Abstract- This work will provide an overview of Operations Research (O.R.) from the perspective of an industrial engineer. The focus of this work is on the basic philosophy behind O.R. and the so-called “O.R. approach” to solving design and operational problems that industrial engineers commonly encounter. In its most basic form, O.R. may be viewed as a scientific approach to solving problems; it abstracts the essential elements of the problem into a model, which is then analyzed to yield an optimal solution for implementation. The mathematical details and the specific techniques used to build and analyze these models can be quite sophisticated and are addressed elsewhere in this handbook; the emphasis of this work is on the approach. A brief review of the historical origins of O.R. is followed by a detailed description of its methodology. This work concludes with some examples of successful real-world applications of O.R.

Keywords: Operation Research, Industrial Engineer, Management Science, Scientific Approach.

1. INTRODUCTION

The British/Europeans refer to "operational research", the Americans to "operations research" - but both are often shortened to just "OR" - which is the term we will use.

Another term which is used for this field is "management science" ("MS"). The Americans sometimes combine the terms OR and MS together and say "OR/MS" or "ORMS". Yet other terms sometimes used are "industrial engineering" ("IE") and "decision science" ("DS"). In recent years there has been a move towards a standardization upon a single term for the field, namely the term "OR".

Operation Research is a relatively new discipline. The contents and the boundaries of the OR are not yet fixed. Therefore, to give a formal definition of the term Operations Research is a difficult task. The OR starts when mathematical and quantitative techniques are used to substantiate the decision being taken. The main activity of a manager is the decision making. In our daily life we make the decisions even without noticing them. The decisions are taken simply by common sense, judgment and expertise without using any mathematical or any other model in simple situations. But the decision we are concerned here with are complex and heavily responsible. Examples are public transportation network planning in a city having its own layout of factories, residential blocks or finding the appropriate product mix when there exists a large number of products with different profit contributions and production requirement.

History of Operation Research

Operation Research is a relatively new discipline. Whereas 70 years ago it would have been possible to study mathematics, physics or engineering (for example) at university it would not have been possible to study Operation Research, indeed the term O.R. did not exist then. It was really only in the late 1930's that operational research began in a systematic fashion, and it started in the UK. As such it would be interesting to give a short history of O.R.

Early in 1936 the British Air Ministry established Bawdsey Research Station, on the east coast, near Felixstowe, Suffolk, as the centre where all pre-war radar experiments for both the Air Force and the Army would be carried out. Experimental radar equipment was brought up to a high state of reliability and ranges of over 100 miles on aircraft were obtained.

It was also in 1936 that Royal Air Force (RAF) Fighter Command, charged specifically with the air defense of Britain, was first created. It lacked however any effective fighter aircraft - no Hurricanes or Spitfires had come into service - and no radar data was yet fed into its very elementary warning and control system.

Operation Research

A common misconception held by many is that O.R. is a collection of mathematical tools. While it is true that it uses a variety of mathematical techniques, operations research has a much broader scope. It is in fact a systematic approach to solving problems, which uses one or more analytical tools in the process of analysis. Perhaps the single biggest problem with O.R. is its name; to a layperson, the term “operations research” does not conjure up any sort of meaningful image! This is an unfortunate consequence of the fact that the name that A. P. Rowe is credited with first assigning to the field was somehow never altered to something that is more indicative of the things that
O.R. actually does. Sometimes O.R. is referred to as Management Science (M.S.) in order to better reflect its role as a scientific approach to solving management problems, but it appears that this terminology is more popular with business professionals and people still quibble about the differences between O.R. and M.S. Compounding this issue is the fact that there is no clear consensus on a formal definition for O.R. For instance, C. W. Churchman who is considered one of the pioneers of O.R. defined it as the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to problems. This is indeed a rather comprehensive definition, but there are many others who tend to go over to the other extreme and define operations research to be that which operations researchers do (a definition that seems to be most often attributed to E. Naddor)! Regardless of the exact words used, it is probably safe to say that the moniker “operations research” is here to stay and it is therefore important to understand that in essence, O.R. may simply be viewed as a systematic and analytical approach to decision-making and problem-solving. The key here is that O.R. uses a methodology that is objective and clearly articulated, and is built around the philosophy that such an approach is superior to one that is based purely on subjectivity and the opinion of “experts,” in that it will lead to better and more consistent decisions. However, O.R. does not preclude the use of human judgment or non-quantifiable reasoning; rather, the latter are viewed as being complementary to the analytical approach. One should thus view O.R. not as an absolute decision making process, but as an aid to making good decisions. O.R. plays an advisory role by presenting a manager or a decision-maker with a set of sound, scientifically derived alternatives. However, the final decision is always left to the human being who has knowledge that cannot be exactly quantified, and who can temper the results of the analysis to arrive at a sensible decision.

2. THE OPERATION RESEARCH APPROACH

Given that O.R. represents an integrated framework to help make decisions, it is important to have a clear understanding of this framework so that it can be applied to a generic problem. To achieve this, the so-called O.R. approach is now detailed. This approach comprises the following seven sequential steps: (1) Orientation, (2) Problem Definition, (3) Data Collection, (4) Model Formulation, (5) Solution, (6) Model Validation and Output Analysis, and (7) Implementation and Monitoring. Tying each of these steps together is a mechanism for continuous feedback.

i) Orientation

ii) Problem Definition

iii) Data Collection

iv) Model Formulation

v) Solution

vi) Validation and Output Analysis

vii) Implementation and Monitoring

While most of the academic emphasis has been on Steps 4, 5 and 6, the reader should bear in mind the fact that the other steps are equally important from a practical perspective. Indeed, insufficient attention to these steps has been the reason why O.R. has sometimes been mistakenly looked upon as impractical or ineffective in the real world.

2.1. Orientation

The first step in the O.R. approach is referred to as problem orientation. The primary objective of this step is to constitute the team that will address the problem at hand and ensure that all its members have a clear picture of the relevant issues. It is worth noting that a distinguishing characteristic of any O.R. study is that it is done by a multifunctional team. To digress slightly, it is also interesting that in recent years a great deal has been written and said about the benefits of project teams and that almost any industrial project today is conducted by multi-functional teams. Even in engineering education, teamwork has become an essential ingredient of the material that is taught to students and almost all academic engineering programs require team projects of their students. The team approach of O.R. is thus a very natural and desirable phenomenon.

2.2. Problem Definition

This is the second, and in a significant number of cases, the most difficult step of the O.R. process. The objective here is to further refine the deliberations from the orientation phase to the point where there is a clear definition of the problem in terms of its scope and the results desired. This phase should not be confused with the previous one since it is much more focused and goal oriented; however, a clear orientation aids immeasurably in obtaining this focus. Most practicing industrial engineers can relate to this distinction and the difficulty in moving from general goals such “increasing productivity” or “reducing quality problems” to more specific, well-defined objectives that will aid in meeting these goals.

2.3. Data Collection

In the third phase of the O.R. process data is collected with the objective of translating the problem defined in the second phase into a model that can then be objectively analyzed. Data typically comes from two sources – observation and standards. The first corresponds to the case where data is actually collected by observing the system in operation and typically, this data tends to derive from the
2.4.3 Physical Models

These are actual, scaled-down versions of the original. Examples include a globe, a scale-model car or a model of a flow line made with elements from a toy construction set. In general, such models are not very common in operations research, mainly because getting accurate representations of complex systems through physical models is often impossible.

2.4.4 Analogic Models

These are models that are a step down from the first category in that they are physical models as well, but use a physical analog to describe the system, as opposed to an exact scaled-down version. Perhaps the most famous example of an analogic model was the ANTIAC model (the acronym stood for anti-automatic-computation) which demonstrated that one could conduct a valid operations research analysis without even resorting to the use of a computer. In this problem the objective was to find the best way to distribute supplies at a military depot to various demand points.

2.4.5 Computer Simulation Models

With the growth in computational power these models have become extremely popular over the last ten to fifteen years. A simulation model is one where the system is abstracted into a computer program. While the specific computer language used is not a defining characteristic, a number of languages and software systems have been developed solely for the purpose of building computer simulation models; a survey of the most popular systems may be found in OR/MS Today (October 1997, pp. 38-46). Typically, such software has syntax as well as built-in constructs that allow for easy model development.

2.4.4 Feature of Simulation Models

They can be used to model very complex systems without the need to make too many simplifying assumptions and without the need to sacrifice detail. On the other hand, one has to be very careful with simulation models because it is also easy to misuse simulation. First, before using the model it must be properly validated. While validation is necessary with any model, it is especially important with simulation. Second, the analyst must be familiar with how to use a simulation model correctly, including things such as replication, run length, warm up etc; a detailed explanation of these concepts is beyond the scope of this chapter but the interested reader should refer to a good text on simulation.

2.4.5 Mathematical Models

This is the final category of models, and the one that traditionally has been most commonly identified with O.R. In this type of model one captures the characteristics of a system or process through a set of mathematical relationships. Mathematical models can be deterministic or probabilistic. In the former type, all parameters used to describe the model are assumed to be known (or estimated with a high degree of certainty). With probabilistic models, the exact values for some of the parameters may be unknown but it is assumed that they are capable of being characterized in some systematic fashion (e.g., through the use of a probability distribution). As an illustration, the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are two very similar O.R. techniques used in the area of project planning.

Before concluding this section on model formulation, we return to our hypothetical example and translate the statements made in the problem definition stage into a mathematical model by using the information collected in the data collection phase. To do this we define two decision variables G and W to represent respectively the number of gizmos and widgets to be made and sold next month. Then the objective is to maximize total profits given by 10G+9W. There is a constraint corresponding to each of the three limited resources, which should ensure that the production of G gizmos and W widgets does not use up more of the corresponding resource than is available for use. Thus
for resource 1, this would be translated into the following mathematical statement $0.7G+1.0W \leq 630$, where the left-hand-side of the inequality represents the resource usage and the right-hand-side the resource availability. Additionally, we must also ensure that each $G$ and $W$ value considered is a nonnegative integer, since any other value is meaningless in terms of our definition of $G$ and $W$. The completely mathematical model is:

Maximize \{Profit = 10G+9W\},

Subject to

- $0.7G+1.0W \leq 630$
- $1.0G + \frac{2}{3} W \leq 708$
- $0.1G+0.25W \leq 135$
- $G, W \geq 0$ and integers.

This mathematical program tries to maximize the profit as a function of the production quantities ($G$ and $W$), while ensuring that these quantities are such that the corresponding production is feasible with the resources available.

2.5 Solution of Problem

The fifth phase of the O.R. process is the solution of the problem represented by the model. This is the area on which a huge amount of research and development in O.R. has been focused, and there is a plethora of methods for analyzing a wide range of models. It is impossible to get into details of these various techniques in a single introductory chapter such as this; however, an overview of some of the more important methods can be found elsewhere in this handbook. Generally speaking, some formal training in operations research is necessary in order to appreciate how many of these methods work and the interested reader is urged to peruse an introductory text on O.R.; the section on "Further Reading" at the end of the chapter lists some good books. It is also worth mentioning that in recent years a number of software systems have emerged which (at least in theory) are "black boxes" for solving various models. However, some formal education in O.R. methods is still required (or at least strongly recommended) before using such systems. From the perspective of the practitioner, the most important thing is to be able to recognize which of the many available techniques is appropriate for the model constructed. Usually, this is not a hard task for someone with some rudimentary training in operations research. The techniques themselves fall into several categories.

2.6 Validation And Analysis Of Solution

Once a solution has been obtained two things need to be done before one even considers developing a final policy or course of action for implementation. The first is to verify that the solution itself makes sense. Oftentimes, this is not the case and the most common reason is that the model used was not accurate or did not capture some major issue. The process of ensuring that the model is an accurate representation of the system is called validation and this is something that (whenever possible) should be done before actual solution. However, it is sometimes necessary to solve the model to discover inaccuracies in it. A typical error that might be discovered at this stage is that some important constraint was ignored in the model formulation - this will lead to a solution that is clearly recognized as being infeasible and the analyst must then go back and modify the model and re-solve it. This cycle continues until one is sure that the results are sensible and come from a valid system representation.

2.7 Implementation And Monitoring

The last step in the O.R. process is to implement the final recommendation and establish control over it. Implementation entails the constitution of a team whose leadership will consist of some of the members on the original O.R. team. This team is typically responsible for the development of operating procedures or manuals and a time-table for putting the plan into effect. Once implementation is complete, responsibility for monitoring the system is usually turned over to an operating team. From an O.R. perspective, the primary responsibility of the latter is to recognize that the implemented results are valid only as long as the operating environment is unchanged and the assumptions made by the study remain valid.

3. APPLICATION OF O.R. IN REAL WORLD

In this section some examples of successful real-world applications of operations research are provided. These should give the reader an appreciation for the diverse kinds of problems that O.R. can address, as well as for the magnitude of the savings that are possible. Without any doubt, the best source for case studies and details of successful applications is the journal Interfaces, which is a publication of the Institute for Operations Research and the Management Sciences (INFORMS). This journal is oriented toward the practitioner and much of the exposition is in laypersons' terms; at some point, every practicing industrial engineer should refer to this journal to appreciate the contributions that O.R. can make. All of the applications that follow have been extracted from recent issues of Interfaces. Some examples of successful O.R. projects are now presented.

3.1 Production Planning At Harris Corporation - Semiconductor Section

For our first application [1], we look at an area that is readily appreciated by every industrial engineer-production planning and due date quotation. The semiconductor section of Harris Corporation was for a number of years a fairly small business catering to a
niche market in the aerospace and defense industries where the competition was minimal.

3.2 Gasoline Blending At Texaco
For another application to production planning, but this time in a continuous as opposed to discrete production environment, we look at a system in use at Texaco [2]. One of the major applications of O.R. is in the area of gasoline blending at petroleum refineries, and virtually all major oil companies use sophisticated optimization models in this area. At Texaco the system is called StarBlend and runs on networked microcomputers. As some background, the distillation of crude petroleum produces a number of different products at different distillation temperatures. Each of these may be further refined through cracking (where complex hydrocarbons are broken into simpler ones) and recombination.

3.3 FMS Scheduling At Caterpillar
For our third application we look at the use of a simulation model. This model was applied to derive schedules for a Flexible Manufacturing System (FMS) at Caterpillar, Inc. [3]. The interested reader may refer to any text on computer integrated manufacturing for details about FMSs; typically, they are systems of general purpose CNC machines linked together by an automated material handling system and completely controlled by computers.

3.4 Fleet Assignment At Delta Airlines
One of the most challenging as well as rewarding application areas of O.R. has been the airline industry. We briefly describe here one such application at Delta Airlines [4]. The problem solved is often referred to as the fleet assignment problem. Delta flies over 2500 domestic flight legs each day and uses about 450 aircraft from 10 different fleets, and the objective was to assign aircraft to flight legs in such a way that revenues from seats are maximized.

3.5 Keycorp Service Excellence Management System
For our final application we turn to the service sector and an industry that employs many industrial engineers - banking. This application [5] demonstrates how operations research was used to enhance productivity and quality of service at KeyCorp, a bank holding company headquartered in Cleveland, Ohio. Faced with increasing competition from nontraditional sources and rapid consolidation within the banking industry, KeyCorp's aim was to provide a suite of world-class financial products and services as opposed to being a traditional bank.

CONCLUSION
This work provides an overview of operations research, its origins, its approach to solving problems, and some examples of successful applications. From the standpoint of an engineer, O.R. is a tool that can do a great deal to improve productivity. It should be emphasized that O.R. is neither esoteric nor impractical, and the interested I.E. is urged to study this topic further for its techniques as well as its applications; the potential rewards can be enormous.

REFERENCES