applied management science

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applied management science

a quick & dirty approach

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I believe that all academics should be prepared to popularize what they are doing. Popularization is especially important for scientists who are engaged in work that may have social implications. Unless the public and politicians are reasonably informed, you see, they have no possible basis on which to make judgments. . . . Making complicated ideas simple and not misleading is a difficult, time-consuming business. Too many scientists feel that they can't be bothered with the stupid public and must get on with their research. But the best scientists are generally good popularizers.

Edmund Leach
Psychology Today, July 1974

preface

For over thirty years the field known as management science (and also as operations research, decision sciences, quantitative analysis) has been growing in complexity and usefulness. The gap between actual business practice and theory has steadily widened, to the point that some operations research courses can be characterized as nothing more than Math Appreciation 101. It is our intention to provide a practical guide to management science that bridges the gap between theory and practice and yet at the same time provides concepts that are mathematically correct. The authors are academic applied mathematicians with much real-world experience in solving operations research problems. This book is an amalgam of our two backgrounds, ideas, and experiences, and has been almost a decade in coming to fruition. Although our tone may at times seem flippant, no disrespect of persons, institutions, or businesses is intended. The sometimes casual style of writing should not mislead readers into thinking that the subject matter is neither important nor without factual base.

TO THE PROFESSOR

Every OR book is arranged in a different order, and the way we have ordered the material may be different from the way you have been teaching your course. Many chapters are interchangeable and can be taught in a different order. Our arrangement of the subject matter simply seems the most logical to us. The field of operations research has no underlying thread that would order topics in a standard way because many problems and techniques can be seen from different viewpoints. Thus some authors would put linear programming first and have every chapter as a variation of linear programming; others would see all problems as network problems and use that as a foundation; while the most elite realize that everything is *really* a calculus of variation problem and deals with information theory and automatic controls!

This book has been used for a standard semester course for junior undergraduates in a business school. There is more than enough for a semester's course, and four or five sections would need to be deleted if one section were covered every hour (assuming 42–45 hours per semester). It has also been used as the primary textbook for an undergraduate introductory class, but could be an excellent supplement for an advanced undergraduate class in business or engineering. It would also fit well into a beginning graduate class where students are more mature and quicker to learn.

One of the pleasures of teaching this book that the professor will quickly appreciate is the absence of the complaining question from future-shocked students, "Where is this technique used?" This should free a great deal of energy to be put to better use than defending appreciation of mathematics!

Finally, the cases and problems are included so that the professor may choose among many ways to teach the course: as a case course, using groups and having presentations; as a lecture course with cases assigned as homework problems; or as a lecture course with students simply doing the problems and an occasional selected case (say one for every section). The modularity of the book also lends itself well to a self-paced or personalized system of instruction, if the professor is so inclined.

TO THE STUDENT

This book is primarily designed for the student who will never take another management science course. After using this text, he or she should be able (1) to understand the processes and techniques involved in operations research and (2) recognize types of problems that occur in the business world and find logical ways to solve them.

For the student who finds this field interesting and wants to pursue it, we expect that the foundation laid in this course will be of great value as a practical reminder when the mathematics gets too thick in the advanced courses. Such tools as matrix algebra, differential and integral calculus, and statistics will be necessary as the student progresses deeper into the complexities underlying the theory, but it is not our intention here to provide theorems and proofs for techniques shown valid years ago. Rather, we provide a common-sense approach (with good mathematical references) as a basis for further study.

TO THE INTERESTED READER

It is the authors' hope that many people will read unaided through this book to acquaint themselves with the problems and techniques of operations research. To this end, there is an example and a solved case for every section so that the reader can become acquainted with the types of problems and techniques without having to solve a multitude of cases and problems.

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The authors wish to acknowledge their debt to several groups of people who have made this book possible. First, we thank the practitioners who have provided the grist for the mill—the actual settings and problems they have encountered and resolved, successfully and unsuccessfully, in their own businesses. Secondly, we are grateful to the students at the Colorado School of Mines, University of Southern California, and San Diego State University who have labored through various editions of this book and provided many of the problems and cases for it. They have helped to eliminate many errors in both the manuscript and answer book. Thirdly, we are indebted to the teaching assistants who, through time and effort spent during the last seven years, provided inestimable help in proofing as well as their own perspectives.

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San Diego, California — Rick Hesse

Golden, Colorado — Gene Woolsey

contents

1
introduction

1.1 QUICK & DIRTY MANAGEMENT SCIENCE

The whole philosophy behind "Quick & Dirty" management science is to present a simple way to attack complex problems. We define *management science* (or operations research) as "the use of logic and mathematics in such a way as not to interfere with common sense." When used, it should look, feel, and taste like good old common sense. (This should do away with the circular definition that "management science is what scientific managers do.") Most management science (abbreviated MS) or operations research (OR) techniques are so esoteric that hardly anyone understands what is being done and, as a consequence, either the technique is not used or the answer is ignored. Most MS/OR books require the use of calculus, matrix algebra, simple algebra, and other higher mathematics for the student to be able to understand and use the techniques. This book will require the student to know—

1. how to add and subtract,
2. how to multiply and divide,
3. know the left from the right,
4. that one number is bigger than another.

It will also require a lot of patience and repetition, which still seem to be the prime ingredients of learning. Doing the simple things well should be the goal, not just a stopover on the way to sophistication. The work required for understanding the concepts is simple, although time-consuming, and will lead to a practical understanding.

Most books present a lot of material on the derivation of techniques, but only a few exercises using them. Furthermore they hardly ever include any "real-world" problems. The problems are artificial, data appears mysteriously, and implementation is ignored. Finally, it is unfortunate that disastrous consequences that may result from an improper application of operations research are never mentioned. It is the authors' intention to correct these faults with this textbook, a radical (and, we hope, a pioneer) departure from the many texts now available.

In this book we are interested in approaching problems that are *real.* By real we mean that these problems are actually encountered in business and industry, sometimes on a daily basis. We assert that in order for the reader to use this book properly, he or she must recognize that learning is a process where first the baby must crawl, then walk, before it can run. The reader who expects to use this book as a tool to become an instant operations researcher must seek

elsewhere. It is hoped that this foundation will be a firm footing for thoughtful problem solvers in business and industry. It will be suggested later that the simple techniques should be used first. There are a number of reasons for this approach: (1) As they are simpler, there is a higher probability that they will be used; (2) there is a good chance that the user will understand what he or she is doing; and (3) simpler techniques are usually cheaper, a fact that gains instant credibility outside of grant-supported institutions. Again, it is learning to do a few common things uncommonly well that provides the firmest foundation.

It would be hoped that some readers might want to go on to more complex techniques to enable them to solve more complex problems. Thus they may wish to progress from this simple "paper and pencil" approach to more difficult problems requiring minicomputers, and finally to full-scale models necessitating large computer systems. A few of these techniques will be presented in the chapters on linear programming and integer programming. The reader should beware, however, of such statements as, "Complex problems require sophisticated solutions." The example set by Alexander the Great when confronted with the Gordian knot should keep us honest. (The Gordian knot was one that could not be untied, so Alexander, in a bold stroke, cut it with his sword, thus simplifying the solution greatly.)

This book is an attempt to popularize, without prostituting, operations research—a first step in understanding an exciting approach to problem solving. With our collective tongues firmly in our respective cheeks, we offer this book as a giant step *backward*.

1.2 MANAGEMENT SCIENCE: INTRODUCTION

Russ Ackoff, a management science professor at the University of Pennsylvania, says that we don't really have problems, we have *messes*. Problems appear in textbooks and also in a vacuum (never tied to the real world). Therefore Ackoff suggests that we deal in "mess management," or how to make problems out of messes. In real-world problems there are no answer books; there are just chaotic conglomerations of conflicting opinions, figures, wants, and desires. The first thing that must be done in management science is to determine what the manager wants done. The best way to begin doing this is to—

1. ask basic, simple questions,
2. observe relevant operations,
3. start paraphrasing the problem,
4. listen to feedback from the manager.

Then the chances of actually discovering the real problem are greatly increased. Once you know the problem to be solved, you have a much better chance of solving it. As an example of trying to discover the problem in the mess, consider the following.

INCIDENT: PATROLLING PARKING

A telephone company manager hired a consultant to work on a scheduling problem that involved trying to minimize the number of female operators at night. The consultant asked the simple question, "Why?" The response was that it was costly to keep several night guards in the parking lot so that the women could be safely escorted to their cars. (Men didn't need to be escorted, and none of them had been raped yet.) Operating on the principle of "doing the dumb things first," the consultant suggested replacing the women operators with men. Unfortunately that wasn't the answer (because it wasn't the problem), and it became obvious to the manager that the problem was more complex than that. Certainly there were costs in patrolling the parking lot, but they were very small compared to the total number of operators being hired and the potential savings of minimizing the number of operators to meet union requirements. After the consultant pointed out these facts, the problem could be restated, but was still very difficult to solve. (The authors have four different colleagues working independently on this problem, with minimal results so far.)

Thus asking *basic, simple questions* and suggesting *simple solutions* led to a definition of the problem through *feedback* from the manager. Another example illustrates the importance of asking simple questions.

INCIDENT: SIMPLE QUESTIONS, SIMPLE ANSWERS

This classic story from the same consultant involves a long tunnel bored through a mountain for a highway. As the highway tunnel began to be used, it was quickly recognized that the multimillion dollar ventilation system was not operating up to expectations. Exhaust gases were building up in the tunnel faster than they could be removed. It had been determined that the buildup was worse in the center of the tunnel and that redesign of the ventilation system would cost several thousand dollars. The consultant sent one of her slowest students to the site for free consulting, knowing that sometimes the slowest students ask the dumbest, simplest questions. The first question the student asked was, "What's the problem?" The answer was that people were complaining of being nauseous after driving through the tunnel. The student then asked, "Why?" The answer was that in the hot climate, people left their windows open, and as they drove through the long tunnel with its carbon monoxide buildup, the fumes would enter the cars. The student then suggested the solution: spend $200 on two signs, one at each end of the tunnel, saying, "*For safety's sake, roll up your windows.*" Of course, the suggested solution solved the problem, except that since it did not use up the amount budgeted for the new ventilation system, it was not an acceptable solution. The actual problem was how to use all the money allocated.

INCIDENT: SNOW JOB

Another problem developed in an area replete with snow during six months of the year. A consultant had extolled the virtues of his students before an audience of skeptical county and city officials at a professional seminar. A city manager asked the consultant if any of his students were present. Two students were quickly produced. To test the students' abilities, the city manager presented them with the following problem: It seems that the city manager was always catching hell from the city council, which met at 6:00 A.M. every Tuesday morning. The usual complaint was that the streets of the town had not been sufficiently plowed. The city manager said, "If I tell you how many plows and sand trucks I have and their rate of work, what is the first question you would ask me to help solve my problem?" The two students flipped a coin to decide who would answer. The winner turned to the city manager and said, "Please produce a map of the town showing where the council members live and the routes they drive to the council chambers. Plow those streets *first.*"

Thus a lot of problems that may seem complex at first can be found to be quite simple; while others that, at first, seem simple after interaction with the manager are found to be complex.

INCIDENT: NO TIME LOST

One of the earliest examples in management science of determining the problem concerns complaints about the slowness of the elevators in a high-rise office building. The management had tried everything: staggering the two elevators, one going to even floors, the other to odd; hiring operators to speed up the service; staggering one elevator to service the first 25 floors, the second to service the next 25, and so on. Finally one consultant had a brilliant idea and promised that for $500 and a couple of workers over the weekend, the complaints would be reduced to almost nothing. The company in desperation yielded to the request, and on Monday morning was surprised to see no changes in the elevators, nor in the speed of the service. The only change was that each elevator door was now a full-length mirror. The number of complaints showed a dramatic decline.

The solution used the difference between perceived time and real time in the following way: As people were waiting at the elevators, the women would look at themselves in the mirrors and make adjustments, while the men would look at the women, and before they knew it, the elevator was there. What was actually done was to create the illusion of not waiting. The problem was not to make the elevators operate more efficiently, but simply to reduce the time a user thought he or she was having to wait. (Did you ever notice that some companies play music over the telephone while you are on hold?)

INCIDENT: THE RIGHT ANSWER TO THE WRONG QUESTION

When one works in Canada, one rapidly discovers that operations research is called operation*al* research and is a profession that originated in England during World War II. Giving the English their due, there is also the story that the original operational research group was the first to discover the principle of giving the right answer to the wrong question. The first known example took place in the celebrated study of optimum utilization of Spitfires and Hurricanes during the battle of Britain. Whenever a Spitfire or Hurricane returned to the aerodrome, careful note was made upon pads made up for the purpose, as to where each bullet hole appeared on the aircraft. This information was then meticulously diagrammed and correlated. Additional armor to protect the plane and pilot was then suggested on the basis of these data. This study experienced the principle of giving the right answer to the wrong question when an unnamed group captain noted that they were counting holes and making recommendations on the basis of the planes that *returned.*

Peter Drucker, author of many books on management, has said that the wrong answer to the right question is not fatal, for further answers may be sought. But the right answer to the wrong question can be disastrous.

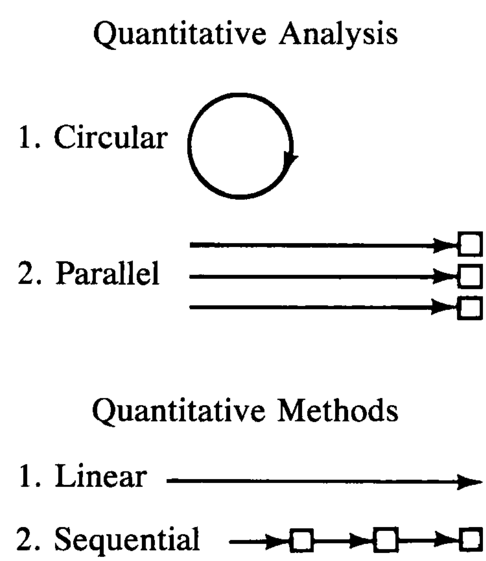
Asking the right questions is not so much an art as it is using common sense and not jumping to conclusions. One of the reasons we don't like to ask questions is that we are afraid of appearing stupid. However, to ask probing questions without ruffling feathers is a difficult task indeed. Until you understand people's problems, you can't help them.

INCIDENT: UNDERMINING ASSUMPTIONS

The last story concerns a mining company that was running into the problem of success (a common problem that has been the downfall of those who can't cope with success). In this case the company was making good progress in digging for ore, but as they got farther and farther back into the tunnels, it took longer and longer to get the ore out, since they had only one track per tunnel. An empty cart would come from the dumping station down to the end of the tunnel, be loaded, and then sent back to be dumped. As the tunnels got longer, so did the wait for another cart to be filled. The problem presented was one of trying to determine where double tracks should be placed to speed up the system of getting the ore out and returning empty cars. The cost involved enlarging tunnels and adding track at appropriate bottlenecks. The main part of the cost was enlarging and shoring up the tunnels. The first questions the consultant asked were, "How wide are the tracks, how much clearance is there between tracks and how much between the walls and the tunnels, and how wide is the tunnel now?" The information was quickly provided, and it didn't take long for the consultant to determine that sufficient tunnel width existed to lay two tracks at each and every bottleneck. The company had just *assumed* that the tunnels needed to be widened, but no one had bothered to measure to be sure. The moral is that when you *assume* you make an *ass* out of *u* and *me*.

Not all messes are as easy to solve as the preceding examples, but a great many are this way, simply because someone didn't ask some basic questions and listen to the feedback. Thus the first thing you should do with the knowledge of operations research is to be sure the solution fits the problem that the manager actually wants to solve. The formulation of a mess into a problem lies much more in the realm of *quantitative analysis* than *quantitative methods*. It is at this point that even the most skilled students realize that they may not be well equipped to analyze, since most math-oriented courses present problems to be solved rather than messes to be analyzed. This book is designed to help you learn how to analyze as well as to solve, to think as well as to do.

Analysis requires the ability to think in "circular" fashion, to look at the mess again and again, turn it over, and view it from many angles, not just one side. It also requires the ability to think in "parallel," holding many possibilities in mind simultaneously. This can be a very uncomfortable feeling for those who have not practiced it, but it is absolutely necessary for good problem formulation—hence the "team approach" in operations research where several people can brainstorm a mess until it becomes a well-defined problem. This is in contrast to problem-solving or quantitative methods which most often are very direct, linear, sequential, and lock-step.



1.3 SOLUTION

Once the mess has been changed into a problem, we will see that there are many different ways that the problem can be formulated. It might be formulated as a table of numbers or a map of distances that looks like a network. Once you have decided upon the problem formulation, there may be many different solution techniques available. In this book you will learn several ways to formulate problems and then several ways to solve them. The genius in problem solving is the person who so formulates the problem and chooses the solution technique that the solution is obvious or simple. There are essentially three different ways to solve operations research problems:

1. Change the problem to fit the solution technique.
2. Change the solution technique to fit the problem.
3. Invent a whole new way to solve the problem.

Usually we choose alternative 1 or 2, although there will be several occasions in this book when we will point out the need for a new technique, which might allow you to become rich and famous.

The important thing to remember is that there are several ways that a problem can be approached and solved. The solution technique should be something that makes sense (that is, the method may not be understood in the sense that all the math is understandable, but that the results make sense and the steps of solution are not impossible). Thus we come to *Woolsey's first law:* "Managers would rather live with a problem they can't solve than use a technique they don't trust." In simple behavioral terms, I would rather not jump out of the frying pan into the fire! This does not mean that managers understand all the mathematics behind it, but it does mean that they believe it can solve their problem. In management science, solution techniques are called *algorithms*, which simply means a clearly defined procedure.

Furthermore, operations research people are hung up on finding the optimum, because that's what we did in our classroom work as students. We found the optimum to nonexistent problems and were hung or ostracized if we didn't. But in the real world, where the data are suspect to begin with and the environment is so turbulent and dynamic that today's optimal answer is tomorrow's near-optimal, managers don't really care if you find the *optimum.* This leads us to *Woolsey's second law:* "Managers don't want the best solution; they simply want a better one." Better than what? Better than what they have right now, for a reasonable price in a reasonable amount of time. The problem with finding the optimum is that sometimes to get from 98 percent to 100 percent of the optimal value may take as long as reaching the 98 percent solution, and managers have neither the money nor the time to waste. This leads to *Woolsey's third law:* "If the solution technique will cost you more than you will save, don't use it!"

The solution techniques fall into the classification of quantitative methods and as such require the ability to think in a linear fashion (not jump ahead or think of several possibilities simultaneously). If one has ever observed brilliant math professors solve problems at the blackboard in a single bound, the impression is given that instead of executing many steps methodically, the answer simply "appears" much like a vision to a clairvoyant. But what actually happens is that the professor is able to do many simple steps very quickly in his mind because he is very good at the simple basics. Where most math students fall down is in the ability to add, subtract, multiply, and divide *symbols,* and hence they get lost in the *methods* (not just the analysis) because they try to do several steps at a time or simultaneously. Another thing that good math professors do is recheck their work mentally once or twice looking for flaws in their mechanics. Again, most math students are afraid to go back and check for fear of finding something wrong or not getting the same answer twice. Many good math people make plenty of mistakes, maybe even more than poor math people, but the difference is that they recognize them and correct them. Thus a word of advice from the authors: Take everything one step at a time. Learn to do the basics, the simple things, well. Don't try to do analysis when doing the solution techniques, but after the technique has been completed, check the answer to see if it "makes sense" (analysis).

The solution techniques (algorithms) will first be labeled either *quick* or *long.* Quick means that the method is very simple and instructions are easy to follow. Long means that it will be a little more involved (either intricate or very lengthy). Second, the algorithm will be labeled either *dirty* or *clean.* Dirty is a mathematical term to indicate that the solution technique cannot be promised to yield an optimal answer, although it may even do so 99 percent of the time. Clean means that the algorithm can be shown to yield a mathematically optimal solution. (However, even the use of a clean algorithm with data that is incorrect or suspicious may yield a dirty answer.) Many of the algorithms that are "Quick & Dirty" are *heuristic,* meaning a procedure based upon common sense and practical considerations but not necessarily optimal.

1.4 DATA

An OR/MS model without data is like a person without a soul. There are too many journal articles that use only fictitious data and do not face the problems of real data gathering. The data can be unavailable, tremendously expensive to get, jealously guarded by a department or an individual, or simply incomplete.

INCIDENT: DIRTY DATA

Each semester our classes are given the assignment of going to a local business and obtaining the costs for inventory problems—usually just the costs of carrying inventory (a combination of cost of capital, insurance, handling, storage, and so on)—and the students are amazed at the reaction of business people. Some business people have no idea what they are talking about; others try valiantly to help the students with some answers; and the smart ones know the figures but won't say so. It is always a valuable experience for any student to find out how hard it is to obtain actual figures and how threatening it can be to the person being asked. If the person doesn't know what the student is talking about, he or she is afraid to admit it, so usually he or she turns the student away or fakes it. This leads to *Woolsey's first law of data*: "The data is wrong." If you ask a machinist how long it takes to machine a piece, will he know how long it will take to the closest minute? Always! Will he give you an answer? Never!

After the direct approach fails, the next move is usually to the accounting office. There the wispy young OR analyst stands trembling at the desk of one of the accountants, buried deep in facts and figures, asking for time estimates. Finally the accountant at the next desk yells, "Toni, just give him a number!" With numbers clutched tightly in hand, the analyst runs back to the office to plug them into the latest algorithm. This leads to *Woolsey's second law of data*: "If you ask the accounting department to give it to you, they'll give it to you every time!"

A wise person once said of computing that the object was insight, not numbers.

INCIDENT: PITFALLS OF COLLECTING DATA

An energetic young man was heading out to an open-pit copper mine to time the arrivals, loading, and departures of dump trucks between the mine and the mill. As he was on his way, his instructor happened to meet him. The instructor was immediately alarmed at the prospect of what the young man was about to do and asked where his binoculars were. Not understanding, the young man asked why he would need them, whereupon the wise instructor informed him of the average life span of those who stand by the roadside with clipboard and stopwatch attempting to time teamster-driven trucks. The instructor pointed out that the young man had a high probability of appearing as an impurity in a copper ingot, coming out of the other end of the mill. The student quickly procured a topographic map of the area and soon located an appropriate spot to take the data (through binoculars).

Thus when trying to obtain data, one should be very aware of the environment and the fact that it may pose a threat to those who are being counted, measured, and observed. It is always a good rule of thumb to wear a hard hat in a plant, for tools have been known to fall upon unsuspecting data gatherers.

INCIDENT: A MORE PERFECT UNION

An enterprising young junior college student landed a job in a machine shop, having had some experience with lathes and metal working. Applying all she knew about operations research, she quickly cut down the time to produce parts so that she was making 40 parts a day within three days. Upon arrival at work the fourth day, she was greeted by the shop steward who wanted to comment upon her performance. The student was quick to explain that she was still getting the hang of it but should be able to up her production to 50 parts per day. The shop steward interrupted her and said that the student didn't quite understand. He then showed her a book which said that according to union standards only 15 of these pieces could be made per day. She was working far over the rate of the other employees and was advised that if she wanted to maintain her health, she ought to make 15 a day, and only 15. Being quick to learn, the student turned out 14 pieces in the first 3 hours, then set up her lathe for the 15th, and read books by the lathe the rest of the day, and was never bothered by the shop steward again!

In this case we see that sometimes data can be constant and that union rules and regulations can certainly have an effect upon OR models. Unless cooperation is secured with the union, the best models in the world may simply yield a theoretically optimal production rate.

INCIDENT: DEAD-END FOR DATA

A young student worked part-time as a switchboard operator for a large department store. Her class assignment was to get some information for a discounting problem from the department store. Being shy of interviewing people, she decided to get the information by telephone. What she experienced was a maze of transferred calls as one manager after another shuttled her around, until after five minutes of dead silence on the other end of the phone she realized that she had been transferred to a dead-end connection for people considered troublemakers!

Remember that gathering and validating data is threatening to many people, expensive, and time consuming. Often the data provided to the questioner is subject to ignorance, error, and evasion and must therefore be treated very carefully.

A final story illustrates the need to be alert to what the real data is and thus the actual problem that needs to be solved.

INCIDENT: A PROBLEM OF DEFINITION

A town in the western United States desired to build a new fire station to better serve its citizens. The old station dated back to territorial days and was a beautiful old relic, but not large enough for the new fire equipment. The town hired a consultant to help in determining the location of the new station, and was interested in knowing what data to collect. Many questions were asked about what the real objective was, such as whether to (1) locate near the buildings with the highest insurance rates or (2) minimize the maximum time to get to any house or building. Finally the consultant asked if he had all the information. The fire chief assured him that he did, whereupon the consultant stated that he had heard differently. The problem as he saw it was not where to locate the new firehouse but what to do with the old one. It seemed that the old station house was in an old part of town that was now mostly a Chicano neighborhood, and the council representative from that district had drummed up considerable support to keep the old station house. He argued that the proposed closing of the old station was another example of exploitation. All the *proposed* locations would be out of his neighborhood and thus reduce fire protection for his people. The problem rapidly became a classic example of the political hot potato. Further, the town could not afford to keep two station houses, so the result was a stalemate. The fire chief was rather surprised that the consultant had done his homework, and asked, "What can you do?"

The consultant suggested that the local chapter of the state Historical Society, which had been trying to save historical landmarks for 15 years and had never been successful, might be persuaded that the old station house was something that could be saved. The present fire equipment could be housed there and the station restored to its former glory and preserved for a small cost which the Society could support. The result would be that the community would have the protection it needed and would not be insulted by the removal of the station house. This proposal was unanimously passed by the City Council, to the delight of the Historical Society, the D.A.R., and the Chicano community.

1.5 CASES

Our primary instruments for teaching the use of management science are the cases in each section. These cases have been rigorously class-tested and are ranked in each section in the order of difficulty, the easier ones coming first. They are *real* cases in that they have come directly from actual situations in business, with perhaps some names and data changed to protect the guilty or the innocent. Some of them have been simplified to a great extent and, as always, they can never duplicate the real situation, that is, you never get to see the original *mess* from which they came.

However, it still should be a challenge for you to formulate and solve some of these, even though the Quick & Dirty algorithms are easy. This is because the data is sometimes cleverly hidden in the words and, as in all cases, there is a need for interpretation and feedback. In most textbook problems there is no need for any feedback since all the variables and constants are clearly given and all you have to do is to plug in the formula. In these present cases it may be necessary for you to formulate and set up the solution and then check with the instructor (who has the answer book and thus is all-wise and all-knowing) and find out if you have decoded the words properly. A lot of problem solving involves communication and feedback, and it is hoped that this will be something that will be learned from these cases.

Another point in favor of the case method is that some of these cases are large enough for teams to work on (or a team could divide up the work on several small ones), thus reinforcing a concept vital to operations research: the team approach to problem solving. You may notice as you begin to work in teams that the human dynamics become quite interesting. There is the disturbing property in mathematics of answers being right or wrong, and invariably where two or more are gathered together, several answers appear. The problem becomes (1) which solution you will hand in, (2) how is that decided, and (3) who gets blame and credit for the work? These are very real difficulties in problem solving and should not be discounted.

Each section of the book has an example with each Quick & Dirty algorithm, and then a case and solution following it. Then there are three or more cases for each section to give you some realistic ideas of situations where the algorithms have been used. Following these cases will be additional short problems which will allow you to sharpen your skills.

Your homework in this book will be done in a very different manner from math courses that you may have had previously. In most math courses the *answer* is important, and perhaps some work showing how you arrived at that answer. In these case studies the *recommendation* is the first important thing to show, then the *numerical answer,* and finally the *math work* or supporting calculations. It is suggested that the format be as follows:

1. *Recommendation.* This should be what you recommend to the manager (or professor) as far as action to take, given the problem stated in the case. This should be in English, not numbers or Greek symbols.
2. *Numerical Answer(s).* This should be the answer to the math problem and may contain all the numbers and Greek symbols usually found in math textbooks. This answer may differ from the recommendation, as it is the answer to the math part of the case, the outcome of applying the Quick & Dirty algorithm, which may yield several answers, one of which must be recommended, or the recommendation may round the math answer.
3. *Math Work.* This should be included for reference for the manager if it is desired to see how you arrived at the answer and recommendation. Of course the work should be neat and orderly, logically presented, so that the manager can follow the solution easily.

Examples of this format may be found throughout this book.

In this book you will find an interdependence between problem (analysis) and solution techniques (methods), and this makes it difficult to classify and organize the book according to problem types or solution techniques. Therefore there will be a brief introduction of each problem type and several solution techniques that could be used. Each problem type will have a solved case to show you how it might be approached, and then the cases will follow.

1.6 MODELS

One of the fundamental concepts of the practice of operations research or management science is the whole idea of a *model* of something. In the authors' generation a model had a very definite meaning which differs from that of today. Usually it meant a model plane, made of balsa wood, paper, glue, decals, wire, a one-piston engine, and hours of patient toil to put it all together so that it might fly. The result was something that looked like the real thing, and even acted like the real thing to the extent that it flew.

Nowadays we still have model planes like the above; however, the ones most often seen are those that are made of plastic and snap together. The primary difference seems to be that the new models require little or no skill to construct. Admittedly, they *do* fly, but somehow lack the resiliency, when crash landed, of the more carefully constructed models.

From the above discussion we can, at once, create some general truths about models of all kinds, including those in this book. We note that usually models that require no skill in construction, or brains on the part of the assembler, do not hold together as well as those that do. We further note that the more realistic the model is, the more time and money must go into it. We also pay a premium price for convenience. The less we have to do or understand, the more we pay (in one way or another). It can be easily verified that the component parts for a really professional model, which requires many hours of construction, cost less than the plane made of plastic that one can take out of the box and launch. We begin to get the sneaky feeling that it's not what the model appears to be that is important, but rather what goes into it. A model is the better, the more nearly it approximates the real thing; in short, if it acts just like the real article. However, some funny things can go wrong with this concept. We tend to assume that just because something *looks* like something else, it will also *act* like that something else. Little experience with other people is needed to convince us that there is precious little correlation between looking sexy, smart, or brave and *being* any of these.

Whenever a simple model is tried, there is always some other OR graduate heard saying that the model will never fly because it is (gasp, choke!) *unsophisticated.* The implication is clear:

sophisticated model = *good*
unsophisticated model = *bad*

As we have stated earlier, these words have lost their meaning. As Humpty Dumpty says in *Through the Looking Glass,* "a word . . . means just what I choose it to mean—neither more nor less. The question is, . . . which is to be master—that's all."[1] Turning to the Oxford Universal Dictionary for an even more complete definition of "sophisticate" we find that the definitions are: "1. To mix with some foreign or inferior substance; to adulterate . . . 2. . . . to render less genuine or honest. 3. To corrupt, pervert, mislead. 4. To falsify by misstatement or by unauthorized alteration."

We quickly conclude from this that the next time someone says he or she wants a sophisticated model, we should ask whether the model is wanted adulterated, ungenuine, dishonest, corrupted, perverted, misleading, or simply falsified. The execution of this bear trap will gleefully be left as an exercise for the student (after all the grades have been posted).

In the early years of operations research, B.C. (before computers), a model of a system was literally that; that is, a copy of the real situation was constructed to scale. A shining example of this would be the actual scale model of the Mississippi–Missouri river drainage basin constructed by the Corps of Engineers in the 1930s. Another excellent example