{14\cdot2304} = 0$		$r_{14\cdot2304} \neq 0$
	$r_{14\cdot2305} = 0$		$r_{14\cdot2305} \neq 0$
	$r_{14\cdot2306} = 0$		$r_{14\cdot2306} \neq 0$
	$r_{14\cdot2307} = 0$		$r_{14\cdot2307} \neq 0$
	$r_{14\cdot2308} = 0$		$r_{14\cdot2308} \neq 0$
	$r_{14\cdot2309} = 0$		$r_{14\cdot2309} \neq 0$
	$r_{14\cdot2310} = 0$		$r_{14\cdot2310} \neq 0$
	$r_{14\cdot2311} = 0$		$r_{14\cdot2311} \neq 0$
	$r_{14\cdot2312} = 0$		$r_{14\cdot2312} \neq 0$
	$r_{14\cdot2313} = 0$		$r_{14\cdot2313} \neq 0$
	$r_{14\cdot2314} = 0$		$r_{14\cdot2314} \neq 0$

Table 50 shows the relationship between education class and Frequency Index Score (FIS) for each operations research technique. The partial correlation coefficient for integer programming, 0,1 programming, nonlinear programming, stochastic programming, game theory, heuristic programming, direct computer search methods, and dynamic programming are observed to be not significant and the null hypothesis is accepted for these techniques. The null hypothesis is rejected and the alternate hypothesis is accepted for linear programming, PERT, critical path method, queueing theory, computer simulation, and exponential smoothing and regression analysis. Weak relationships between the education class and the use of the techniques are observed for queueing theory, computer simulation, and exponential smoothing and regression analysis. Weak-moderate relationships are observed between education class and the use of PERT and CPM.

TABLE 50

THE RELATIONSHIP BETWEEN EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASS AND THE FREQUENCY INDEX SCORE (FIS) FOR EACH OPERATIONS RESEARCH TECHNIQUE (N = 275)

Operations Research Techniques	Correlation Coefficient	Partial Correlation Coefficient (PCC)	Ranking (PCC)	Student t Value (PCC)	Significance Level
1. Linear Programming	.250	.185	3	3.100	< .01
2. Integer Programming	.103	.067	12	1.105	n.s.[a]
3. 0, 1 Programming (Binary)	.148	.101	7	1.669	n.s.[a]
4. Nonlinear Programming	.131	.081	9	1.339	n.s.[a]
5. Stochastic Programming	.121	.078	10	1.390	n.s.[a]
6. PERT	.282	.268	1	4.580	< .001
7. Critical Path Method (CPM)	.313	.252	2	4.400	< .001
8. Queueing Theory	.197	.164	6	2.739	< .01
9. Game Theory	.077	.046	13	.751	n.s.[a]
10. Computer Simulation	.240	.182	4	3.055	< .01
11. Heuristic Programming	.134	.078	10	1.290	n.s.[a]
12. Exponential Smoothing--Regression Analysis	.221	.173	5	2.890	< .01
13. Direct Computer Search Methods	.134	.083	8	1.347	n.s.[a]
14. Dynamic Programming	-.017	-.087	14	--	n.s.[a]

[a]Not significant at the .05 level.

Hypothesis 8: There is no significant relationship between the cross-effects of the firm size (number of employees) class, the industry group (investment per employee) class, and the education (top manufacturing executive) class and the extent of usage of each operations research techniques in manufacturing firms.

H_{08}:

$R_{12301} = 0$	$R_{12401} = 0$	$R_{13401} = 0$	$R_{123401} = 0$
$R_{12302} = 0$	$R_{12402} = 0$	$R_{13402} = 0$	$R_{123402} = 0$
$R_{12303} = 0$	$R_{12403} = 0$	$R_{13403} = 0$	$R_{123403} = 0$
$R_{12304} = 0$	$R_{12404} = 0$	$R_{13404} = 0$	$R_{123404} = 0$
$R_{12305} = 0$	$R_{12405} = 0$	$R_{13405} = 0$	$R_{123405} = 0$
$R_{12306} = 0$	$R_{12406} = 0$	$R_{13406} = 0$	$R_{123406} = 0$
$R_{12307} = 0$	$R_{12407} = 0$	$R_{13407} = 0$	$R_{123407} = 0$
$R_{12308} = 0$	$R_{12408} = 0$	$R_{13408} = 0$	$R_{123408} = 0$
$R_{12309} = 0$	$R_{12409} = 0$	$R_{13409} = 0$	$R_{123409} = 0$
$R_{12310} = 0$	$R_{12410} = 0$	$R_{13410} = 0$	$R_{123410} = 0$
$R_{12311} = 0$	$R_{12411} = 0$	$R_{13411} = 0$	$R_{123411} = 0$
$R_{12312} = 0$	$R_{12412} = 0$	$R_{13412} = 0$	$R_{123412} = 0$
$R_{12313} = 0$	$R_{12413} = 0$	$R_{13413} = 0$	$R_{123413} = 0$
$R_{12314} = 0$	$R_{12414} = 0$	$R_{13414} = 0$	$R_{123414} = 0$

H_{18}:	$R_{12301} \neq 0$	$R_{12401} \neq 0$	$R_{13401} \neq 0$	$R_{123401} \neq 0$
	$R_{12302} \neq 0$	$R_{12402} \neq 0$	$R_{13402} \neq 0$	$R_{123402} \neq 0$
	$R_{12303} \neq 0$	$R_{12403} \neq 0$	$R_{13403} \neq 0$	$R_{123403} \neq 0$
	$R_{12304} \neq 0$	$R_{12404} \neq 0$	$R_{13404} \neq 0$	$R_{123404} \neq 0$
	$R_{12305} \neq 0$	$R_{12405} \neq 0$	$R_{13405} \neq 0$	$R_{123405} \neq 0$
	$R_{12306} \neq 0$	$R_{12406} \neq 0$	$R_{13406} \neq 0$	$R_{123406} \neq 0$
	$R_{12307} \neq 0$	$R_{12407} \neq 0$	$R_{13407} \neq 0$	$R_{123407} \neq 0$
	$R_{12308} \neq 0$	$R_{12408} \neq 0$	$R_{13408} \neq 0$	$R_{123408} \neq 0$
	$R_{12309} \neq 0$	$R_{12409} \neq 0$	$R_{13409} \neq 0$	$R_{123409} \neq 0$
	$R_{12310} \neq 0$	$R_{12410} \neq 0$	$R_{13410} \neq 0$	$R_{123410} \neq 0$
	$R_{12311} \neq 0$	$R_{12411} \neq 0$	$R_{13411} \neq 0$	$R_{123411} \neq 0$
	$R_{12312} \neq 0$	$R_{12412} \neq 0$	$R_{13412} \neq 0$	$R_{123412} \neq 0$
	$R_{12313} \neq 0$	$R_{12413} \neq 0$	$R_{13413} \neq 0$	$R_{123413} \neq 0$
	$R_{12314} \neq 0$	$R_{12414} \neq 0$	$R_{13414} \neq 0$	$R_{123414} \neq 0$

Table 51 shows the relationships between the Frequency Index Score (FIS) on each operations research technique and all the possible combinations of firm size, industry group, and education classes. The direction and degree relationship is expressed as a multiple correlation coefficient. The F distribution statistic is an appropriate statistical test for the multiple correlation coefficient. Testing at the .05 level, the study shows that the null hypothesis is accepted for all possible combinations of firm size, industry group, and education for integer programming and game theory. The null hypothesis is accepted for the combination of industry group and

TABLE 51

THE RELATIONSHIPS BETWEEN THE FREQUENCY INDEX SCORES (FIS) ON EACH OPERATIONS RESEARCH TECHNIQUE AND COMBINATIONS OF FIRM SIZE (NUMBER OF EMPLOYEES) CLASS, INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) CLASS AND EDUCATION (TOP MANUFACTURING EXECUTIVE) CLASS (N = 275)

Operations Research Techniques	Firm Size and Industry Group Classes			Firm Size and Education Classes			Industry Group and Education Classes			Firm Size, Industry Group and Education Classes		
	MCC*	F Value	Significance Level	MCC*	F Value	Significance Level	MCC*	F Value	Significance Level	MCC*	F Value	Significance Level
1. Linear Programming	.266	6.878	< .01	.284	7.925	< .01	.296	8.675	< .01	.320	10.305	< .01
2. Integer Programming	.131	1.577	n.s.	.131	1.577	n.s.	.127	1.481	n.s.	.147	1.995	n.s.
3. 0, 1 Programming (Binary)	.200	3.764	< .05	.218	4.507	< .01	.161	2.404	n.s.	.223	4.727	< .01
4. Nonlinear Programming	.185	3.201	< .05	.168	2.624	< .05	.178	2.956	< .05	.201	3.803	< .01
5. Stochastic Programming	.174	2.820	< .05	.183	3.130	< .05	.137	1.728	n.s.	.190	3.383	< .05
6. PERT	.205	3.963	< .01	.317	10.092	< .01	.295	8.611	< .01	.332	11.190	< .01
7. Critical Path Method (CPM)	.291	8.357	< .01	.368	14.150	< .01	.330	11.039	< .01	.378	15.059	< .01
8. Queueing Theory	.232	5.139	< .01	.277	7.507	< .01	.200	3.764	< .05	.281	7.744	< .01
9. Game Theory	.119	1.298	n.s.	.120	1.320	n.s.	.091	.754	n.s.	.127	1.481	n.s.
10. Computer Simulation	.282	7.804	< .01	.329	10.965	< .01	.248	5.920	< .01	.332	11.190	< .01
11. Heuristic Programming	.216	4.421	< .01	.211	4.209	< .01	.170	2.688	< .05	.229	4.999	< .01
12. Exponential Smoothing--Regression Analysis	.225	4.817	< .01	.278	7.566	< .01	.228	4.953	< .01	.281	7.744	< .01
13. Direct Computer Search Methods	.191	3.420	< .05	.181	3.060	< .05	.176	2.888	< .05	.208	4.085	< .01
14. Dynamic Programming	.219	4.551	< .01	.194	3.533	< .05	.150	2.079	n.s.	.235	5.280	< .01

*Note: MCC = Multiple Correlation Coefficient
$P(F > 2.600) = .05$, $P(F > 3.78) = .01$

education classes for stochastic programming and for dynamic programming. All other multiple correlation coefficients are significant, the null hypothesis is rejected and the alternate hypothesis that the multiple correlation coefficients are not equal to zero is accepted. The relationship between the firm size and industry group classes and the use of operations research techniques is observed to be weak to weak-moderate for all of the techniques. The relationship between firm size and education classes and the use of the operations research techniques are observed to be moderate for PERT, critical path method (CPM) and computer simulation, and weak to weak-moderate for all other techniques. The relationship between industry group and education classes and the use of operations research techniques is observed to be moderate for CPM and weak to weak-moderate for all other techniques. The relationship between firm size, industry group, and education classes, and the use of operations research techniques is observed to be moderate for linear programming, PERT, CPM and computer simulation and weak to weak-moderate for all other techniques.

Results of the Nonresponse Study

The objective of the nonresponse study was to:

1. To endeavor to determine whether the respondents in the sample are representative of the population in terms of the education classes represented.

2. To endeavor to determine whether the respondents in the sample are biased toward or away from operations research techniques.

Technically, the only way to insure absolute assurance that the sample is representative of the population is to experience a 100 percent response rate on the mail survey. Since a 100 percent response rate is seldom experienced, nonresponse studies have become popular in endeavoring to provide additional information indicating the representativeness of a sample. This is the aim of the nonresponse study in this research: to provide additional information concerning the comparison of the distribution of firms among the education classes between the nonrespondents and the respondents and to compare the extent of usage of operations research techniques of the nonrespondents with the respondents.

Table 52 shows the comparison of the education of the nonresponding top manufacturing executives with the respondents. The number of respondents in each education class is shown and compared with the number of nonrespondents expected to be present in each education class based on the percentages present in the respondent firms included in the sample (275). A chi-square goodness of fit test was conducted; the results indicate that there is no significant difference between the distribution of firms in the different education classes between the nonrespondents and

TABLE 52

A COMPARISON OF THE EDUCATION (TOP MANUFACTURING EXECUTIVE) OF THE NONRESPONDENTS WITH RESPONDENTS

Education Class (C_i)	Nonrespondents (O_i)	Respondents (e_i)	$\frac{(O_i - e_i)^2}{e_i}$
C_1	1	1.833	.038
C_2	0	1.244	1.244
C_3	3	3.207	.013
C_4	9	5.563	2.123
C_5	5	6.153	.216
Total	18	18.000	3.634*

*Note: $P(X_4^2 > 9.490) = .05$

the respondents. On this point the research concludes that the sample utilized in this research (275 firms) is representative of the population when considering the distribution of firms among the education classes.

Table 53 shows a comparison of the number of firms which use any operations research techniques between the nonrespondents and the respondents. The number of nonrespondents which indicated the use of operations research techniques and the absence of the use of operations research techniques is compared with the expected number of firms in these to categories based on the information derived from the respondent firms in the sample (275 firms). A chi-square goodness of fit test was conducted; no significant difference was found between the portion of firms using any operations research techniques among the nonrespondents and the portion of firms using any operations research techniques among the respondent firms in the sample (275 firms). This research concludes that the sample (275 firms) is representative of the population when considering the use of any operations research techniques by the firms.

Table 54 shows the comparison of Frequency Index Scores (FIS) of the nonrespondents and the respondents. The FIS means and variances are compared for the respondent firms and nonrespondent firms. A chi-square test of significance was utilized to determine if there was a significant difference between the variances of the respondent

TABLE 53

A COMPARISON OF THE NUMBER OF FIRMS WHICH USE ANY OPERATIONS RESEARCH TECHNIQUES BETWEEN THE NONRESPONDENTS AND THE RESPONDENTS

Use Operations Research Techniques?	Number of Firms: Nonrespondents (o_i)	Number of Firms: Respondents (e_i)	$\frac{(o_i - e_i)^2}{e_i}$
Yes	12	8.705	1.247
No	6	9.295	1.168
Total		18.000	2.415*

*Note: $P(X_1^2 > 3.84) = .05$

TABLE 54

A COMPARISON OF THE FREQUENCY INDEX SCORES (FIS) OF THE NONRESPONDENTS AND THE RESPONDENTS

Statistic Name	Respondent Firms Statistic Value	Nonrespondent Firms Statistic Value	Statistical Test Employed	Statistical Test Value	Level of Significance
FIS Mean ($\overline{X}_i$)	16.558	17.333	t*	.704	< .05
FIS Variance (S_i)	4.592	2.867	X^2*	6.629	< .05

*Note: These tests of significance are discussed and explained in Appendix B-3.

firms and the nonrespondent firms. The conclusion was that there was no significant difference between the two variances. The FIS means were then compared between the respondent firms and the nonrespondent firms utilizing a Student t test of significance. The conclusion was that there was no significant difference between the FIS means of the respondent firms and the nonrespondent firms. This research concludes that the 275 firms in the sample are representative of the population when considering the extent of usage of operations research techniques.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The problem of this study was to ascertain the extent of adoption of operations research techniques by manufacturing organizations in a geographical region. This problem was investigated in a mail survey of the manufacturing firms with 250 or more employees in Oklahoma and the five states with common borders with Oklahoma. The following summary of that investigation is the basis for the conclusions and recommendations presented in this chapter.

Summary

State registers of manufacturers were utilized to provide pertinent data on all firms in the population. These sources show (1) name of the firm, (2) address, (3) class of products manufactured, (4) telephone number, (5) the top manufacturing executive's name and title, and (6) the number of employees class. The population of 1398 firms was stratified into two strata: Firm Size (number of employees) and Industry Group (investment per employee). Computer programs were utilized to select a proportional stratified random group of 500 firms as recipients of the mail survey.

A preliminary questionnaire instrument was designed and pilot tested in on-site interviews with executives from six leading Oklahoma City manufacturers. Insights into the understanding of operations research terminology by practitioners, user oriented questionnaire instruction suggestions, and questionnaire format suggestions provided informational constraints for a final questionnaire instrument design. A two-wave mailing program was executed which featured an advance letter, a cover-letter and the questionnaire, and a followup postcard in the first wave and a cover letter and questionnaire in the second wave. Each letter was individually typed and addressed to the top manufacturing executive at each location.

The mail survey resulted in a 55 percent (275/500) response rate. A telephone nonresponse study was executed featuring a stratified random sampling of the nonrespondents. This study verified that the nonrespondents were statistically equivalent to the respondents concerning the education of the top manufacturing executives and the extent of the firms' use of operations research techniques.

The data from the completed questionnaires of the respondents were transferred to IBM cards for final analysis. Statistics used in descriptive statistical analysis and inferential statistical analysis were generated by the OSIRIS computer software package of the Institute for

Social Research, University of Michigan.

Descriptive statistical analysis was performed on the data to provide information to answer five specific research questions about the extent of adoption of operations research techniques by the firms in the sample. Each of these research questions was not directly associated with a subsequently tested hypothesis, because each was intended to be informational in character providing one element of a collective description of the extent of usage of operations research techniques by the firms in the sample.

The five research questions were directed toward the Firm Size and Industry Group strata of firms concerning (1) the operations research techniques used and the frequency of use by the firms, (2) the operations research organizational units and the number of operations research personnel in the firms, (3) the types of manufacturing problems analyzed with these techniques by the firms, (4) management's opinion of the overall results achieved by personnel using these techniques in the firms, and (5) the problems encountered in using these techniques.

Eight hypotheses were formulated and tested in this study. These eight hypotheses actually consisted of two groups of four hypotheses each. The first group of hypotheses tested the relationship of (1) firm size, (2) industry group, (3) education of the top manufacturing executive, and (4) the cross effects of these factors, to the extent of usage of operations research techniques. The second group of hypotheses tested the relationship of (5) firm size, (6) industry group, (7) education of the top manufacturing executive, and (8) the cross effects of these factors, to the extent of usage of <u>each</u> operations research technique.

To test each of the eight hypotheses, a Frequency Index Score (FIS) was developed for each operations research technique for each firm of the sample and a total Frequency Index Score (FIS) for all techniques for each firm in the sample.

Partial correlation coefficients were computed between the single factors mentioned above and the FIS for each technique and the total FIS for each firm. Multiple correlation coefficients were computed between all possible combinations of these factors and the FIS for each technique and the total FIS for the firms. The null hypotheses stated that all of these correlation coefficients were zero. The hypotheses were tested at the conventional significance level of .05 or less. This means that the probability of concluding that the correlation coefficients are not zero when in fact they are zero is less than .05 (Type I error).

The eight hypotheses of this study provide additional insights into the answers to the research questions by identifying some factors or combinations of factors which tend to be present when operations research techniques are used by firms.

Conclusions

On the basis of the findings of this investigation, conclusions were drawn regarding the extent of adoption of operations research techniques in manufacturing firms in a geographical region and the identification of some of those factors or combinations of factors which tend to be present when operations research techniques are used.

The Extent of Adoption of Operations Research Techniques by Manufacturing Organizations

The results of analyzing the data associated with the research questions of this study led to the following conclusions:

1. Nearly one-half of the firms used operations research techniques and almost one-half of the using firms used four or more techniques. Over two-thirds of the using firms used PERT and CPM and over one-half used linear programming, exponential smoothing and regression analysis, and computer simulation. This indicates a moderately wide usage of operations research techniques in these firms.

2. A total of 773 operations research personnel was employed in 95 firms of the 275 firms of the sample. The mean number of operations research personnel increases progressively as the size of the firm increases. Firms in the paper, primary metals, chemicals and petroleum industries dominate all other industries by employing 41.7 percent of the total operations research personnel and two-thirds of the companies which employ 20 or more operations research personnel are from

these continuous process industries. The predominate organizational arrangement for operations research personnel is to integrate them into other line and staff groups with broader purposes. Moderate popularity was shown for the formal staff groups of (1) systems analysis and data processing, (2) operations research/management science, (3) process, product and technical engineering, and (4) production planning, scheduling and control.

3. The using firms ranked the manufacturing problems analyzed most by operations research techniques as (1) production planning and control, (2) project planning and control, (3) inventory analysis and control, and grouped very closely in fourth, fifth and sixth were quality control, analyzing capital investment projects, and maintenance planning. The using firms ranked the operations research techniques as being the most flexible in being applied to a variety of manufacturing problems as (1) linear or nonlinear programming, (2) computer simulation, (3) PERT and CPM, (4) exponential smoothing and regression analysis, and (5) queueing theory. Only slight variations to these rankings were observed across all firm size and industry group classes.

4. The overall results achieved by operations research personnel were rated good to very good by nearly 80 percent of the using firms. No firms rated the results as poor. These ratings in the larger firms appear to be affected by the practice of delegating the responsibility for completing the questionnaire from top management to managers of operations research functions, thus contaminating with an upward bias.

5. The problems encountered in using operations research techniques were ranked as (1) production personnel are inadequately trained, (2) competent personnel with quantitative training are scarce, (3) staff personnel don't sell these solutions and approaches, and (4) returns from expenditures on these techniques are inadequate. These rankings may also contain the bias discussed in conclusion 4.

Some Factors or Combinations of Factors Which Tend to be Present When Operations Research Techniques Are Used

The results of testing the hypotheses of this study led to the following conclusions:

1. Partial correlation analysis demonstrated a significant (weak - moderate) relationship between firm size and the use of operations research techniques. The distributions of the percentage of firms using any techniques, the number and frequency of use of the techniques, and the mean number of operations research personnel per firm, across the firm size classes reinforced the significance of the relationship. The positive form of hypothesis number one has been adequately substantiated.

2. Partial correlation analysis demonstrated a significant (weak) relationship between industry group and the use of operations research techniques. The intermittent nature of this trend across industry group classes was observed for the percentage of firms using any techniques, the number and frequency of use of the techniques, and the mean number of operations research personnel per firm; therefore demonstrating the positive but weak relationship. The positive form of hypothesis number two has been adequately substantiated.

3. Partial correlation analysis demonstrated a significant (weak - moderate) relationship between the education of the top manufacturing executive and the use of operations research techniques. The intermittent nature of the trends for the percentage of firms using any techniques, and the number and frequency of use of the techniques, and the continuous trend for the mean number of operations research personnel per firm, across all education classes supported this conclusion. The positive form of hypothesis number three has been adequately substantiated.

4. Multiple correlation analysis demonstrated a significant (moderate) relationship between the possible combinations of firm size, industry group and education of the top manufacturing executive on the one hand and the use of operations research techniques on the other. The positive form of hypothesis number four has been adequately substantiated.

5. Partial correlation analysis demonstrated a significant (weak to moderate) relationship between firm size and the use of <u>each</u> operations research technique, except for integer programming, nonlinear programming, game theory, and direct computer search methods, which were not significant. The positive form of hypothesis number five has been adequately substantiated for all techniques except for those mentioned above.

6. Partial correlation analysis demonstrated a significant (weak to moderate) relationship between industry group and the use of linear programming and dynamic programming, whereas all other techniques were not significant. The positive form of hypothesis number six has been adequately substantiated for linear programming and dynamic programming and rejected for all other techniques.

7. Partial correlation analysis demonstrated a significant (weak-moderate to moderate) relationship between the education of the top manufacturing executive and the use of linear programming, PERT, CPM, queueing theory, computer simulation and exponential smoothing and regression analysis, whereas all other techniques were not significant. The positive form of hypothesis number seven has been substantiated for these techniques mentioned above and rejected for all other techniques.

8. Multiple correlation analysis demonstrated a significant (weak to moderate) relationship between all the possible combinations of firm size, industry group and education of the top manufacturing executive on the one hand and the use of <u>each</u> operations research technique on the other, with two exceptions: (1) integer programming and game theory with all possible combinations of the factors, and (2) 0,1 programming, stochastic programming and dynamic programming with the combination of industry group and education of the top manufacturing executive, which were all not significant. With the exception of the combination of factors and techniques noted above, the positive form of hypothesis number eight has been substantiated.

Recommendations

The conclusions reached in this study indicate: (1) a moderately wide spread usage of operations research techniques among manufacturing firms, (2) a relative concentration of operations research personnel in the continuous process industries, (3) an integration of operations research personnel into other line and staff groups with broader purposes, (4) the ranking of manufacturing problems most commonly analyzed with operations research techniques, (5) the operations research techniques which are most flexible in being applied to a variety of manufacturing problems, (6) general satisfaction with the results of operations research personnel activities, and (7) the identification of the most common problems encountered in the use of operations research techniques in manufacturing firms. Accordingly, the following recommendations are made:

1. Colleges and universities should require all students who are majoring in fields which will bring them into contact with manufacturing personnel to have a general background in operations research terminology and applications.

2. Courses in production/operations management should emphasize PERT, CPM, linear programming, exponential smoothing and regression analysis, computer simulation and queueing theory; particularly as these techniques apply to production planning and control, project planning and control, and inventory analysis and control.

3. Advanced courses in production/operations management should integrate the operations research techniques proficiency with the behavioral aspects of "selling" solutions and approaches to other less quantitatively trained organizational members.

4. Further research similar to this study should be conducted in other segments of our economy, particularly in service industries, such as health care, and governmental agencies; to provide a multi-market measure of the demand for training in operations research.

5. Further research in manufacturing is needed to determine in much more detail how firms use operations research techniques. Particular attention should be given to classes of firms such as large firms and firms from continuous process industries. Detailed problem descriptions and their solutions could result in cases to provide classroom and training program realism. This research could also result in the application of documented successful solutions to heretofore unsolved problems in other industries.

6. Further research in manufacturing needs to determine the shortcomings of particular operations research techniques in solving particular operations problems. Then and only then can better solution methods be developed.

7. Institutions of higher learning should be more aware of the training programs of regional manufacturers and should conduct research into their needs for assistance in developing and evaluating company employee training programs which include such topics as operations research.

8. The facilities of manufacturers and the resources of colleges and universities should be researched for potential areas of cooperation in education programs that would provide work-study opportunities in areas such as operations research.

9. Colleges and universities should conduct research into the needs of regional manufacturers for on-campus formal adult continuing education programs to augment company employee training programs in such areas as operations research.

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APPENDICES

APPENDIX A

QUESTIONNAIRE

APPENDIX A-1

PILOT TEST QUESTIONNAIRE

A REGIONAL SURVEY AMONG MANUFACTURING EXECUTIVES

(Please check the appropriate box for each question.)

SECTION A: INFORMATION ABOUT YOU

I. Have you attended training sessions or seminars on the uses of computers, model building, or quantitative techniques such as: Linear Programming, PERT and CPM, Queueing Theory, Game Theory, Simulation, Heuristic Programming, Direct Search Methods, Dynamic Programming, Forecasting Models, etc.? .... Yes☐ No☐

II. Have you attended college? .... Yes☐ No☐

(If "No," please skip to Section B.)

III. How many years have you attended college?

1. 2 or less ....☐
2. More than 2, but less than 4 ....☐
3. 4 or more ....☐

IV. What was your major field of study in college?

1. Engineering ....☐
2. Mathematics, statistics, physics or other sciences ....☐
3. Business ....☐
4. Education, psychology, sociology or other social sciences ....☐
5. Other (please specify) ___________________

V. When did you last attend one full year of college?

1. Before 1950 ....☐
2. 1950-1959 ....☐
3. 1960-1969 ....☐
4. 1970-present ....☐

SECTION B: INFORMATION ABOUT QUANTITATIVE TECHNIQUES IN YOUR COMPANY

I. Do personnel at your location use <u>any</u> of the following quantitative techniques in manufacturing?

1. Network Planning Models (PERT, CPM)
2. Waiting Line Models (Queueing Theory)
3. Competitive Models (Game Theory)
4. Forecasting Models (moving average, regression, exponential smoothing, etc.)
5. Dynamic Programming
6. Computer Simulation
7. Heuristic Programming
8. Direct Search Methods
9. Mathematical Programming (linear, integer, binary, nonlinear)

Yes☐ No☐

(If "No," please skip to Question V of this section.)

II. How often are the following quantitative techniques used at your location in manufacturing?

	ROUTINELY	PERIODICALLY	OCCASIONALLY	RARELY	NEVER
1. Linear Programming	☐	☐	☐	☐	☐
2. Integer Programming	☐	☐	☐	☐	☐
3. 0,1 Programming (Binary)	☐	☐	☐	☐	☐
4. Nonlinear Programming	☐	☐	☐	☐	☐
5. Stochastic Programming	☐	☐	☐	☐	☐
6. PERT	☐	☐	☐	☐	☐
7. Critical Path Method (CPM)	☐	☐	☐	☐	☐
8. Queueing Theory	☐	☐	☐	☐	☐
9. Game Theory	☐	☐	☐	☐	☐
10. Computer Simulation	☐	☐	☐	☐	☐
11. Heuristic Programming	☐	☐	☐	☐	☐
12. Forecasting Models (moving average, regression, exponential smoothing, etc.)	☐	☐	☐	☐	☐
13. Direct Search Methods	☐	☐	☐	☐	☐
14. Dynamic Programming	☐	☐	☐	☐	☐
Other (Please Specify)					
15. ________________	☐	☐	☐	☐	☐
16. ________________	☐	☐	☐	☐	☐
17. ________________	☐	☐	☐	☐	☐
18. ________________	☐	☐	☐	☐	☐

III. Which quantitative techniques are used to study the following types of manufacturing problems at your location? (Please check the boxes that apply.)

	MATHEMATICAL PROGRAMMING	PERT, CPM	SIMULATION	QUEUEING THEORY	FORECASTING MODELS	DYNAMIC PROGRAMMING	HEURISTIC PROGRAMMING	DIRECT SEARCH METHODS	GAME THEORY
1. Facility location ..	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. Line balancing	☐	☐	☐	☐	☐	☐	☐	☐	☐
3. Blending	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. Reducing trim waste.	☐	☐	☐	☐	☐	☐	☐	☐	☐
5. Material allocation	☐	☐	☐	☐	☐	☐	☐	☐	☐
6. Capacity allocation	☐	☐	☐	☐	☐	☐	☐	☐	☐
7. Product mix	☐	☐	☐	☐	☐	☐	☐	☐	☐
8. Logistics studies ..	☐	☐	☐	☐	☐	☐	☐	☐	☐
9. Facilities layout ..	☐	☐	☐	☐	☐	☐	☐	☐	☐
10. Production planning and control ...	☐	☐	☐	☐	☐	☐	☐	☐	☐
11. Inventory analysis and control	☐	☐	☐	☐	☐	☐	☐	☐	☐
12. Project planning and control	☐	☐	☐	☐	☐	☐	☐	☐	☐
13. Waiting lines	☐	☐	☐	☐	☐	☐	☐	☐	☐
14. System reliability .	☐	☐	☐	☐	☐	☐	☐	☐	☐
15. Equipment design analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐
16. Maintenance planning	☐	☐	☐	☐	☐	☐	☐	☐	☐
17. Service crew size ..	☐	☐	☐	☐	☐	☐	☐	☐	☐
18. Holding area size ..	☐	☐	☐	☐	☐	☐	☐	☐	☐
19. Machines per operator	☐	☐	☐	☐	☐	☐	☐	☐	☐
20. Analyzing capital investment projects.	☐	☐	☐	☐	☐	☐	☐	☐	☐
21. Quality control	☐	☐	☐	☐	☐	☐	☐	☐	☐
Others (Please Specify)									
22. ____________	☐	☐	☐	☐	☐	☐	☐	☐	☐
23. ____________	☐	☐	☐	☐	☐	☐	☐	☐	☐
24. ____________	☐	☐	☐	☐	☐	☐	☐	☐	☐

IV. 1. Approximately how many personnel at your location use the following techniques in manufacturing: Mathematical Programming, PERT and CPM, Queueing Theory, Game Theory, Simulation, Heuristic Programming, Direct Search Methods, Dynamic Programming, Forecasting Models, etc.? (If necessary, please combine personnel who use these techniques part-time to arrive at an estimate of equivalent full-time personnel) .... _____

2. How many formal staff groups at your location assist manufacturing (as their primary function) by using these techniques to analyze manufacturing operations? .... _____

How many college-trained personnel are in each of these formal staff groups?

Group #1 _____, Group #2 _____, Group #3 _____, Group #4 _____

3. In your opinion, what results have these personnel produced while using these quantitative techniques?

Excellent ☐ , Very Good ☐ , Good ☐ , Fair ☐ , Poor ☐

V. What problems has your company encountered in using the following quantitative techniques: Mathematical Programming, PERT and CPM, Queueing Theory, Game Theory, Simulation, Heuristic Programming, Direct Search Methods, Dynamic Programming, Forecasting Models, etc.? (Please check each box that applies.)

1. Lack of top management interest .... ☐
2. Production personnel have inadequate training .... ☐
3. Inadequate computer .... ☐
4. Inability of staff personnel to sell these approaches and solutions .... ☐
5. Inadequate return from expenditures on these techniques .... ☐
6. High turnover of quantitative personnel .... ☐
7. Quantitative personnel are too impractical .... ☐
8. Staff personnel's reluctance to assist in implementation of quantitative solutions .... ☐
9. It takes too long to get answers .... ☐
10. These models and solutions are too simple .... ☐
11. Scarcity of competent personnel with quantitative training .... ☐
12. Inadequate data for models .... ☐
13. Others (please specify) ______________________________

VI. Please comment on any other use of quantitative techniques at your location or problems associated with their use which you have not mentioned in the questionnaire _______

A REGIONAL SURVEY AMONG MANUFACTURING EXECUTIVES

(Please check the appropriate box for each question.)

SECTION A: INFORMATION ABOUT YOU

I. Have you attended training sessions or seminars on any of the following: uses of computers, computer model building, Linear Programming, PERT and CPM, Queueing Theory, Game Theory, Computer Simulation, Heuristic Programming, Direct Computer Search Methods, Dynamic Programming, Exponential Smoothing-Regression Analysis, etc.? .... Yes ☐ No ☐

II. Have you attended college? .... Yes ☐ No ☐

(If "No," please skip to Section B)

III. How many years have you attended college?

1. 2 or less ....☐
2. More than 2, but less than 4 ....☐
3. 4 or more ....☐

IV. What college degrees have you received?

1. None ....☐
2. Bachelors ....☐
3. Masters ....☐
4. Doctors ....☐

V. What was your major field of study in college?

1. Engineering ....☐
2. Mathematics, statistics, physics or other sciences ....☐
3. Business ....☐
4. Education, psychology, sociology or other social sciences ....☐
5. Other (please specify) ______________________________

VI. When did you last attend one full year of college?

1. Before 1950 ....☐
2. 1950-1959 ....☐
3. 1960-1969 ....☐
4. 1970-present ....☐

SECTION B: INFORMATION ABOUT QUANTITATIVE TECHNIQUES IN YOUR COMPANY

I. Do personnel at your location use **any** of the following quantitative techniques in manufacturing?

1. Network Planning Models (PERT, CPM)
2. Waiting Line Models (Queueing Theory)
3. Competitive Models (Game Theory)
4. Exponential Smoothing—Regression Analysis
5. Dynamic Programming
6. Computer Simulation
7. Heuristic Programming
8. Direct Computer Search Methods
9. Linear Programming

(If "No," please skip to Question VI of this section.) Yes ☐ No ☐

II. How often are the following quantitative techniques used at your location in manufacturing?

		Routinely	Occasionally	Never
1.	Linear Programming	☐	☐	☐
2.	Integer Programming	☐	☐	☐
3.	0, 1 Programming (Binary)	☐	☐	☐
4.	Nonlinear Programming	☐	☐	☐
5.	Stochastic Programming	☐	☐	☐
6.	PERT	☐	☐	☐
7.	Critical Path Method (CPM)	☐	☐	☐
8.	Queueing Theory	☐	☐	☐
9.	Game Theory	☐	☐	☐
10.	Computer Simulation	☐	☐	☐
11.	Heuristic Programming	☐	☐	☐
12.	Exponential Smoothing—Regression Analysis	☐	☐	☐
13.	Direct Computer Search Methods	☐	☐	☐
14.	Dynamic Programming	☐	☐	☐
	Others (Please Specify)			
15.	______________________	☐	☐	☐
16.	______________________	☐	☐	☐
17.	______________________	☐	☐	☐
18.	______________________	☐	☐	☐

III. Which quantitative techniques are used to study the following types of manufacturing problems at your location? (Please check the boxes that apply. More than one box may be checked for each line.)

		Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing —Regression Analysis	Other Techniques (Please write the techniques in the blanks and check the boxes that apply.)		
1.	Facility location	☐	☐	☐	☐	☐	☐	☐	☐
2.	Line balancing	☐	☐	☐	☐	☐	☐	☐	☐
3.	Chemical or Ingredient Blending	☐	☐	☐	☐	☐	☐	☐	☐
4.	Reducing trim waste	☐	☐	☐	☐	☐	☐	☐	☐
5.	Material allocation	☐	☐	☐	☐	☐	☐	☐	☐
6.	Capacity allocation	☐	☐	☐	☐	☐	☐	☐	☐
7.	Product mix	☐	☐	☐	☐	☐	☐	☐	☐
8.	Logistics studies	☐	☐	☐	☐	☐	☐	☐	☐
9.	Facilities layout	☐	☐	☐	☐	☐	☐	☐	☐
10.	Production planning and control	☐	☐	☐	☐	☐	☐	☐	☐
11.	Inventory analysis and control	☐	☐	☐	☐	☐	☐	☐	☐
12.	Project planning and control	☐	☐	☐	☐	☐	☐	☐	☐
13.	Waiting lines	☐	☐	☐	☐	☐	☐	☐	☐
14.	System reliability	☐	☐	☐	☐	☐	☐	☐	☐
15.	Equipment design analysis	☐	☐	☐	☐	☐	☐	☐	☐
16.	Maintenance planning	☐	☐	☐	☐	☐	☐	☐	☐
17.	Service crew size	☐	☐	☐	☐	☐	☐	☐	☐
18.	Holding area size	☐	☐	☐	☐	☐	☐	☐	☐
19.	Machines per operator	☐	☐	☐	☐	☐	☐	☐	☐
20.	Analyzing capital investment projects	☐	☐	☐	☐	☐	☐	☐	☐
21.	Quality control	☐	☐	☐	☐	☐	☐	☐	☐
	Others (Please specify)								
22.	______	☐	☐	☐	☐	☐	☐	☐	☐
23.	______	☐	☐	☐	☐	☐	☐	☐	☐
24.	______	☐	☐	☐	☐	☐	☐	☐	☐

IV. 1. Do you have formal staff groups at your location whose **primary function** is to assist manufacturing to analyze manufacturing operations by using the following techniques: Linear Programming, PERT and CPM, Queueing Theory, Game Theory, Computer Simulation, Heuristic Programming, Direct Computer Search Methods, Dynamic Programming, Exponential Smoothing-Regression Analysis, etc.? .... Yes ☐ No ☐

(If "NO," please skip to question 3)

2. What are the titles of these formal staff groups and how many college trained personnel are in each group who devote the majority of their time to the use of these techniques?

	Formal Staff Group Title	Number of Personnel
a.	______________	______
b.	______________	______
c.	______________	______
d.	______________	______

3. How many college trained personnel devote the majority of their time to the use of these techniques in assisting manufacturing in analyzing manufacturing operations, but are integrated into other line or staff groups with broader purposes? .... ______

4. In your opinion, what overall results have these personnel achieved while using these quantitative techniques?

Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor ☐

V. What problems has your company encountered in using the following quantitative techniques: Linear Programming, PERT and CPM, Queueing Theory, Game Theory, Computer Simulation, Heuristic Programming, Direct Computer Search Methods, Dynamic Programming, Exponential Smoothing—Regression Analysis, etc.? (Please check each box that applies).

1. Top Management doesn't understand .... ☐
2. Production personnel are inadequately trained .... ☐
3. The Computer is inadequate .... ☐
4. Staff personnel don't sell these approaches and solutions .... ☐
5. Returns from expenditures on these techniques are inadequate .... ☐
6. The turnover of quantitative personnel is high .... ☐
7. Quantitative personnel are too impractical .... ☐
8. Staff personnel are reluctant to assist in the implementation of quantitative solutions .... ☐
9. It takes too long to get answers .... ☐
10. These models make too many unrealistic assumptions .... ☐
11. Competent personnel with quantitative training are scarce .... ☐
12. Data for these models is inadequate .... ☐
13. Others (please specify) ____

____

VI. Please comment on any other use of quantitative techniques at your location or problems associated with their use which you have not mentioned in the questionnaire ______________________

____

____

____

____

APPENDIX B

STATISTICAL ANALYSIS CONSIDERATIONS

APPENDIX B-1

ORDINAL DATA AND PARAMETRIC STATISTICS

There is an unsettled question in statistical literature which has resisted academic consensus: Under what circumstances should parametric and nonparametric tests of significance be used? If the academicians were dichotomized into two extreme positions on this issue, their respective positions would be:

1. Unless all of the assumptions of the parametric tests can be satisfied, nonparametric tests must be used.
2. Parametric tests are and should be used universally as the everyday tools of statistics. Nonparametric tests should be used only as screening devices or in cases of extreme gross deviations from parametric assumptions.

Nonparametric statistical research led to a variety of publications during the early to mid-1950's.[1] This rise of interest in nonparametric tests stems from two main sources. One is the concern about the use of parametric tests when the

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[1] A. L. Edwards, Statistical Methods for the Behavioral Sciences (New York: Rinehart, 1954); L. E. Moses, "Non-parametric Statistics for Psychological Research," Psychological Bulletin, 1952, 49, pp. 122-43; F. Mosteller, and Q. R. Bush, "Selected Quantitative Techniques," In G. Lindsey (Ed.), Handbook of Social Psychology, Vol. 1, Theory and Method (Cambridge, Mass.: Addison-Wesley, 1954); S. Siegel, Non-parametric Statistics for the Behavioral Sciences (New York: McGraw-Hill, 1956).

underlying assumptions of normality and homogeneity of variance are not met and the other is whether the measurement scale is appropriate for the application of parametric procedures.

During the late 1950's and early 1960's a substantial number of publications examined these objections to parametric statistics and sought to measure the performance of parametric tests when the assumptions were violated. The parametric F test is most generally used as the vehicle for comparison to nonparametric tests when the parametric assumptions are violated. The conclusions are also generally applied to the parametric t-test and correlation analysis as special cases of the F test.[2]

The three main points of comparison between parametric and nonparametric tests are significance level, power, and versatility.

Significance Level

The main conclusion of the various investigators is that the lack of normality and homogeneity of variance has little effect.

> No matter what the variance differences may be, samples as small as five will produce results for which the true probability of rejecting the null hypothesis at the .05 level will more than likely be within .03 of that level. If the sample size is as large as 15, the true

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[2] N. H. Anderson, "Scales and Statistics: Parametric and Nonparametric," Psychological Bulletin, 1961, 58, No. 4, pp. 305-16.

> probabilities are quite likely within .01 of the nominal value.[3]

Exceptions to this conclusion are where one finds heterogeneity of variance and (1) great differences in sample sizes and (2) the one-tailed t-test.[4] These exceptions become insignificant as sample sizes approach 25. Boneau states that "with sample sizes of 25 or greater these parametric tests become functionally nonparametric."[5]

In most cases departures from normality and homogeneity of variance do not affect the significance level of the F, t, and correlation parametric tests.

Power

Dixon and Massey reflect the views of many investigators:

> Rank order tests are nearly as powerful as parametric tests under equinormality. Consequently, there would seem to be no pressing reason in most investigations to use parametric techniques for reasons of power if an appropriate rank order test is available. Of course, the loss of power involved is dichotomizing the data for a median-type test is considerable.[6]

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[3]C. A. Boneau, "The Effects of Violations of Assumptions Underlying the t-Test," Psychological Bulletin, 1960, 57, pp. 49-64.

[4]Boneau, "The Effects of Violations of Assumptions Underlying the T-Test;" E. F. Lindquist, Design and Analysis of Experiments (Boston: Houghton-Mifflin, 1953); W. G. Cochran, "Some Consequences when the Assumptions for the Analysis of Variance Are Not Satisfied," Biometrica, 1947, 3, pp. 22-38; and N. H. Anderson, "Scales and Statistics."

[5]Boneau, Ibid.

[6]W. J. Dixon and F. J. Massey, Jr., Introduction to Statistical Analysis (2nd ed.) (New York: McGraw-Hill, 1957); J. Gaito, "Nonparametric Methods in Psychological Research," Psychological Reports, 1959, 5, pp. 115-25.

Parametric tests can claim no particular improvement in power over nonparametric tests.

Versatility

The breadth of applicability of many parametric tests is emphasized by the following examples.

The use of replications in analysis of variance as a factor in the design makes it possible to test and partially control for snift in apparatus, procedure, or population during the course of an experiment.[7] Similar arguments could be given for latin squares when subjects are given successive treatments;[8] orthogonal polynomials and trend tests for correlated scores;[9] and the multivariate analysis of variance which is applicable to correlated dependent variables measured on incommensurable scales.[10]

The point to these examples is that their analysis is more or less routine when parametric procedures are used. However, they are handled inadequately or not at all by nonparametric methods.[11]

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[7] Gaito, Ibid.

[8] M. B. Wilk and O. Kempthorne, "Fixed, Mixed, and Random Models," Journal of American Statistics Association, 1955, 50, pp. 1144-67.

[9] D. A. Grant, "Analysis of Variance Tests in the Analysis and Comparison of Curves," Psychological Bulletin, 1956, 53, pp. 141-54.

[10] C. R. Rao, Advanced Statistical Methods in Biometric Research (New York: Wiley, 1952).

[11] N. H. Anderson, "Scales and Statistics," p. 307.

Anderson summarized the work of these investigators and concluded:

> It thus seems fair to conclude that parametric tests constitute the standard tools of psychological statistics. In respect of significance level and power, one might claim a fairly even match. However, the versatility of parametric procedures is quite unmatched and this is decisive. Unless and until nonparametric tests are developed to the point where they meet the routine needs of the researcher as exemplified by the above designs, they cannot realistically be considered as competitors to parametric tests. Until that day, nonparametric tests may best be considered as useful minor techniques in the analysis of numerical data.[12]

Gaito agrees with Anderson in his conclusion: "An investigator would want to use parametric methods unless there is definite information to indicate great deviation from the assumptions."[13]

Can Parametric Tests be Performed with Ordinal Data?

Siegel's answer to this question would be an unqualified "No."[14] Anderson feels that Siegel's position is completely incorrect:

> When equinormality obtains, the F or t tests may be applied without qualm. It will then answer the question it was designed to answer: can we reasonably conclude that the difference between the means of the groups is real or rather due to chance?"[15]

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[12]N. H. Anderson, Ibid., p. 307.

[13]J. Gaito, "Nonparametric Methods in Psychological Research," p. 123.

[14]S. Siegel, Nonparametric Statistics (New York: McGraw-Hill, 1956).

[15]N. H. Anderson, "Scales and Statistics: Parametric and Nonparametric," p. 309.

Lord agrees with Anderson:

> The statistical test can hardly be cognizant of the empirical meaning of the numbers with which it deals. Consequently, the validity of a statistical inference cannot depend on the type of measuring scale used.

If equinormality does not hold, parametric tests may still be used with about the same level of significance in most cases. The parametric test might have less power than a rank order test so that the nonparametric test would be preferred. This assumes, of course, that a comparable non-parametric test is available. In either case, the choice of statistical test would be based on statistical considerations without any relevancy to the scale type.

Conclusion

There is ample support in the current literature to use parametric tests (F, t, and correlation analysis) in the analysis of ordinal scale data such as that used in this study. The inability to assume normality and homogeneity of variance is no barrier to the use of parametric tests. Inferential statistical analysis which uses a nonparametric partial correlation analysis to examine cross effects is not available; consequently, partial correlation analysis, a parametric test was used to analyze ordinal data in this research.[18]

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[16] F. M. Lord, "On the Statistical Treatment of Football Numbers," American Psychologist, VIII (1953), pp. 750-51.

[17] N. H. Anderson, "Scales and Statistics," p. 309.

[18] S. Siegel, Nonparametric Statistics for the Behavioral Sciences (New York: McGraw-Hill, 1956), pp. 228-29; William L. Hays, Statistics for the Social Sciences (New York: Holt, Rinehart & Winston, Inc., 1973), p. 786; Hubert M. Blalock, Jr., Social Statistics (New York: McGraw-Hill, 1972), p. 311.

APPENDIX B-2

SIMPLE, PARTIAL AND MULTIPLE CORRELATION ANALYSIS

Simple Correlation Analysis

Correlation analysis in general seeks to determine the closeness of the relationship between variables. Simple Correlation Analysis seeks to measure the closeness of the relationship between two variables. Unless otherwise stated, correlation analysis means linear correlation analysis which seeks to fit a straight line to the paired observations.

The measure of the relationship between variables is the coefficient of correlation.[1]

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

where: r = coefficient of correlation

X = observed value of independent random variable

Y = observed value of dependent random variable, observed simultaneously with X for paired observations

N = number of observations

[1] Chou, Ya-lun, Statistical Analysis with Business and Economic Applications (Jamaica, New York: Holt, Rinehart and Winston, Inc., 1969), p. 617.

The value of r may range from -1.0 to +1.0. The value of r generally has the following meanings:

r = -1.0 = perfect negative correlation. As X increases in value, Y decreases and as X decreases, Y increases in value unit for unit.

r = 0 = no relationship.

r = +1.0 = perfect positive correlation. As X increases in value, Y increases and as X decreases, Y decreases in value unit for unit.

The sign of r indicates the direction of the relationship and the magnitude indicates the degree of the relationship. No precise meaning can be attached to the magnitude of r except to develop experience in the relationships being investigated over time and interpret experimental results in light of experience. For example, r = .300 can be highly important to investigators in some fields of psychological research and be a very weak relationship in the physical sciences: this must be determined by relating experimental results to the experience in the field.[2]

This research describes values of r as follows:

r = 0 - .009 = very weak

r = .100 - .199 = weak

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[2]William C. Guenther, Concepts of Statistical Inference (New York: McGraw-Hill, 1954), p. 241.

r = .200 - .299 = weak-moderate

r = .300 - .399 = moderate

r = .400 - .499 = strong

r = .500 - 1.000 = very strong

Interpretation of r must not go beyond relationships and into cause and effect relationships. A very large positive r does not indicate that the independent variable has "caused" the dependent variable to increase, but <u>only</u> that as one variable increases, the other variable also increases.

Partial Correlation Analysis

Partial correlation analysis permits the measure of the relationship between one dependent variable and one independent variable with other specified independent variables "held constant" statistically.

The measure of the relationship between one independent variable and one dependent variable is the partial correlation coefficient. The lower case r is used as the symbol for the coefficient of partial correlation, with the subscripts indicating the two principal dependent and independent variables by listing them first and designating the variables held constant. Thus, $r_{12 \cdot 34}$ indicates that the correlation reported is between variables 1 and 2 and that the variables held constant are those numbered

3 and 4.[3]

If $r_{12\cdot 34}$ is the partial correlation coefficient between X_1 and X_2 keeping X_3 and X_4 constant:[4]

$$r_{12\cdot 34} = \frac{r_{12\cdot 3} - r_{14\cdot 3}r_{24\cdot 3}}{\sqrt{(1 - r^2_{14\cdot 3})(1 - r^2_{24\cdot 3})}}$$

where: $r_{12\cdot 3} = \dfrac{r_{12} - r_{13}r_{23}}{\sqrt{(1 - r^2_{13})(1 - r^2_{23})}}$

where: r_{12} = simple correlation coefficient between variables 1 and 2.

Fortunately standard computer software packages are available so that manual calculations of these partial correlation values are unnecessary. The OSIRIS subroutine package from the Institute for Social Research, University of Michigan, was used for this purpose in this research. The sign and magnitude of the partial correlation coefficient is interpreted in the same way as the simple correlation coefficient.

Multiple Correlation Analysis

Multiple Correlation Analysis permits the measure of the relationship between two or more independent variables

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[3]Leonard J. Kazmier, Statistical Analysis for Business and Economics (New York: McGraw-Hill Book Company, 1967), p. 290.

[4]Murray R. Spiegel, Statistics (New York: McGraw-Hill Book Company, 1961), p. 272.

on the one hand with one dependent variable on the other.

The measure of the relationship between a single dependent variable and several independent variables taken as a group is the multiple correlation coefficient. The symbol for the multiple correlation coefficient, R, is usually written with a subscript, and in the subscript the number 1 always refers to the single dependent variable. Thus, $R_{1\cdot 23}$ indicates that the coefficient is a measure of the relationship between the dependent variable 1 and the independent variables 1 and 2 taken as a group.

If $R_{1\cdot 23}$ is the multiple correlation coefficient between X_1 and (X_2 and X_3):[5]

$$R_{1\cdot 23} = \sqrt{\frac{r_{12}^2 + r_{13}^2 - 2r_{12}r_{13}r_{23}}{1 - r_{23}^2}}$$

where: r_{12} = simple correlation coefficient between X_1 and X_2.

The computer software package of OSIRIS was also utilized to compute multiple correlation coefficients in this study.

The sign and magnitude of the multiple correlation coefficient are interpreted in the same way as the simple correlation coefficient discussed earlier in this appendix.

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[5] Murray R. Spiegel, Statistics, p. 271.

APPENDIX B-3

STATISTICAL TESTS OF SIGNIFICANCE

Partial Correlation Tests of Significance

The t test employed to test the simple correlation can be used to test the significance of partial correlation when the number of degrees of freedom is reduced by the number of variables. Thus, to test the significance of $r_{12\cdot3}$:[1]

$$t = r_{12\cdot3}\sqrt{\frac{n - k}{1 - r^2_{12\cdot3}}}$$

where: $r_{12\cdot3}$ = partial correlation coefficient between variables 1 and 2, holding variable 3 constant.

n = number of observations

k = total number of independent and dependent variables (in this example $k = 3$).

t = the Student t value

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[1]Ya-lun Chou, Statistical Analysis with Business and Economic Applications (Jamaica, New York: Holt, Rinehart and Winston, Inc., 1969), p. 651.

Multiple Correlation Tests of Significance

The multiple correlation coefficient, R, is known to be distributed as an F distribution; consequently, the F test may be employed to test the significance of R.[2]

$$F = \frac{R^2_{1\cdot 23}}{1 - R^2_{1\cdot 23}} \cdot \frac{N - m - 1}{m}, \quad \delta_1 = m, \quad \delta_2 = N - m - 1$$

where: $R_{1\cdot 23}$ = the multiple correlation coefficient between variable 1 and (variables 2 and 3).

N = number of observations

m = number of independent variables (in this example $m = 2$)

δ_1 = degrees of freedom_1

δ_2 = degrees of freedom_2

Goodness of Fit between the Observed Nonrespondents and the Respondents

The chi-square test may be employed to determine if two distributions are statistically equivalent.[3]

$$X^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}, \quad df = n - 1$$

where: X^2 = the chi-square value

o_i = the observed value in the i^{th} class of the distribution.

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[2]Helen M. Walker and Joseph Lev, <u>Statistical Inference</u> (New York: Henry Holt & Company, 1953), p. 451.

[3]Chou, <u>Statistical Analysis with Business and Economic Applications</u>, p. 453.

e_i = the expected value of the i^{th} class of distribution

n = the number of observations

df = degrees of freedom

This chi-square test of significance was used in this study to determine if the distribution of the observed nonresponses among the education classes and the use of any operations research techniques (yes, no) was statistically equivalent to the respondents.

Testing the Statistical Equivalence of the Extent of Use of Operations Research Techniques between the Respondents and the Nonrespondents

The Frequency Index Score (FIS) was developed as a measure of the extent of usage of operations research techniques by each responding firm. The FIS actually measures the number of operations research techniques used and the frequency of use of the techniques by the firms.

There are 14 operations research techniques delineated in this study.[4] Each firm received a score for each technique based on the following frequency of use:

Never = 1 point
Occasionally = 2 points
Routinely = 3 points

[4]Note: These 14 operations research techniques were identified in a comprehensive literature search, by this author, which included both operations management texts and journal articles. These techniques were mentioned most often by the contemporary works in operations management, which were included in this search.

A firm could therefore receive a minimum FIS of 14 and a maximum FIS of 42.

The FIS mean of the respondents was compared for statistical equivalence with the FIS mean of the observed nonrespondents. Appendix B-1 indicates that parametric statistical tests may be performed on ordinal data (such as the FIS in this study) when the following conditions are present; however, the results of the test may be questioned:

a. The number of subjects represented by the two means are greatly different <u>and</u> the variances of the two distributions are significantly different, or

b. A one-tailed t test is employed when great differences in variances exist.

When either of the above conditions is present the level of significance can be increased substantially, thus reducing the precision of the test.

In this study the number of observations of the respondents (275) is greatly different from the nonrespondents (18). In order to use the two-tailed Student t distribution to test the significance of the difference between the two FIS means, the variances should be statistically equivalent if the level of significance (α) is to be predictable. The statistical equivalence of the two variances can be tested by the chi-square statistic:[5]

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[5]Chou, <u>Statistical Analysis</u>, p. 382.

$$X^2 = \frac{(n - 1)s_1^2}{s_2^2}, \quad df = n - 1$$

where: X^2 = chi-square value

s_1^2 = the variance of the observed nonrespondents' FIS

s_2^2 = the variance of the respondents' FIS

n = number of observed nonrespondents

df = degrees of freedom

Since the analysis in Chapter IV of this report indicated the statistical equivalence of the two variances using the above chi-square formula, the FIS means were tested for equivalence using the two-tailed Student t test:[6]

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}, \quad df = n_1+n_2-2$$

where: t = Student t value

$\bar{X}_1$ = FIS mean for respondents

$\bar{X}_2$ = FIS mean for nonrespondents

n_1 = number of respondents (275)

n_2 = number of observed nonrespondents (18)

s_1^2 = variance of the respondents' FIS

s_2^2 = variance of the observed nonrespondents' FIS

df = degrees of freedom

---

[6] *Ibid.*, p. 779.

APPENDIX B-4

POWER OF THE TEST

A conventional significance level (α) of .05 or less was used in this study. This means that the probability of a Type I error (the error that occurs when a true null hypothesis is rejected) is .05 or less. Type II errors (the errors that occur when false null hypotheses are accepted) are usually controlled by two methods: selecting a control level for Type II errors (β) and thus fixing sample size N or conversely selecting a sample size N and thus fixing the level for Type II errors (β). The latter method was utilized in this study.

The sample size, N = 275, fixed the level of Type II errors (β) in the tests of significance in this study. β can be calculated from mathematical formulas or more conventionally the value of $1 - \beta$ (power of the test) can be read directly from curves provided in statistical texts. The power of the test is generally interpreted as the power of the test to avoid making a Type II error. As β approaches zero, the power of the test ($1 - \beta$) can be observed to approach 1.00, thus indicating that the probability of accepting a false null hypothesis is near zero.

The values of $1-\beta$ in the charts found in statistical texts indicate that with an $\alpha = .05$ and $N = 275$, $1-\beta \approx 1.00$ (off the charts) and consequently β is near zero. Therefore, the probability of concluding that the correlation coefficients of this study are zero when, in fact, they are not, is equal to zero.[1]

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[1]Helen M. Walker and Joseph Lev, Statistical Inference (New York: Henry Holt & Company, 1953).

APPENDIX C

RAW DATA

RAW DATA OF RESPONDING FIRMS

The raw data collected on responding firms were transferred from the mail questionnaire to IBM cards according to the card format shown below.

Data Card Format

Information	Column(s)
<u>First Card</u>	
Firm Number (001 to 515)	1-3
Firm Size Class (1,2,3, or 4)	4
Industry Group Class (1,2,3,4,5, or 6)	5
Education Class (1,2,3,4, or 5)	6
Response to Question A-I (1 or 2)	11
Response to Question A-II (1 or 2)	12
Response to Question A-III (1, 2, or 3)	13
Response to Question A-IV (1, 2, 3, or 4)	14
Response to Question A-V (1, 2, 3, 4, or 5)	15
Response to Question A-VI (1, 2, 3, or 4)	16
Response to Question B-I (1 or 2)	17
Response to Question B-II-1 (1, 2, or 3)	18
Response to Question B-II-2 (1, 2, or 3)	19
Response to Question B-II-3 (1, 2, or 3)	20
Response to Question B-II-4 (1, 2, or 3)	21
Response to Question B-II-5 (1, 2, or 3)	22
Response to Question B-II-6 (1, 2, or 3)	23
Response to Question B-II-7 (1, 2, or 3)	24
Response to Question B-II-8 (1, 2, or 3)	25
Response to Question B-II-9 (1, 2, or 3)	26
Response to Question B-II-10 (1, 2, or 3)	27
Response to Question B-II-11 (1, 2, or 3)	28
Response to Question B-II-12 (1, 2, or 3)	29
Response to Question B-II-13 (1, 2, or 3)	30
Response to Question B-II-14 (1, 2, or 3)	31
Response to Question B-II-15 (1, 2, or 3)	32
Response to Question B-II-16 (1, 2, or 3)	33
Response to Question B-II-17 (1, 2, or 3)	34
Response to Question B-II-18 (1, 2, or 3)	35

Information	Column(s)
Response to Question B-III	
Problems (00, 01, 02, ..., 24: one problem	36-37
in any column group at right. When all	43-44
problems are listed for each firm, zeros	50-51
are entered in the remainder of the column	57-58
groups at right.)	64-65
	71-72
Techniques (1, 2, 3, 4, or 5: the OR tech-	38-42
niques applied to the manufacturing prob-	45-49
lems above are entered in the groups of	52-56
five columns at right which immediately	59-63
follow the manufacturing problem column	66-70
groups checked above.)	73-77
Card Number (1)	80
<u>Second Card</u>	
Firm Number (001 to 515)	1-3
Firm Size Class (1, 2, 3, or 4)	4
Industry Group Class (1, 2, 3, r, 5, or 6)	5
Education Class (1, 2, 3, 4, or 5)	6
Response to Question B-III Continued	11-12
Problems (00, 01, 02, ..., 24: one problem in	18-19
any column group at right. When all prob-	25-26
lems are listed for each firm, zeros are	32-33
entered in the remainder of the column groups	39-40
at right.)	46-47
	53-54
	60-61
	67-68
Techniques (1, 2, 3, 4, or 5: the OR tech-	13-17
niques applied to the manufacturing prob-	20-24
lems above are entered in the groups of	27-31
five columns at right which immediately	34-38
follow the manufacturing problem column	41-45
groups checked above.)	48-52
	55-59
	62-66
	69-73
Response to Question B-IV-1 (1 or 2)	74
Response to Question B-IV-2	
Staff Groups (1, 2, 3, 4, 5, 6, 7, 8 and	75
9: any staff group code number may be	
entered in the column at right.)	
Number of Employees (1 to 99: the number	76-77
of employees in the staff group checked	
above is entered in the column at right.)	

Information	Column(s)
Card Number (2)	80
<u>Third Card</u>	
Firm Number (001 to 515)	1-3
Firm Size Class (1, 2, 3, or 4)	4
Industry Group Class (1, 2, 3, 4, 5, or 6)	5
Education Class (1, 2, 3, 4, or 5)	6
Response to Question B-IV-2 Continued	
Staff Groups (1, 2, 3, 4, 5, 6, 7, 8, or 9:	11
any staff group code number may be entered	14
in any column at right; zeros are entered	17
in the remainder of the columns.)	20
	23
	26
	29
	32
Number of Employees (1 to 99: the number of	12-13
employees in the staff groups checked	15-16
above is entered in the column groups	18-19
at right which immediately follow the	21-22
staff group column checked above.)	24-25
	27-28
	30-31
	33-34
Response to Question B-IV-3 (00 to 99)	36-37
Response to Question B-IV-4 (1, 2, 3, 4, or 5)	38
Response to Question B-V-1 (00 or 01)	39-40
Response to Question B-V-2 (00 or 02)	41-42
Response to Question B-V-3 (00 or 03)	43-44
Response to Question B-V-4 (00 or 04)	45-46
Response to Question B-V-5 (00 or 05)	47-48
Response to Question B-V-6 (00 or 06)	49-50
Response to Question B-V-7 (00 or 07)	51-52
Response to Question B-V-8 (00 or 08)	53-54
Response to Question B-V-9 (00 or 09)	55-56
Response to Question B-V-10 (00 or 10)	57-58
Response to Question B-V-11 (00 or 11)	59-60
Response to Question B-V-12 (00 or 12)	61-62
Response to Question B-V-13 (00 or 13)	63-64
Response to Question B-V-14 (00 or 14)	65-66
Card Number (3)	80

```
004113    1132322                                                                          1
004113                                                                                     2
004113                                                                                     3
005112    22      111111211131111     01  3  02  3  07  3  10  3  11  3  12 2              1
005112                                                                      2              2
005112                                024                                                  3
006113    2132322                                                                          1
006113                                                                                     2
006113                                     02     05          11                           3
010113    2132 22                                                                          1
010113                                                                                     2
010113                                                                                     3
011113    2132432                                                                          1
011113                                                                                     2
011113                                                                                     3
013114    113233131111211111111                                                            1
013114                                                                      2              2
013114                                                                                     3
015113    2132322                                                                          1
015113                                                                      2              2
015113                                                                                     3
018115    1132212111111111111111111                                                        1
018115                                                                                     2
018115                                                                                     3
019112    12      111111221111211     12 2   21     5                                      1
019113                                                                      2              2
019112                                013  02                 11                           3
020114    1133332111111111111111111                                                        1
020114                                                                                     2
020114                                                                                     3
024111    22      2111111111111111111                                                      1
024111                                                                                     2
024111                                                                                     3
```

029114	1132332111111111111111111							1
029114								2
029114								3
037114	2132332111111111111111111							1
037114								2
037114								3
038114	213233121111111111111	101						1
038114							2	2
038114			05	07	1112			3
040111	212132211111111111111							1
040111								2
040111								3
042114	113233211111111111111							1
042114								2
042114								3
043111	22 2111111111111111							1
043111							2	2
043111								3
045111	22 2111111111111111							1
045111								2
045111								3
046113	112111121111221111211	051	081	101	111	12 2		1
046113							2	2
046113		0102030405			11			3
048113	2132312111111111111111111							1
048113							2	2
048113								3
049113	212131211111111111111							1
049113								2
049113								3
051115	113211131111113111111	051	061	1012	111			1
051115							1101	2
051115		024	0203	09				3

053114	213213	211111111111111				1
053114						2
053114						3
054111	22	211111111111111				1
054111					2	2
054111						3
055112	212142	211111111111111				1
055112						2
055112						3
057111	22	211111111111111				1
057111					2	2
057111						3
060111	22	211111111111111				1
060111						2
060111						3
062111	22	211111111111111				1
062111					2	2
062111						3
063111	22	2111111111111111111				1
063111						2
063111						3
064114	213221	111111211111111	12 2			1
064114					2	2
064114			014			3
065111	22	211111111111111				1
065111					2	2
065111						3
066114	213211	111111211111111	12 2			1
066114					2	2
066114				02		3
067112	113112	211111111111111				1
057112						2
067112						3

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068113    11213121111111111111                                                  1
068113                                                                          2
068113                                                                          3
071113    21322321111111111111                                                  1
071113                                                                          2
071113                                                                          3
072115    11341311111121111211     12 2    21     5                             1
072115                                                                    2     2
072115                                                                          3
073114    11323221111111111111                                                  1
073114                                                                    2     2
073114                                                                          3
074113    11212211111121111211     12 2    21     5                             1
074113                                                                    2     2
074113                             023                                          3
075125    21331211111121111111     12 2    16 2                                 1
075125                                                                    2810  2
075125                             003                                          3
079124    21321212111111111111     061     101                                  1
079124                                                                    2     2
079124                               3                                          3
080122    21211112111131111211     1012  5201                                   1
080122                                                                    2     2
080122                                                                          3
081123    21323221111111111111                                                  1
081123                                                                          2
081123                                                                          3
082125    11322212111133212111     011    02    4 071 3  10 2 4 12 2   19  34   1
082125                                                                    1202  2
082125                             053      04       0809    12                 3
085124    11323221111111111111                                                  1
085124                                                                    2     2
085124                                                                          3
```

086123	1111312111111111111111							1
086123							2	2
086123								3
090121	22 211111111111111							1
090121								2
090121								3
092123	2132311211211131211111	061	101	111	211			1
092123							2	2
092123			05					3
093121	22 21111111111111							1
093121								2
093121								3
096125	2134221332313321312 11	051	061	081	10 2	111		1
096125							2	2
096125		043						3
099122	12 211111111111111							1
099122								2
099122								3
100124	2133332111111111111111							1
100124								2
100124								3
103125	113221211111111111111							1
103125								2
103125								3
104123	1121212111111111111111							1
104123								2
104123								3
105125	1132111111111331111111	10 2	11 2	12 2				1
105125							2	2
105125		043						3
107125	1132111111111331121111	10 2	12 2	14 3	15 3			1
107125							2	2
107125		3						3

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110125    113213121221222121212   021    051    061    071    081    1012  5  1
110125    11123 512 2   13    4 1612   191 3  201                       1903  2
110125                            033  02        07      11                   3
111125    113313111111331111311   11   3  12 2   14     5                     1
111125                                                                 2      2
111125                               01020304      08    11                   3
112124    213212131111212131311   021    071    081    10 2   11   512 2      1
112124    13   4 14    515  3  161   17   4 18   4 191    201           1304  2
112124                            063  02  04      08    11                   3
118134    213212121111211111211   051    061    1012   12 2                   1
118134                                                                  1102  2
118134                            003  02      06        11                   3
120134    1132312111111111111111                                              1
120134                                                                        2
120134                                                                        3
124135    113211111111211111111   10 2   12 2                                 1
124135                                                                 2      2
124135                                 02                11                   3
125134    2132122111111111111111                                              1
125134                                                                        2
125134                                                                        3
126134    113332122222332121311   011    021    041    111  4 20    5         1
126134                                                                 2      2
126134                               0102  04                                 3
128134    113231131121111111111   021    051    061    071    101    111      1
128134    191                                                           1103  2
128134                            014                080910                   3
131133    213232211111111111111                                               1
131133                                                                        2
131133                                                                        3
133131    22    211111111111111                                               1
133131                                                                        2
133131                                                                        3
```

134134	21322211111122111111	12 2			1
134134				2	2
134134		023 02	11		3
139135	11321111111111111211	11 5			1
139135					2
139135			1112		3
140135	11321121111111111111				1
140135				2	2
140135					3
141135	21213321111111111111				1
141135					2
141135					3
142135	11321121111111111111				1
142135					2
142135					3
145132	12 11111111111211	10 2 12 2 21 5			1
145132				2	2
145132		043010 2			3
146133	21211221111111111111				1
146133					2
146133		05			3
147135	11321321111111111111				1
147135					2
147135					3
148134	21321111111211111211	10 511 512 2 16 5			1
148134				2	2
148134		02			3
150135	11341212211122112111	10123 12 2			1
150135				2	2
150135		023 02			3
151133	11212311111133111111	10 2 12 2			1
151133				2	2
151133		023 02			3

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152134    2132222111111111111111                                               1
152134                                                                         2
152134                                        05                               3
156135    113213211111111111111                                                1
156135                                                                         2
156135                                                                         3
158133    113132121111221111111    11 2                                        1
158133                                                                   2     2
158133                             043  02                11                   3
159131    22     21111111111111                                                1
159131                                                                   2     2
159131                                                                         3
161135    113212211111111111111                                                1
161135                                                                   2     2
161135                                    03                                   3
162135    113312111111211111311    21    5                                     1
152135                                                                   2     2
162135                                                                         3
164133    213231211111111111111                                                1
164133                                                                         2
164133                                                                         3
165135    113211111111221111111    10 2   12 2                                 1
165135                                                                   2     2
165135                             023  0203        08                         3
166134    213332211111111111111                                                1
166134                                                                         2
166134                                                                         3
167134    213222211111111111111                                                1
167134                                                                         2
167134                                                                         3
168134    113231111111221111111    10 2                                        1
168134                                                                   2     2
168134                             024        05        10                     3
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169135	113211211111111111111			1
169135				2
169135				3
172144	213332211111111111111			1
172144				2
172144				3
173144	113233111111211111111	10 2 12 2		1
173144			2	2
173144		023 0304 07 11		3
175142	212112211111111111111			1
175142				2
175142				3
176143	111132211111111111111			1
176143				2
176143				3
178143	213232121111111121211	201 3 5		1
178143			2	2
178143		035 03 07 10		3
179145	1132122111111111111111			1
179145				2
179145				3
180142	12 121111221111111	101 12 2		1
180142			2	2
180142		0102 0405 07 09 1112		3
181144	113231211111111111111			1
181144			2	2
181144		02401 0405 08		3
182142	12 111111311121111	10 2 11 3 12 2 17 3		1
182142			2	2
182142				3
183145	113213211111111111111			1
183145				2
183145				3

184143	2132322111111111111			1
184143			2	2
184143				3
188143	2132421111111111211	10 511 5		1
188143			2	2
188143		013		3
191144	1132321211111121111	021 05 3 071 101 11 3 191		1
191144			2	2
191144		013 0203 08		3
192144	2132112111111111111			1
192144			2	2
192144				3
195144	2133342111111111111			1
195144				2
195144				3
199154	1132112111111111111			1
199154			2	2
199154				3
200154	1132112111111111111			1
200154			2	2
200154				3
201151	22 2111111111111			1
201151				2
201151				3
202153	2132322111111111111			1
202153				2
202153				3
203153	1111121321121112121 1	071 101 3 11 3 12 2 1612 211		1
203153			1703	2
203153		014 02		3
204151	22 2111111111111			1
204151				2
204151				3

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206151      22     211111111111111                                                               1
206151                                                                                           2
206151                                                                                           3
207153      2132422111111111111111                                                               1
207153                                                                                           2
207153                                                                                           3
209153      113252132112221131322     011 3  031     051    5061     081      101 3 5  1
209153      11  3  12 2   16  3  20   3 5                                         1702  2
209153                                0140102  04     0708     1112                     3
210153      213231211111111111111                                                                1
210153                                                                                           2
210153                                                                                           3
211151      22     211111111111111                                                               1
211151                                                                                           2
211151                                                                                           3
213154      113231211111111111111                                                                1
213154                                                                                           2
213154                                                                                           3
214154      113231211111111111111                                                                1
214154                                                                                           2
214154                                                                                           3
219153      213232111111211111111     12 2                                                       1
219153                                                                                2          2
219153                                                                                           3
221152      212111211111111111111                                                                1
221152                                                                                2          2
221152                                                                                           3
222153      213231211111111111111                                                                1
222153                                                                                           2
222153                                                                                           3
225154      213211211111111111111                                                                1
225154                                                                                           2
225154                                                                                           3
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229151	22 211111111111111			1
229151			2	2
229151		04		3
235154	113234211111111111111			1
235154				2
235154				3
236151	22 211111111111111			1
236151				2
236151		05		3
237155	113312131111121111111	061 12 2 201		1
237155			1501	2
237155		014 0405		3
238154	213211111111221111111	12 2		1
238154				2
238154				3
240155	213323211111111111111			1
240155				2
240155				3
241155	113311111111323121211	02 4 10 2 20 3		1
241155			2	2
241155		025		3
242153	213242211111111111111			1
242153				2
242153				3
243155	113213111111321111111	10 2 12 2		1
243155			2	2
243155		0040102 04 09 11		3
244154	113112111111222111311	10 2 4511 4 12 2 5		1
244154			2	2
244154		013 02		3
245154	213433211111111111111			1
245154				2
245154				3

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246155    113211132223332131311    02   3  041 3  051 3  071 3  081    101 3    1
246155    111 3  12 2   13  34 14  3  16 2   517   4 18  3  20  3  211 3  2     2
246155                             0240102   04  0607  09  11                   3
247154    113231121231222121211    071     101    111    12 2                   1
247154                                                                    2     2
247154                             0720102   04      08    11                   3
249154    213332221111111111111    071     111    191                           1
249154                                                                    2     2
249154                                                                          3
250154    213234211111111111111                                                 1
250154                                                                          2
250154                                                                          3
251151    22    121111111121212    011 3   031    12 2   201 3                  1
251151                                                                    2     2
251151                             04                                           3
252155    113211211111111111111                                                 1
252155                                                                    2     2
252155                                                                          3
253155    113221211111111111111                                                 1
253155                                                                          2
253155                                                                          3
254152    212141211111111111111                                                 1
254152                                                                          2
254152                                                                          3
256155    213213111111121111111    16 2                                         1
256155                                                                    2     2
256155                                       04            11                   3
257155    113313211111111111111                                                 1
257155                                                                          2
257155                                                                          3
258153    112112211111111111111                                                 1
258153                                                                          2
258153                                                                          3
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260153	2132 1111111121111111	10 2 12 2		1
260153			2	2
260153				3
262163	21323121111111111111			1
262163			2	2
262163				3
263164	21322121111111111111			1
263164			2	2
263164				3
264165	11321113133122111111	031 051 061 071 101 111		1
264165	12 2 201		2	2
264165		02401 06		3
265165	113212121111231131211	03 3 08 3 12 2 20 3		1
265165			1509	2
265165		022010203 05 07 0910		3
266163	21323121111111111111			1
266163			2	2
266163				3
269165	11322211111111111211	10 511 512 2		1
269165			2	2
269165		014 05		3
271164	11323321111111111111			1
271164			2	2
271164				3
272164	21321212111122111211	071 12 2 14 521 5		1
272164			1703	2
272164	403	023 03		3
273165	11321313212122222322	031 10 2 4 11 4 12 2 16 2 201		1
273165	21 5		2	2
273165		004 02 04 08 11		3
274164	21321221111111111111			1
274164				2
274164				3

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275164    213221211111111111111                                                  1
275164                                                                           2
275164                                                                           3
276165    113212121111121111111                                                  1
276165                                                                 2         2
276165                                                                           3
279165    113212132122332132321     021   5051    061    071    101 3 5111 3 5   1
279165    12 2   15   3  16 2   211                                   1102       2
279165    706809                    12501    04      08    11                    3
280163    213231111111121121211     12 2   16 2   20   3 521   5                 1
280163                                                                 2         2
280163                                                     1112                  3
281162    12     131111121121211    011    071    081    101   514  3  15  3     1
281162    16 2   201    21     5                                      1302       2
281162                              014      04         09    12                 3
282165    113212132111331121111     031    071    081    101    111    12 2      1
282165    16 2                                                        1502       2
282165    603                       025                                          3
283165    113212131111221111211     031    071    10    511    516 2             1
283165                                                                1801       2
283165                              053  02             09                       3
290165    113211131111121121211     031    061    071    101    15  3  16 2      1
290165    201    21    5                                              1102       2
290165                              005                                          3
291165    113214131111131131111     031    071    10 23  11  3  12 2             1
291165                                                                           2
291165                              034                    11                    3
296165    113212111111111121111     11  3                                        1
296165                                                                 2         2
296165                              013    03                                    3
299162    2121312111111111111111111                                              1
299162                                                                           2
299162                                                                           3
```

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300165     113211211111111111111                                                          1
300165                                                                                    2
300165                                                                                    3
303213     112234111111211121111    10 2    11   3                                        1
303213                                                                          1702      2
303213                              02401                         11                      3
305214     113232121111331111211    021     051     061     101     12 2    21      5     1
305214                                                                          1202      2
305214                              003   02                      11                      3
306211     22     21111111111111                                                          1
306211                                                                                    2
306211                                                                                    3
307212     211111211111111111111                                                          1
307212                                                                                    2
307212                                                                                    3
310214     213211211111111111111                                                          1
310214                                                                          2         2
310214                                                                                    3
311215     113323211111111111111                                                          1
311215                                                                                    2
311215                                                                                    3
316215     113313111111122111311    02    4 10      512 2                                 1
316215                                                                          1704      2
316215                              023                                                   3
319224     213211111111121121311    11     512 2    15   3   17   3   19   3              1
319224                                                                          1716      2
319224                              043   02                      11                      3
323221     22     21111111111111                                                          1
323221                                                                                    2
323221                                                                                    3
324223     112232211111111111111                                                          1
324223                                                                                    2
324223                                                                                    3
```

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326225    113332121111112131111    041     05  3  07  3  10    4 111 34          1
326221                                                                  1705  2
326225                             043  020304            11                 3
327221    22    211111111111111                                               1
327221                                                                        2
327221                                                                        3
328221    22    211111111111111                                               1
328221                                                                        2
328221                                                                        3
329224    213211211111111111111                                               1
329224                                                                 2      2
329224                                                                        3
330225    113211111111222121211    11  34512 2   15  34520  3                 1
330225                                                                  704   2
330225                                                                        3
331224    113232111111113111311    06   4 10   4511    520    5               1
331224                                                                 2      2
331224                             003      04      08    11                 3
332225    113213121121223131211                                               1
332225                                                                 2      2
332225                             0930102    05          11                 3
333224    213332211111111111111                                               1
333224                                                                        2
333224                                                                        3
335233    112131111111212131211    05  3  06  3  07  3  10  34511  34512 2    1
335233    19  3                                                        2      2
335233                             0120102  04      08    11                 3
337233    213231111111131111111    10 2                                       1
337233                                                                 2      2
337233                                 02                                     3
338231    22   2 111111111111111                                              1
338231                                                                        2
338231                                                                        3
```

```
339233    112131211111111111111                                                         1
339233                                                                                  2
339233                                                                                  3
342235    113211131111122111211   061    101    11 2   12 2   14    5                   1
342235                                                                        2         2
342235                               01     04     07                                   3
344235    113211131111311121311   021    10123 511   3 512 2                            1
344235                                                                        1710      2
344235                            054      04        0910                               3
346233    213232132111332131322                                                         1
346233                                                                        1505      2
346233    802                     054                                                   3
347232    211111211111111111111                                                         1
347232                                                                                  2
347232                                                                                  3
348235    113212111111321121211   10    511     512 2    20   3                         1
348235                                                                        2         2
348235                            033  02  0405     08     1112                         3
349235    113211122222333131211   021 3  051 3  06  3  071    08  3  10123              1
349235    11  3  12 2   14  3  15123  21  3                                   2         2
349235                            043  02    05     08                                  3
355235    113231131111321121111   01 2   05   3  06  3  07  3  09 2   10 23             1
355235    11  3  12  3  15  3  16 2   21 23                                   1202      2
355235    700                     004  02           08     11                           3
356235    113221121111222111211   10 2  5111    20  3                                   1
356235                                                                        2         2
356235                            014  02                                               3
357235    113312111111321121211   05    507     510 2    12 2   14  3  15  3            1
357235    20  3                                                               2102      2
357235    810505                  002                          12                       3
359235    113211111111213121311   04  3  05  3  10  3  11  3  12 2   13   4             1
359235                                                                        1104      2
359235                            0330102    05                                         3
```

361245	21322321111111111111			1
361245			2	2
361245				3
362244	11323111111111121111	10 3 11 3		1
362244			2	2
362244		015 05		3
363245	11322211111133111111	12 2 16 2		1
363245			2	2
363245		022 02 08 11		3
366244	11323121111111111111			1
366244				2
366244				3
367244	11333221111111111111			1
367244				2
367244				3
368245	11341311111122111111	12 2		1
368245			1701	2
368245		013 09		3
371242	12 11111122111111	08 2 10 2		1
371242				2
371242				3
375245	11321111111211121111	10 2 11 23 12 23 21 3		1
375245			2	2
375245		043 04		3
380255	11321212111131111211	101 12 2 21 5		1
380255			2	2
380255		022 02 0607 11		3
382254	21322221111111111111			1
382254				2
382254				3
383255	11323121111111111111			1
383255				2
383255				3

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384254    11323221111111111111                                                          1
384254                                                                                  2
384254                                          05                                      3
385255    11323221111111111111                                                          1
385255                                                                                  2
385255                                                                                  3
388255    11321313111222213321     011     02 2    051     061     07  3   081          1
388255    20   3                                                               2        2
388255                             015   02     05       09                             3
389254    11323221111111111111                                                          1
389254                                                                                  2
389254                                                                                  3
391255    11321321111111111111                                                          1
391255                                                                                  2
391255                             153   02                       1112                  3
393254    11323113111112112111     011     031     061     071     081     10 23        1
393254    12 2    14  3  15  3  161    191     201     211                     2        2
393254                             024   02                                             3
395265    11321221111111111111                                                          1
395265                                                                                  2
395265                                                                                  3
397265    11345313332133212232     05    508   3  09   3  101     111     12 2          1
397265    14  3  15  3  161    191    201 3  211   5                           1704     2
397265    801                      014   02                       1112                  3
399265    11331111111222111211                                                          1
399265                                                                         2        2
399265                                                                                  3
400264    21322121111111111111                                                          1
400264                                                                         2        2
400264                                                                                  3
403265    11321112112212113232     05  3 506   3 510   3 512 2   15   3  201 3          1
403265    21   3 5                                                             2        2
403265                             204                                                  3
```

405264	213211111111121111111	16 2								1
405264									2	2
405264				05						3
407265	113212111111121111211	15	516 2							1
407265									2	2
407265				05						3
408265	113211111111111121211	16	3 5							1
408265									2602	2
408265		033								3
409265	113211131111131131111	031	061		071	101 3	16 2			1
409265									1103	2
409265		203				10				3
410264	213211131111231111111	031	061		071	10 2	111	16 2		1
410264									1107	2
410264		004								3
415264	21321221111111111111111									1
415264										2
415264										3
418265	113311211111111111111									1
418265									2	2
418265										3
419265	113211211111111111111									1
419265									2	2
419265										3
420263	213241211111111111111									1
420263										2
420263										3
423314	213211211111111111111									1
423314									2	2
423314										3
424314	113233131111311121311	021	051		061	101	11 3	12	2	1
424314	16 2 21 5								1102	2
424314	202	033	02	04	06	11				3

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426314     113342122111221121111      051     09  3  1012    11  3  16 23             1
426314                                                                          1710   2
426314                                003       04          09                         3
427354     113332121111211111111      101     12 2                                     1
427354                                                                                 2
427354                                                                                 3
429325     113211211111111111111                                                       1
429325                                                                          2      2
429325                                                                                 3
430324     213431211111111111111                                                       1
430324                                                                          2      2
430324                                                                                 3
431323     213231111111122121111      10 2    12 2    13    4 15   3                   1
431323                                                                          2      2
431323                                      02                                         3
437325     223211211111111111111                                                       1
437325                                                                                 2
437325                                                                                 3
438324     213211211111111111111                                                       1
438324                                                                          2      2
438324                                                                                 3
441335     113312111111332121312      02   345031     05  3   061    08   4 09   4     1
441335     101 3·  11  34512 2   161     17   4 18   4 19   4 211   5         1702   2
441335     804402                     0440102   04                                     3
442335     113211111111221111111      12 2                                             1
442335                                                                          2      2
442335                                             05         10                       3
444334     213211211111111111111                                                       1
444334                                                                          2      2
444334                                                                                 3
446331     21112221111111111111111                                                     1
446331                                                                                 2
446331                                042   02                    12                     3
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448335   113214111111221131211    11     51? 2    15   3                                 1
448335                                                                          1602  2
448335                            082                                                 3
450334   213212211111111111111                                                        1
450334                                                                                2
450334                                                                                3
452335   113212121323331131211    01   3   05   3   06   3   101  3   111     1? 2    1
452335   151  3   201  ?                                                              2
452335                            104                         10   12                 3
453344   113332121112222121111    051  3   06   3   071  3   08    4  10   3   111    1
453344   12  2    13   34  16   34  17   34  18   34  19   4  201  3           2      2
453344                                 02     05        0910   12                     3
454344   213221111111121111111    16  2                                               1
454344                                                                         2      2
454344                                 02                 11                          3
456344   113242 11111111111111                                                        1
456344                                                                                2
456344                                                                                3
458344   113232111111221111111    10  2    12  2                                      1
458344                                                                         2      2
458344                            003                                                 3
451345   113211211111111111111                                                        1
461345                                                                                2
461345                                                                                3
46234?   111141211111111111111                                                        1
452343                                                                         2      2
462343                                                                                3
464344    13211121112331131311    011     03     505  23   061      071     10     5  1
464344   12  2    15   3   16  2    211  3  5                                  2      2
464344                            075          05        09     12                    3
466353   213231132132223121313    01   3   021      031     041     051     061       1
466353   071     08   3   091     1012    11     512  2    13    4  14   4  151  3  1024  2
466353                            045              08                                 3
```

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467352    21212121111111111111                                               1
467352                                                                       2
467352                                                                       3
468355    21331121111111111111                                               1
468355                                                                 2     2
468355                                                                       3
469355    11321221111111111111                                               1
469355                                                                 2     2
459355                                                                       3
471354    11323111111221111111    12 2                                       1
471354                                                                 2     2
471354                                                                       3
472354    11323213111133111111    021    031    041    061    1012  111        1
472354    12 2   161    211                                            2     2
472354                                                                       3
473355    21331112121133212121 1  0112   071 3  0912   101 3  12 2  15 2     1
473355    20 2                                                         2     2
473355                            003                                        3
475364    21321113113111111211    041    101   511    515    521    5        1
475364                                                                 2     2
475364                            005                                        3
476364    21321112111113113121 1  061    11    512 2  20  3                  1
476364                                                                 1302  2
476364                            003      04  06  0809101112                3
477364    21321112112222122212    01  3  021  4 06  3  071   5101   12 2     1
477364    13  4 171    211   5                                         1205  2
477364    101402901               013  020304             11                 3
482365    11331113211112223133 1  011    031 3 5061 3  071 3  10  34512 23   1
482365    14  3  201 3  21   5                                         1816  2
482365                            154  02  04             1112               3
483365    11331213111112112121 1  011    031    061    071    101    121     1
483365    15  3  16 2   201                                            1730  2
483365                            253                      12                3
```

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484364    21321121111111111111                                              1
484364                                                              2       2
484364                                                                      3
487365    11331113133133213121 1                                            1
487365                                                              1106    2
487365    707315605               202         05                            3
488365    11321212111112111121 1  02    5031   508 2   10    512 2   161    1
488365                                                              1703    2
488365    504                     023                      12               3
489363    11213121111111111111                                              1
489363                                                                      2
489363                                                                      3
491362    21213112231133212131 2  011   502   45061  45091  4 10   511  3 5 1
491362    12 2   13   4 16 2   17  4 18   4 211   5                 1204    2
491362    601401                  004                    11                 3
496424    11343112222133223231 2  02  3   03  3 506  3  081   509  3  10 2  1
496324    11  3 512 2   13   4 14 3 515  3 516 23  21  3 5          1308    2
496424    701                     004                                       3
498425    11331113221232213222 1  02  3  051    061 3  081    10  3 511  3 5 1
498425    12 23  14  3  15  3  20 3  21    5                        1       2
498425                            273     04    07  09  1112                3
502445    21331113111133213323 1  021    06  3  071    10  3  11  3  12 2   1
502445    13  3  14  3  171    20 3                                 1305    2
502445                            044                                       3
506445    11321113131131212111 1  011    031    05  3  06  3  071    101 3  1
506445    11  34 122    14  3  151 3  16   4 17   4 19  3  20  3  21 23 1719 2
506445    703705702               5030102  04     08    1112                3
513463    21323113213133212231 2  01  3  031    051 3  061 3  071 3  081 3  1
513463    101 3  12  2  13   4 17 3                                 1325    2
513463                            075              09    12                 3
```

APPENDIX D

SUPPORTING TABLES

APPENDIX D-1

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: FIRMS WITH 250-499 EMPLOYEES (A_1)

Manufacturing Problems	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
	Operations Research Techniques						
Facility location	5	2	3	0	0	10	11
Line balancing	6	0	2	2	1	11	10
Chemical or Ingredient Blending	8	0	1	0	0	9	13
Reducing trim waste	2	0	1	0	0	3	20
Material allocation	10	0	2	0	1	13	8
Capacity allocation	12	0	0	0	0	12	9
Product mix	17	0	3	0	0	20	5
Logistics studies	8	0	1	0	0	9	13
Facilities layout	0	0	0	0	0	0	21
Production planning and control	21	23	7	3	10	64	1
Inventory analysis and control	13	3	11	3	8	38	3
Project planning and control	0	44	0	0	1	45	2

APPENDIX D-1 (Continued)

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Waiting lines	0	0	1	3	0	4	18
System reliability	0	0	3	0	3	6	15
Equipment design analysis	0	0	5	0	0	5	16
Maintenance planning	3	14	1	0	2	20	5
Service crew size	0	0	2	3	0	5	16
Holding area size	1	0	2	1	0	4	18
Machines per operator	6	0	2	2	0	10	11
Analyzing capital investment projects	11	1	8	0	4	24	4
Quality control	5	0	2	0	11	18	7
Total	128	87	57	17	41		
Rank	1	2	3	5	4		

APPENDIX D-2

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: FIRMS WITH 500-999 EMPLOYEES (A_2)

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	2	3	2	1	1	9	10
Line balancing	3	1	1	1	0	6	12
Chemical or Ingredient Blending	3	0	0	0	0	3	16
Reducing trim waste	1	0	1	0	0	2	18
Material allocation	3	0	6	0	3	12	6
Capacity allocation	6	0	4	1	1	12	6
Product mix	4	0	4	0	1	9	11
Logistics studies	2	1	2	0	0	5	14
Facilities layout	0	1	1	0	0	2	21
Production planning and control	7	11	9	3	7	37	1
Inventory analysis and control	4	2	10	3	6	25	2
Project planning and control	0	17	2	0	0	19	3

APPENDIX D-2 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	0	1	0	1	18
System reliability	0	0	3	0	1	4	15
Equipment design analysis	1	1	7	1	2	12	6
Maintenance planning	2	8	1	0	1	12	6
Service crew size	0	0	2	1	0	3	16
Holding area size	1	0	1	0	0	2	18
Machines per operator	3	0	2	1	0	6	12
Analyzing capital investment projects	4	1	8	0	1	14	4
Quality control	3	1	5	0	5	14	4
Total	49	47	71	13	29		
Rank	2	3	1	5	4		

APPENDIX D-3

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: FIRMS WITH 1000-4999 EMPLOYEES (A_3)

Manufacturing Problems	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
	Operations Research Techniques						
Facility location	5	1	3	0	1	10	19
Line balancing	4	0	1	3	3	11	8
Chemical or Ingredient Blending	6	0	1	0	3	10	19
Reducing trim waste	3	0	0	0	0	3	20
Material allocation	4	1	4	0	0	9	13
Capacity allocation	9	0	4	1	1	15	4
Product mix	7	0	3	0	1	11	8
Logistics studies	0	1	1	2	0	4	18
Facilities layout	3	1	1	2	0	7	14
Production planning and control	11	5	5	1	5	27	1
Inventory analysis and control	3	0	4	1	6	14	5
Project planning and control	1	19	1	0	0	21	2

APPENDIX D-3 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	1	5	0	6	16
System reliability	0	0	1	1	0	2	21
Equipment design analysis	2	1	6	0	1	10	10
Maintenance planning	3	8	2	1	0	14	5
Service crew size	1	0	2	4	0	7	14
Holding area size	1	0	2	3	0	6	16
Machines per operator	1	0	0	3	0	4	18
Analyzing capital investment projects	5	2	5	0	0	12	7
Quality control	8	0	2	0	8	16	3
Total	75	39	49	27	29		
Rank	1	3	2	5	4		

APPENDIX D-4

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: FIRMS WITH 5000+ EMPLOYEES (A_4)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Facility location	1	0	1	0	0	2	18
Line balancing	1	0	2	0	0	3	15
Chemical or Ingredient Blending	2	0	1	0	1	4	12
Reducing trim waste	0	0	0	0	0	0	21
Material allocation	2	0	2	0	0	4	12
Capacity allocation	2	0	5	0	0	7	3
Product mix	3	0	1	0	0	4	12
Logistics studies	3	0	1	0	1	5	7
Facilities layout	0	0	1	0	0	1	20
Production planning and control	2	1	4	0	1	8	1
Inventory analysis and control	0	0	4	1	2	7	3
Project planning and control	0	5	1	0	0	6	5

APPENDIX D-4 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	1	2	0	3	15
System reliability	0	0	4	0	1	5	7
Equipment design analysis	1	0	3	0	1	5	7
Maintenance planning	0	3	1	1	0	5	7
Service crew size	1	0	2	2	0	5	7
Holding area size	1	0	1	0	0	2	18
Machines per operator	1	0	1	1	0	3	15
Analyzing capital investment projects	1	1	4	0	0	6	5
Quality control	1	1	3	0	3	8	1
Total	22	11	43	7	10		
Rank	2	3	1	5	4		

APPENDIX D-5

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_1

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Facility location	0	0	1	0	0	1	13
Line balancing	2	0	1	1	0	4	7
Chemical or Ingredient Blending	0	0	0	0	0	0	17
Reducing trim waste	0	0	0	0	0	0	17
Material allocation	5	0	0	0	0	5	5
Capacity allocation	3	0	0	0	0	3	8
Product mix	0	0	1	0	0	1	13
Logistics studies	1	0	0	0	0	1	13
Facilities layout	0	0	1	0	0	1	13
Production planning and control	6	3	1	0	1	11	1
Inventory analysis and control	2	0	4	0	0	6	4
Project planning and control	0	10	0	0	0	10	2

APPENDIX D-5 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	0	0	0	0	17
System reliability	0	0	0	0	0	0	17
Equipment design analysis	0	0	0	0	0	0	17
Maintenance planning	0	4	1	0	0	5	5
Service crew size	0	0	1	1	0	2	10
Holding area size	1	0	1	0	0	2	10
Machines per operator	1	0	0	1	0	2	10
Analyzing capital investment projects	1	1	1	0	0	3	8
Quality control	1	0	1	0	6	8	3
Total	23	18	14	3	7		
Rank	1	2	3	5	4		

APPENDIX D-6

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_2

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	1	0	0	0	0	1	19
Line balancing	2	0	2	1	0	5	12
Chemical or Ingredient Blending	0	0	1	0	1	2	18
Reducing trim waste	1	0	0	0	0	1	19
Material allocation	3	0	1	0	0	4	14
Capacity allocation	5	0	2	1	0	8	6
Product mix	3	0	2	0	0	5	12
Logistics studies	5	0	0	0	1	6	10
Facilities layout	0	0	1	0	0	1	19
Production planning and control	4	9	1	3	4	21	1
Inventory analysis and control	4	2	6	2	7	21	1
Project planning and control	0	12	1	0	0	13	3

APPENDIX D-6 (Continued)

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Waiting lines	0	0	0	4	0	4	14
System reliability	0	0	3	0	3	6	10
Equipment design analysis	0	0	7	1	2	10	4
Maintenance planning	2	5	1	0	0	8	6
Service crew size	0	0	2	2	0	4	14
Holding area size	1	0	1	1	0	3	17
Machines per operator	3	0	3	2	0	8	6
Analyzing capital investment projects	4	1	3	0	1	9	5
Quality control	2	0	2	0	3	7	9
Total	40	29	39	17	22		
Rank	1	3	2	5	4		

APPENDIX D-7

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_3

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Facility location	1	3	3	1	1	9	6
Line balancing	4	0	2	1	1	8	9
Chemical or Ingredient Blending	1	0	0	0	0	1	20
Reducing trim waste	1	0	1	0	0	2	16
Material allocation	3	0	6	0	1	10	4
Capacity allocation	4	0	4	0	0	8	8
Product mix	2	0	2	0	1	5	11
Logistics studies	0	0	1	1	0	2	16
Facilities layout	0	1	0	1	0	2	16
Production planning and control	8	13	8	1	5	35	1
Inventory analysis and control	4	2	6	3	7	22	2
Project planning and control	0	18	1	0	0	19	3

APPENDIX D-7 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	0	1	0	1	20
System reliability	0	0	1	0	1	2	16
Equipment design analysis	2	1	4	0	0	7	10
Maintenance planning	1	3	0	0	1	5	11
Service crew size	0	0	1	2	0	3	14
Holding area size	1	0	1	1	0	3	14
Machines per operator	2	0	1	2	0	5	11
Analyzing capital investment projects	2	1	5	0	1	9	6
Quality control	2	1	3	0	4	10	4
Total	38	43	50	14	23		
Rank	3	2	1	5	4		

APPENDIX D-8

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_4

Manufacturing Problems	Operations Research Techniques						
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	2	2	0	0	0	4	11
Line balancing	2	0	0	0	0	2	16
Chemical or Ingredient Blending	1	0	0	0	1	2	16
Reducing trim waste	0	0	0	0	0	0	20
Material allocation	1	1	4	0	0	6	8
Capacity allocation	1	0	3	0	0	4	11
Product mix	5	0	1	0	0	6	8
Logistics studies	0	1	0	1	0	2	16
Facilities layout	0	0	0	0	0	0	20
Production planning and control	3	5	4	0	2	14	1
Inventory analysis and control	1	1	6	1	1	10	3
Project planning and control	0	10	1	0	0	11	2

APPENDIX D-8 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	2	1	0	3	14
System reliability	0	0	2	0	0	2	16
Equipment design analysis	1	0	2	0	0	3	14
Maintenance planning	0	5	1	2	0	8	6
Service crew size	1	0	3	3	0	7	7
Holding area size	1	0	2	1	0	4	11
Machines per operator	2	0	1	2	0	5	10
Analyzing capital investment projects	3	1	5	0	1	10	3
Quality control	2	1	4	0	2	9	5
Total	26	27	41	11	7		
Rank	3	2	1	4	5		

APPENDIX D-9

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_5

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	5	1	3	0	0	9	6
Line balancing	2	1	1	1	0	5	10
Chemical or Ingredient Blending	5	0	0	0	0	5	10
Reducing trim waste	3	0	1	0	0	4	13
Material allocation	4	0	1	0	1	6	8
Capacity allocation	6	0	0	0	0	6	8
Product mix	7	0	3	0	0	10	4
Logistics studies	4	0	1	0	0	5	10
Facilities layout	2	1	0	0	0	3	16
Production planning and control	9	7	5	1	2	24	1
Inventory analysis and control	4	0	3	1	1	9	6
Project planning and control	0	18	0	0	1	19	2

APPENDIX D-9 (Continued)

Manufacturing Problems	Operations Research Techniques					Total	Rank
	Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis		
Waiting lines	0	0	1	2	0	3	16
System reliability	0	0	2	1	0	3	16
Equipment design analysis	1	1	2	0	0	4	13
Maintenance planning	3	5	1	0	1	10	4
Service crew size	0	0	1	2	0	3	16
Holding area size	1	0	2	0	0	3	16
Machines per operator	3	0	0	1	0	4	13
Analyzing capital investment projects	4	2	6	0	1	13	3
Quality control	5	0	2	0	2	9	6
Total	68	36	35	9	9		
Rank	1	2	3	4	4		

APPENDIX D-10

THE NUMBER OF FIRMS APPLYING OPERATIONS RESEARCH TECHNIQUES TO MANUFACTURING PROBLEMS: INDUSTRY GROUP (INVESTMENT PER EMPLOYEE) B_6

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Facility location	4	0	2	0	1	7	11
Line balancing	2	0	0	2	3	7	11
Chemical or Ingredient Blending	12	0	2	0	2	16	8
Reducing trim waste	1	0	0	0	0	1	21
Material allocation	3	0	2	0	2	7	11
Capacity allocation	10	0	4	1	2	17	6
Product mix	14	0	2	0	1	17	6
Logistics studies	3	1	3	0	0	7	11
Facilities layout	1	0	1	1	0	3	17
Production planning and control	11	3	6	2	9	31	1
Inventory analysis and control	5	0	4	1	6	16	8
Project planning and control	1	17	1	0	0	19	2

APPENDIX D-10 (Continued)

Manufacturing Problems	Operations Research Techniques: Linear or Nonlinear Programming	PERT, CPM	Computer Simulation	Queueing Theory	Exponential Smoothing --Regression Analysis	Total	Rank
Waiting lines	0	0	0	3	0	3	17
System reliability	0	0	3	0	1	4	16
Equipment design analysis	0	0	6	0	2	8	10
Maintenance planning	2	15	1	0	1	19	2
Service crew size	1	0	2	2	0	5	15
Holding area size	1	0	1	1	0	3	17
Machines per operator	2	0	0	1	0	3	17
Analyzing capital investment projects	9	1	7	0	1	18	5
Quality control	5	0	2	0	12	19	2
Total	87	37	49	14	43		
Rank	1	4	2	5	3		

APPENDIX E

SUPPORTING DOCUMENTS

APPENDIX E-1

The University of Oklahoma 307 West Brooks, Room 103 Norman, Oklahoma 73069

College of Business Administration
Department of Management

October 31, 1973

Mr. H. G. Bosch, Manager
Baychem Corporation
Chemagro Company Division
Post Office Box 4913, Station F
Kansas City, Missouri 64120

Dear Mr. Bosch:

We believe that college students who expect to work in industry should be taught the basic business skills being used in today's business environment. To this end we are conducting a regional survey among industrial executives to gather information on the use of certain quantitative techniques in manufacturing.

In a few days you will receive a short questionnaire which will take just a few minutes to complete. Your answers will be kept confidential and used only in combination with others to get a composite picture.

Your prompt reply is critically important to our research effort. Please help us prepare young people to be more productive business employees.

Cordially yours,

Nicholas Baloff
Dean

NB:kmr

The University of Oklahoma 307 West Brooks, Room 106A Norman, Oklahoma 73069

College of Business Administration
Department of Management

November 5, 1973

Mr. H. G. Bosch, Manager
Baychem Corporation
Chemagro Company Division
Post Office Box 4913, Station F
Kansas City, Missouri 64120

Dear Mr. Bosch:

THIS IS THE SURVEY WE WROTE YOU ABOUT.

We are conducting a regional survey among manufacturing executives to gather information on the use of certain quantitative techniques in industry. This study will help us equip students with the necessary quantitative skills to be more productive business employees.

It will take but a few moments of your time to answer the simple questions on the enclosed form. Your answers will be kept confidential and used only in combination with others to get a composite picture. Your answers are very important to the accuracy of our research because your company represents an important segment of our sample.

SECTION A of the questionnaire concerns information about you and should be filled out by only you. SECTION B concerns information about the use of certain quantitative techniques in your firm.

We enclose a stamped reply envelope for your convenience. Thank you for your valuable and prompt assistance.

Sincerely,

Norman Gaither

NG:kmr

Enclosure

APPENDIX E-3

The University of Oklahoma 307 West Brooks, Room 103 Norman, Oklahoma 73069

College of Business Administration
Department of Management

November 28, 1973

Mr. H. G. Bosch, Manager
Baychem Corporation
Chemagro Company Division
Post Office Box 4913, Station F
Kansas City, Missouri 64120

Dear Mr. Bosch:

We mailed the enclosed form to you as a member of a scientifically selected sample of regional manufacturing executives. The overwhelming majority have been kind enough to help us with this important project by sending in their answers. If you were one of them, this is our way of saying, "Thank you."

In case you were away or too busy to complete the questionnaire before, may we ask you to do so now? We are trying to get as near to a "perfect survey" as possible. This would mean getting a reply from everyone who received the questionnaire.

SECTION A of the questionnaire concerns information about you and should be filled out by <u>only</u> you. SECTION B concerns information about the use of certain quantitative techniques in your firm. This study will help us equip students with the necessary quantitative skills to be more productive business employees.

I'll appreciate your earliest reply, and I am enclosing a self-addressed envelope for your convenience. Of course, answers will be used only for constructing statistical tables. Many thanks for your help in this survey.

Sincerely yours,

Norman Gaither

NG:kmr

Enclosure