Operations Research

Module-1 (updated 2014)

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Introduction

Basic managerial functions are *Decision* and *Control*. Management is a varied field of endeavors and managers carry out many tasks. Managers examine and evaluate many alternatives for selecting optimum method to meet their required goal. The effectiveness and efficiency of any organization largely depends upon the quality of decision making capability of its executive management. Whereas the quality of decision making depends upon the input information – when the input information is large and the problem is complex, the decision arrived may not be so easy and effective. Hence such complex processes required quantitative methods / tools as an aid for it.

Managerial decision making can be divided into two main perspectives – *the structured form of the problem* and *the unstructured form of the problem*. In the *structured form* we obtain the procedure for getting the best solutions; and in the *unstructured form* we deal with the human instinct for formulizing the decision. Non-tangible information needs to be added by the decision maker on the basis of his experience. For the solution of the problem, we can define the managerial activities in the following three categories:

- ✓ *Strategic Planning* – deciding and working out strategic or long term goals and policies for the business and hence paying attention to the resources requirements and allocations.
- ✓ *Management Monitoring and Control* – this activity involves the acquisition and effective utilization of the resources so as to ensure that the decision being implemented is well within time frame and cost parameters such that the organizational goals are accomplished.
- ✓ *Operational Control* – this activity is meant for controlling specific tasks within the overall framework. For all these activities to be accomplished without much hindrances, we need support in terms of various managerial techniques. Management Science or Decision Science or Operations Research thus helps for decision making process.

Terminology

The British / Europeans refers to “Operational Research”, the Americans to “Operations Research” – but both are often shortened to just “OR”, and this short form / term shall be frequently used in this book.

Another term which is used for this field is “Management Science” (“MS”). The Americans often combine the terms OR and MS together and say it as “OR/MS” or “ORMS”. Yet another terms that are frequently used are “Industrial Engineering” (“IE”) and “Decision Science” (“DS”). However in recent years there has been a move towards standardization upon a single term for this field of study as “OR”.

Management Science or Operations Research is the application of a scientific approach towards solving management problems in order to help managers to make better decisions. This scientific approach towards solving of managerial problems makes extensive use of quantitative analysis. Management Science encompasses a number of mathematically oriented techniques which can be applied towards the solving of management problems.

History

However initially this effective business science was not used for any managerial decision making.

Some of you may have moral *qualms* about discussing about OR as to what are, at root, more effective ways to kill people. However we cannot change the history and what is presented below is essentially what happened, whether one likes it or not…….

Year – 1936

Early in 1936 the British Air Ministry established Bawdsey Research Station, on the east cost, near Felixstone, 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.

It had become clear that radar would create a whole new series of problems in fighter direction and control, so in late 1936 some experiments started at Biggin Hill in Kent in order to search out for the effective use of such data. *This early work, attempting to integrate radar data with the ground based observer data for fighter interceptions, was the start of* OR.

Year – 1937

The first three major pre-war air-defense exercises were carried out in the summer of 1937. The experimental radar station at Bawdsey Research Station was brought into operation and the information derived from it was fed into the 'general air-defense warning and control system'. From the early warning point of view, this exercise was encouraging, but the tracking information obtained from the radar, after filtering and transmission through the control and display network, was not very satisfactory.

Year – 1938

In July 1938 a second major pre-war air-defense exercise was carried out. Four additional radar stations were installed along the coast and it was hoped that Britain now had an aircraft location and control system greatly improved both in coverage and effectiveness. But it was not so! The exercise revealed, rather that a new and more serious problem had arisen, this was the need to coordinate and correlate the additional, and often conflicting information received from the additional radar stations. With the out-break of war apparently imminent, it was observed that something new – drastic if necessary – had to be attempted. Some new approach(s) were needed for this.

Accordingly, on the termination of the exercise, the Superintendent of Bawdsey Research Station, A.P.Rowe, announced that although the exercise had again demonstrated the technical feasibility of the radar system for detecting aircraft, its operational achievements still feel far short of the requirements. He therefore proposed that a crash program of research into the operational – as opposed to the technical – aspects of the system should begin immediately. *The term "Operational Research" [RESEARCH into (military) OPERATIONS] was coined as a suitable description of this new branch of applied science.* The first team was selected from among the scientists of the Radar Research Group on the same day.

Year – 1939

In the summer of 1939 Britain held what was to be its last pre-war air-defense exercise. It involved some 33000 men, 1300 aircraft, 110 anti-craft guns, 700 search-lights and 100 barrage-balloons. This exercise showed a great improvement in the operation of the air-defense warning and control system. The contribution made by the OR teams was so apparent that the Air Officer Commander-in-Chief RAF Fighter Command (Air Chief Marshal Sir Hugh Dowding) requested that, on the out-break of the war, they should be attached to his headquarters at Stanmore in North London.

Initially, they were designated with “Stanmore Research Section”. In 1941 they were re-designated with “Operational Research Section”, wherein the term was formalized and officially accepted, and similar sections were setup at other RAF Commands.

Year – 1940

On May 15 – 1940, with German forces advancing rapidly in France, Stanmore Research Section was asked to analyze the French request for 10 additional fighter squadrons (12 aircraft a squadron – so 120 aircraft in all) when the losses were running at some three squadrons every two days (that is, 36 aircraft every two days). They prepared graphs for Winston Churchill (the British Prime Minister of that time) based upon a study of current daily losses and replacement rates, indicating how rapidly such a move would deplete fighter strength. No aircraft were sent and most of those currently in France were recalled.

This is held by some to be the most strategic contribution to the course of the war made by OR (as the aircraft and pilots saved were consequently available for the successful air defense of Britain, the Battle of Britain).

Year – 1941 onwards

In 1941 an Operational Research Section (ORS) was established in Coastal Command which was to carry out some of the most well-known OR work in World War-II.

The responsibility of the Coastal Command was to a large extent, the flying of long-range sorties by single aircraft with the objective of sighting and attacking surfaced U-boats (German sub-marines). Amongst the problems that ORS considered were:

- *Organization of flying maintenance and inspection* – here the problem was that in a squadron each aircraft, in a cycle of approximately 350 flying hours, required in terms of routine maintenance 7 minor inspections (lasting 2 to 5 days each) and a major inspection (lasting 14 days). How then was flying and maintenance to be organized to make best use of squadron resources?

  ORS decided that the current procedure, whereby an aircrew had their own aircraft, and that aircraft was serviced by a devoted ground crew, was inefficient (as it meant that when the aircraft was out of action the aircrew was also inactive). They proposed a central garage system whereby the aircraft were sent for maintenance when required and each aircrew drew a (different) aircraft when required.

  The advantage of this system was plainly that flying hours should be increased. The disadvantage of this system was that there was loss in morale as the ties between the aircrew and “their” plane/ground crew and the ground crew and “their” aircrew/plane were broken.

  In one trial (over 5 months) when flying was organized by ORS the daily operational flying hours were increased by 61% over the previous best achieved with the same number of aircraft, their system was accepted and implemented.

- *Comparison of aircraft type* – here the problem was one of deciding, for a particular type of operation, the relative merits of different aircraft in terms of factors, such as, miles flown per maintenance man per month, lethality of load, length of sortie, chance of U-boat sighting, and so on.

- *Improvement of attack-kill probability (the probability of attacking and killing a U-boat)*- experience showed that it required some 170 man-hours by the maintenance and ground staff to produce one hour of operational flying and more than 200 hours of flying to produce one attack on a surfaced U-boat. Hence over 34000 man-hours of effort were required necessarily to attack a U-boat.

  In early 1941 the attack-kill probability was 2% to 3%, that is, between 1.1 million to 1.7 million man-hours were needed by the Coastal Command to destroy one U-boat. *It is in this area that the greatest contribution was made by the OR in Coastal Command (therefore we shall discuss this in more detail so as to understand the importance of OR in decision making in a more understandable manner. Also the students should note here that, I have ignored the question of U-boat being attacked and damaged, but not killed, so as to remove the complications in the discussions.*

  Plainly, in the above calculations, the "weak link" is the low-attack-kill probability and it is this that really needs to be improved.

  The main weapon of attack against a surfaced (when spotted) U-boat was dept charges dropped in a stick (typically six 250 lb or 110 kg depth charges) in a more or less straight line along the direction of the flight of the attacking aircraft. After hitting the water a depth charge sinks whilst at the same time being carried forward by its own momentum. After a pre-set time delay, or upon reaching a certain depth it explodes and any U-boat within a certain distance (the lethal radius) is fatally damaged. Six variables were considered as influencing the kill probability, which were:

• Depth (time setting) for depth charge explosion.	• Aiming errors in dropping the stick	• Spacing between successive depth charges in the stick.
• Lethal radius	• Orientation of the stick with respect to the U-boat.	• Low level bombing-sights.

  Now let us understand these variables in understanding OR contribution one-by-one:

  - *Depth (time setting) for depth charge explosion* – in the first two years of the war, depth charges were mainly set for explosion at a depth of 30/45 meters (this figure having being set years ago and never altered since). *Analysis* of pilot reports by ORS showed that in 40% of attacks the U-boat was either still visible or had been submerged less than 15 seconds (these are the U-boats that we would expect to have most chance of killing as we have a good idea of their position). Since the lethal radius of a depth charge was about 5 to 6 meters, it was cleat that a shallower setting was necessary. Explosion at a depth of 15 meters was initiated and as new fuses became available at 10 meters and then 8 meters.

  - *Lethal radius* – as mentioned above that the standard 250 lb depth charge was believed to have a lethal radius of only 5 to 6 meters. Plainly to increase this radius (within the 250 lb limit) the chemical explosive inside the depth charge should be more powerful (for example, increasing the lethal radius by just 20% increases the lethal volume (sphere) around the depth charge by 72.8%). The best chemical explosive currently available were therefore introduced.

Note here that, it could be argued (and was) that since a 250 lb depth charge had too small a lethal radius a bigger charge (600 lb or 270 kg) was prescribed by the Air Staff) was needed. *ORS suggested* 100 lb or 45 kg on the basis that it would be more effective to have many small explosions rather than one large explosion. (As an analogy would you prefer to throw many balls at a small target or one large ball?). In fact neither alternative ever really preceded past the trial stage due to increasing success with the 250 lb depth charge. *This illustrated the concept of "trade-off" which often appears in OR in that, for a given total bomb load we have to make a choice (called as trade-off) between bomb-size and number of bombs (from one big to many small ones).*

- *Aiming errors in dropping the stick* – by the end of 1942 it had become clear that too many pilots were reporting having had "straddled" a target U-boat with a stick of depth charges without sinking it. Either their claims were unduly optimistic (the ORS view) or the lethal radius of a depth charge was much less than currently believed (the Air Staff view).

  To settle the issue, cameras were installed for recording U-boat attacks. *Analysis of 16 attacks indicated that ORS were right*. This analysis also showed that pilots were following tactical instructions and "aiming off" (aiming ahead of the U-boat to allow for its forward travel during fall of the depth charges). However analysis also revealed that had they not aimed off 50% more kills would have been recorded. Pilots were therefore instructed not to aim off.

- *Orientation of the stick with respect to the U-boat* – here the question was whether to attack from the beam, quarter or along the U-boat track. No definite answer was really reached until 1944 when it was concluded that track attacks were more accurate (probably due to the pilot using the U-boat wake to help him line the plane up).

- *Spacing between successive depth charges in a stick* – in the early part of the war this spacing was specified at 12 meters. ORS calculated that increasing this to 33 meters would increase the kills by 35% and this was done.

- *Low level bomb-sights* – for much of the war all low level attacks on U-boats were the pilots acting as bomb aimer / release. Although pilots (and Air Staff) believed they were accurate but the photographic evidence did not support this belief of the pilots and ORS pressed for bomb-sights to be provided. By late 1943 a low level (Mk.III) sight came into use thereby increasing the kills per attack by 35%.

The overall effect of all the measures discussed above was such that by 1945 the attack-kill probability had risen to over 40% (the students should note that it started with 2 to 3%).

Although scientists had (plainly) been involved in the hardware side of the warfare (that is, designing better planes, bombs, tanks and so on), the scientific analysis of the operational use of military resources had never been taken place in a systematic fashion before the World War – II. Military personnel, often by no means stupid, were simply not trained to undertake such analysis.

The early OR workers came from different disciplines, one group consisted of physicist, two physiologists, two mathematical physicist and a surveyor. What such people brought to their work were "scientifically trained" minds, used to query assumptions, logic, exploring hypothesis, devising experiments, collecting data, analyzing numbers, and so on so forth. Many too were of high intellectual caliber (at least four UK wartime OR personnel were later to win Nobel Prize when they returned to their peace-time disciplines).

By the end of the Second World War OR was well established in the armed services both in UK and in USA.

Following the end of the Second World War OR took a different course in the UK as opposed to that in the USA. In UK (as mentioned above already) many of the distinguished OR workers returned to their original peace-time disciplines. As such OR did not spread particularly well, except for few isolated industries, such as, iron / steel and coal. In USA OR spread to the universities so that systematic training in OR for future workers began.

Therefore, from above discussion the students can well judge and conclude that OR started just before Second World War in Britain with the establishment of teams of scientists to study the strategic and tactical problems involved in military operations (hence the then name "Operational Research"). The objective was to find the most effective utilization of limited military resources by the use of quantitative techniques. Thereafter, following the end of the war OR spread, although it spread in different ways in the UK and USA.

The students should note that, the growth of OR since it began (and especially in the last 30 years) is, to a large extent, the result of the increasing power and widespread availability of computers. Most (though not all!) OR involves carrying out a large number of numeric calculations, without computers this would simply not been possible. Now many customized tools are available (freeware and paid) for solving complex problems of OR. One of the software that is generally used for solving OR is TORA. Also many templates in Excel are now available on the internet for the same.

(The students are advised to have a search of these tools and see for themselves their utility and effectiveness in solving OR complex problems).

Manager, Management and Operations Research

Managers need to make wide range of decisions everyday. They are trained to do that, that is why they are hired and that is why they are paid for. Some of these decisions are made largely on the basis of intuition or gut feelings. For example, decision to increase or reduce the selling price of a product considering the demand and competitive activity, is a result of an intuitive analysis of the buying behavior of the customer and the pricing strategy of the competitor. On the other hand, deciding which combination of machines, jobs to be done and available employees generates the lowest total manufacturing cost for a large plant is a decision which can benefit from some of the quantitative methods or to say some OR tools and techniques.

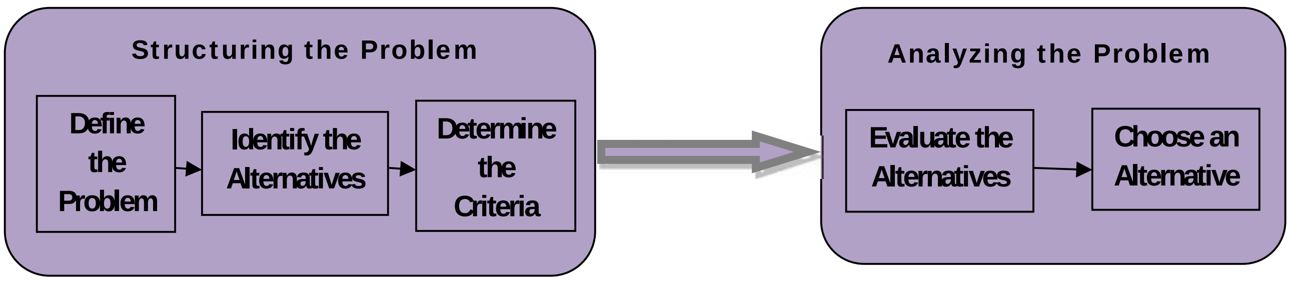
Managers are evaluated primarily on the result of their decisions and successful managers use quantitative approaches towards decision making. These approaches are known as Operations research or Management Science or Decision Science or quantitative Analysis for management or Quantitative Techniques for management and so on.

OR is the application of a scientific approach towards solving management problems in order to help the managers to make better decisions. This scientific approach towards solving managerial problems makes extensive use of quantitative analysis. OR encompasses a number of mathematically oriented techniques which can be applied to solve management problems.

OR is a recognized and well established discipline in the field of Business Administration for increasing the efficiency and productivity of business firms. Quantitative methods towards decision making are used when the problem is complex; the problem involves many variables; there is/are data which describes the decision environment; workable models are available for the problem; the goal of the decision maker or that of the organization can be described in quantitative terms; and finally if there is/are data which describes the value or utility of the different possible alternatives.

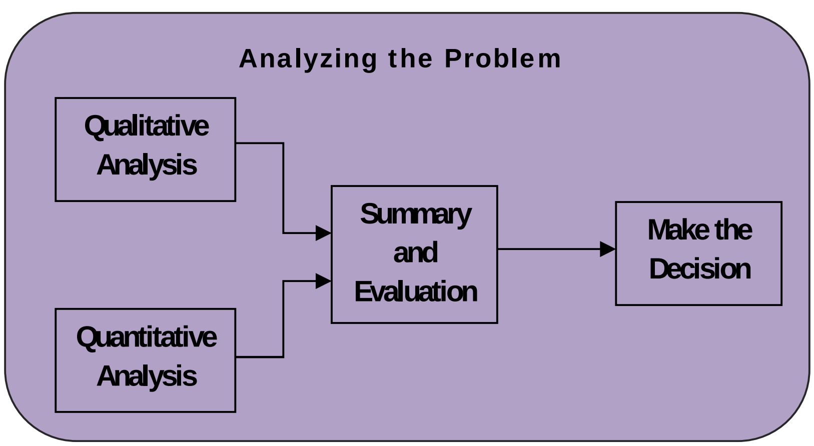
Initially, OR extended into the process-type industries and as these industries started characterizing in large volumes of relatively few products, the savings were high because even a small amount of money saved per unit of product on large volume could add up to crores of rupees saved. In addition, a high capital-to-worker ratio in the new automated industries meant relatively fewer employees whose duties were mainly in supervision, maintenance and control. Therefore, the employees needed maximum efficiency in decision making for day-to-day routine working.

The figure below illustrates the decision making process which a manager generally adopts in order to have an efficient solution to the problem.



Clearly, the analysis phase of the decision making involves two main phases: Structuring of the Problem and Analyzing the Problem.

"Analyzing the Problem" phase can be further simplified as illustrated below:



Now, let us discuss the Qualitative and Quantitative analysis in detail along with the Quantitative Techniques that are generally adopted by the managers in decision making process.

Qualitative Analysis – it is primarily based on the judgment and experience of the managers and it includes the manager's intuition regarding the problem. Such a analysis is emphasized in situations wherein the manager has similar experience for the problem or if the problem is relatively simple to be decided upon. Such a analysis is generally not recommended if the problem is complex and the manager is not having enough experience to deal with such like problems.

Quantitative Analysis – it is a scientific approach towards managerial decision making. This approach starts with data that are manipulated or processed into information that is valuable for making decisions. This processing and manipulating of raw data into meaningful information is the heart of quantitative analysis. Computers have greatly enhanced the use of quantitative analysis for solving managerial problems.

Quantitative approach to problem solving requires the managers to concentrate on quantitative data or facts pertaining to the problem and then develop mathematical models that describe the objectives, constraints and other relationships that exist in the problem. Then the manager uses one or more quantitative methods to make a decision or solution to the problem faced, based on the quantitative aspects of the problem.

Quantitative techniques or methods are primarily mathematical or statistical techniques used in managerial decision making. Quantitative approach towards problem solving requires collection of large amount of data and development of mathematical models. Quantitative techniques, such as, Goal Programming, Linear Programming, Non-linear programming, Transportation Method, Assignment Method, Queuing Models, Game Theory Methods, Simulation Methods, and so on, are used to synchronize and have an aid towards effective and efficient managerial decision making under complex and uncertain situations in order to achieve the objectives and goals of the organization.

Note that, although the skills in the qualitative approach are inherent in the managers and usually increase with experience, managers can acquire skills of the quantitative approach only by studying the assumptions and methods of Decision Science or Operations Research. A manager's decision making effectiveness can be increased by learning more about quantitative methodologies or techniques and by better understanding its contribution to the decision making process. Knowledge in quantitative decision making procedures enables the managers to be in a much comfortable position so as to compare and evaluate the qualitative and quantitative sources of recommendations and to combine the two sources in order to make the best possible and optimistic decision.

For successful application and implementation of the quantitative analysis towards decision making the management science expert must work in close coordination with the manager of the user department or the user of the results. Once the management science expert and the manager who wishes to use the result of the quantitative analysis agrees about the adequacy of the problem structure, a model can be developed to represent the problem mathematically. The quantitative techniques can then be used to determine the optimum or best solution to the developed mathematical model.

Some of the reasons for using quantitative approach towards managerial decision making are:

- the problem is complex and a good solution cannot be developed without the use of quantitative analysis;
- the problem might involve heavy investment of money and hence, a thorough analysis of the problem is desired before attempting to make a decision; and
- the problem is repetitive and time as well as effort may be saved by relying on quantitative techniques to make routine decisions.

But there is a black side towards approach towards managerial decision making, some of the limitations to this are:

- quantitative methods for most of the problems are time consuming and are elaborate;
- quantitative methods for most of the problems are difficult in identifying uncertainties which may make coordination with the system difficult; and
- quantitative methods for most of the problems are treated as a supporting tool to analyze mathematical models and may not be acceptable to many decision makers.

Definitions of Operations Research

✓ "Operations Research is concerned with scientifically deciding how to best design and operate man-machine systems usually requiring the allocation of scarce resources".

- *Operations Research Society, America*

✓ "Operations Research is the application of the methods of science to complex problems in the direction and management of large systems of men, machines, materials and money in the industry, business, government and defense. The distinctive approach is to develop a scientific model of the system by incorporating measurement of factors, such as, chance and risk, with which to predict and compute the outcomes of alternative decisions, strategies and controls. The purpose is to help the management in determining the policy and actions scientifically".

- *Operations Research Society, United Kingdom*

✓ "Operations Research is a systematic application of quantitative methods, techniques and tools to the analysis of the problems involving operation of systems".

"Operations Research is essentially a collection of mathematical techniques and tools which in conjunction with a system approach are applied to solve practical decision problems of an economic or engineering nature".

- *Dallenbach and Gorge (1978)*

✓ "Operations Research may be described as a scientific approach to decision making that involves the operations of organizational systems".

- *P.S. Hill and G.J. Lieberman (1980)*

✓ "Operations Research is in the most general sense can be characterized 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 operations with optimum solutions to the problems".

- *Churchman, Ackoff and Arnoff (1957)*

✓ "Operations Research is 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 operations with optimum solutions to the problems".

- *Churchman*

- ✓ "Operations Research is a scientific approach to problem solving for executive management".

  - *H.M. Wagner*

- ✓ "Operations Research is a scientific method of providing executive departments with a quantitative basis for decisions under their control".

  - *P.M. Morse and G.E. Kimball*

- ✓ "Operations Research has been described as a method, an approach, a set of techniques, a team activity, a combination of many disciplines, an extension of particular disciplines (mathematics, engineering, economics), a new discipline, a vocation, even a religion. It is perhaps some of all these things".

  - *S.L. Cook (1977)*

- ✓ "Operations Research is applied decision theory. It uses any scientific, mathematical or logical means to attempt to cope with the problems that confront the executive, when he tries to achieve a through-going rationality in dealing with his decision problems".

  - *D.W. Miller and M.K. Stan*

- ✓ "Operations Research utilizes the planned approach (updated scientific method) and an interdisciplinary team in order to represent complex financial relationships as mathematical models for the purpose of providing a quantitative basis for decision making and uncovering new problems for quantitative analysis".

  - *Thierauf and Klekamp*

- ✓ "Operations Research is the attack of modern science on problems of likelihood that arise in the management and control of men and machines, materials and money in their natural environment, its special technique is to invent a strategy of control by measuring, comparing and predicting probable behavior through a scientific model of a situation".

  - *Stafford Beer*

- ✓ "Operations Research is an art of giving 'bad answers' to the problems which otherwise have 'worse answers' ".

  - *Unknown*

Nature of Operations Research

Different characteristics constituting the nature of Operations Research can be briefed as under:

- *Inter disciplinary team approach* – OR has the characteristic that it is done by a team of scientists drawn from various disciplines, such as mathematics, statistics, economics, engineering, physics, and so on. It is essentially an interdisciplinary team approach. Each member of the OR team is benefited from the view point of the other so that a workable solution is obtained through such collaborative study and has a greater chance of acceptance by the management.

- *Systems approach* – OR emphasizes on the overall approach to the system. This characteristic of OR is often referred to as 'system orientation'. This orientation is based on the observation that in the organized systems the behavior of any part ultimately has some effect on every other part. But all these effects are not significant and even not capable of detection. Therefore, the essence of system orientation lies in the systematic search for significant interactions in evaluating actions of any part of the organization. In OR an attempt is made to take into account all the significant effects and to evaluate them as a whole. OR thus considers the total system for getting the optimum decisions.

- *Scientific method* – OR involves scientific and systematic attack of complex problems to arrive at the optimum solution. In other words, OR uses techniques of scientific research. Thus OR comprehends both aspects, viz, scientific research on the phenomena of operating systems and the associated engineering activities aimed at applying the results of the research.

- *Goal oriented optimum solution* – OR tries to optimize a well-defined function subject to given constraints and as such is concerned with the optimization theory.

- *Helpful in improving the quality of the solution* – OR cannot give perfect solutions to the problems. It merely gives 'bad answers' to the problems which otherwise have 'worse answers'. Thus OR simply helps in improving the quality of the solution but does not result into perfect solution to the problem.

- *Requires willing executives* – OR does require the willingness on the part of the executive for experimentation to evaluate the costs and the consequences of the alternative solutions of the problem. It enables the decision maker to be objective in choosing an alternative from amongst many possible alternatives.

- *Reduces complexity* – OR tries to reduce the complexity of business operations and does help the executives in correcting a troublesome function and to consider innovations which are too costly and complicated as well to experiment with the actual practice.

- *Use of models* – OR uses models built by quantitative measurement of the variables concerning a given problem and also derives a solution from the model using one or more of the diversified solution techniques. A solution may be extracted from a model either by conducting experiments on it or by means of mathematical analysis. The sole purpose is to help the management to determine its policy and actions scientifically.

The above details may be summarized in the following points for better understanding the characteristics / nature of OR,

- ✓ OR uses mixed team approach to find out optimum solution;
- ✓ OR uses scientific methods to arrive at optimum solution;
- ✓ OR takes into account all significant factors and evaluates them as a whole, that is, it considers a *wholistic approach*;
- ✓ OR is interdisciplinary team approach to find out optimum returns;
- ✓ OR emphasizes on overall approach to the system;
- ✓ OR tries to optimize the total output by maximizing the profit and minimizing the loss or cost, that is, it considers *realistic approach*;

- ✓ OR improves the quality of the solution output;
- ✓ OR deals more in *experiments and induction* rather than *analysis and deduction*, that is it considers *generalistic approach*;

Thus, OR attempts to locate the best or optimum solution to the problem under consideration. For this purpose, it is necessary that a measure of effectiveness is defined which is based on the goal of the organization. This measure is then used as the basis to compare the alternative courses of action.

From above one may conclude that OR must be viewed as both a science and an art. As *science*, OR provides mathematical techniques and algorithms for solving appropriate decision problems. As *art*, OR is a success in all the phases that precede and succeed the solution of the problem which largely depends on the creativity and personal ability of the decision making analyst.

Phases in Operations Research

The approach to Operations Research can be divided into THREE logical phases, as discussed below:

- ***Phase – I*** *Judgement Phase* : The problem starts with the identification of the problem as faced in real life. The solution to the problem can be then directed towards the organizational objective. It will involve various variables related to the specific objective. It is only then that the application of an appropriate measure and its usefulness to the organization can be formulated and put into structural form with relevant essential information for the decision maker.

  In short this phase includes: identification of the problem; selection of appropriate solution and values of various variables related to the solution; use of appropriate scale of measurement; and finally formulation of an appropriate model of the problem.

- ***Phase –II*** *Research Phase* : In this phase, relevant data is collected for the problem related parameters so as to define and understand the problem and its entirety. This data is then put into use for formulation of an appropriate model and then decide as to how to validate the result out of the given information, by data testing the hypothesis so selected. There may be requirements for additional data to test its applicability over a wide range of observations and variability. Based on the analysis and verification of the data, the usefulness or desirability of the model, predictions can be made. The generalization of the results and consideration of alternative methods for '*what if*'' system is then standardized.

  In short this phase takes the longest time and includes: observation and data collection for understanding the problem; formulation of the model; observation and experimentation of test models; analysis of available resources; predictions of various results; and finally generalization of the results and finding alternative methods.

- ***Phase –III*** *Action Phase* : During this phase, the recommendations for the implementation of the decision so arrived are made by the person carrying out the analysis. This final recommendation has to be based on the actual problem and its reasons for arising including the environment in which the problem occurred. Various assumptions, limitations and omissions for the objective need to be spelt out in this phase.

In short this phase consists of making recommendations for decision process by those who first posed the problem for consideration or by anyone in a position to make a decision influencing the operation in which the problem occurred.

Models in Operations Research and their Classification

A *model* is a simplified representation of an operation or a process in which only the basic aspects of a typical problem under consideration are considered.

The objective of the model is to provide a means for analyzing the behavior of the system for the purpose of improving its performance.

The very essence of OR lies in the construction and use of *models*. When a real life situation is represented in some abstract form, whether physical or mathematical, bringing out relationships of its major ingredients, a model is said to be formed. The model so formed, need not describe all the aspects of this situation, but it should signify and identify important factors and their relationships to describe the total solution. Hence, models do not and cannot represent every aspect of reality because of the real life problems of innumerable and changing characteristics to be represented. Therefore models are limited approximation of reality problems.

A model is constructed to analyze and understand the given system for the purpose of improving its performance. The reliability of the solution obtained from a model depends on the validity of the model in representing the system being investigated or studied. A model, however allows the analyst to examine the behavioral changes of the system without affecting the on-going process in the system under study.

Models in OR are classified on the following basis:

- ✓ On the basis of *Function* ;
- ✓ On the basis of *Structure* ;
- ✓ On the basis of *Time Reference* ;
- ✓ On the basis of *Degree of Certainty* ; and
- ✓ On the basis of *Degree of Quantification*

Apart from above major classifications some models are also classified as *General* or *Specialized* models based on the *Degree of Generality*. Also, *Two-Dimensional* or *Multi-dimensional* models based on the *Degree of Dimensionality*; and *Closed* or *Open* based on the *Degree of Closure*.

Now let us discuss the various types under the broad classifications given above in detail.

- *Models Based on Function*
  - ➢ **Descriptive Models** – are those which simply describe some aspects of a situation, based on observation, survey, questionnaire results or other variable data concerned with a situation. These models do not predict or recommend anything. Examples are, Plant layout diagrams, Organizational, Flow charts and so on.

- **Predictive Models –** are those which indicate 'if something happens, what will follow'. They indicate the relationship between dependent and independent variables and permit trying out " *what if* " questions. Using these models one can predict the outcomes due to given set of alternatives for the problem.

- **Normative or Optimization Models –** are those which provide the 'best' or 'optimum' solution to the problem(s) subject to certain limitations on the use of the resources. Examples are, Mathematic model formulating an objective function subject to restrictions (or constraints) on the resources in context of the problem. These models prescribe " *what the decision maker has to do* ".

• *Models Based on Structure*

- **Physical Models** – these models provide a physical representation of the real object(s) under study in a reduced size or scaled model. Examples are, Scaled models of proposed aircraft under design or prototype construction.

  Physical models are further classified as under:

  ✓ ***Iconic Models*** – an icon is the description of an object as its image. An iconic model is a scaled version of the system it represents. It represents the system as it is by scaling it up or down. Examples are, Blue prints of buildings, Photographs, Drawings, and so on.

  ✓ ***Analog Models*** **–** represents a system like an iconic model but not as the exact replica of the actual system. They represent a system by a set of properties different from those of the original system and does not resemble it physically. Examples are, Maps, Organizational charts, Graphs of time series, Frequency curves, and so on.

- **Symbolic Models –** are those which are used to represent actual problems using symbols, such as, letters or numbers, so as to represent variables and their relationships to describe the properties of the system.

  Symbolic models are further classified as under:

  ✓ ***Verbal Models*** **–** are those which describe a situation in written or spoken words or sentences. Examples are, Books, Reports, Speeches, and so on.

  ✓ ***Mathematical Models*** **–** are those which involve the use of mathematical operators, such as, +, -, ×, ÷, etc. to represent relationships among various variables of the system in order to describe the properties or behavior of the system. Examples are, Economic order quantity model used in inventory management, Cost-volume-profit model used in break-even analysis, and so on.

• *Models Based on Time Reference*

- **Static Models** – these models represent a system at some specified time and do not account for change over time. Examples are, Economic order quantity models.

- **Dynamic Models** – these models considers time as one of the variables and allows the impact of changes due to change in time. Examples are, Dynamic programming, and so on.

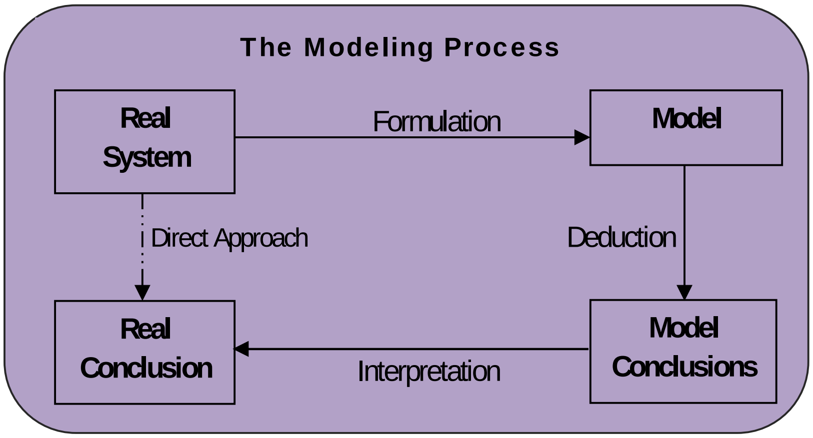
- *Models Based on Degree of Certainty*
  - **Deterministic Models** – in these models all the parameters, constants and functional relationships are assumed to be known with certainty when the decision is taken. Examples are, Linear programming models, and so on.
  - **Probabilistic or Stochastic Models** – are those models in which at least one parameter or decision variable is a random variable. In such cases, consequences or payoffs due to certain changes in the independent variable cannot be predicted with certainty, but it is possible to predict a pattern of values of both variables by their probability of distribution. Examples are, Models representing insurance against risk of fire, accidents, sickness, and so on.

- *Models Based on Quantification*
  - **Qualitative Models** – these are descriptive models wherein mental or verbal description is used to represent the situation.
  - **Quantitative Models –** in this model there is processing and manipulating of raw data into meaningful information.

    Quantitative models are further classified as under:

    - ***Analytical Models*** – these are those which have a specified mathematical structure and can be solved using analytical or mathematical techniques. Examples are, Linear programming models for determining the optimum product mix, and so on.
    - ***Heuristic Models*** – are those which employ some set of rules which though not optimal do facilitate problem solving when applied consistently.
    - ***Simulation Models*** – are those that have mathematical structure but are not solved using mathematical techniques. They are essentially a computer assisted experimentation of a mathematical model of a real life problem. Simulation models are used to describe and evaluate the behavior of a system under certain assumptions over a period of time.

The Modeling Process – An Overview



In the above figure, it has been assumed that there is something real, which is referred to as *real system* and that there is some understandable reason for dealing with it – that is a *problem* related to the real system, which calls for definite *conclusions*.

Now let us understand each stage / phase of this modeling process in detail,

Stage – I *Formulation* – this is the first step in the modeling process wherein the construction of an appropriate mode is done for the problem. This step requires a set of coordinated decisions as to what aspects of the real life system should be incorporated in the model, what aspects to be ignored, what assumptions to be made and into what form the model should be casted, and so on.

Stage – II *Deductions* – this involves the techniques that depend on the nature of the model. It may involve solving equations, executing a computer program, expressing a sequence of logical statements, whatever necessary to solve the problem relative to the model.

Stage – III *Interpretations* – this is the final step and involves human judgement. The model conclusions need to be translated to 'real world conclusions' cautiously, because of possible discrepancies between the model and its real-world referent.

Therefore, from above we may conclude citing the following principles or Guidelines for a perfect model,

- ✓ Beware of molding the problem to fit the technique;
- ✓ Models should be validated prior to its implementation;
- ✓ Do not build a complicated model when a simple one will suffice;
- ✓ The deduction stage of modeling must be conducted rigorously;
- ✓ Beware of overselling a model;
- ✓ Make a note that models cannot replace decision-makers;
- ✓ A model cannot be any better than the information that goes into it;
- ✓ Some of the primary benefits of modeling are associated with the process of developing the model;

- ✓ The model should neither be pressed to do nor criticized for failing to do that for which it was never intended; and
- ✓ The model should never be taken too literally.

Characteristics of a Good Model

Based on the discussions done so far, following characteristic points may be pointed for a '*good model*':

- ✓ It should be capable of taking into account new formulations without having any significant change in its frame;
- ✓ The assumptions made in the model should be as small as possible;
- ✓ The model should be simple and coherent. The number of variables used should be less;
- ✓ The model should be open to parametric type of treatment; and
- ✓ The model should be such that it takes least time in its construction for the problem.

Limitations of a Model

Also one may conclude upon following points of limitations for a model in OR:

- ✓ The models are only an attempt in understanding the operations, so these cannot be considered as absolute in any sense; and
- ✓ The validity of any model with regard to corresponding operation can only be verified by carrying the experiment and relevant data characteristics, which may not be possible every time.

General Solution Methods for Operations Research Models

- ✓ *Numerical Methods* – these are related to ' trial and error ' methods in which there are numerical computations at each step. When the analytical methods are not able to achieve the solution then these methods are used. In this method the algorithm uses an initial solution and then iteratively reaches up to the final solution. The trial solution is replaced by the improved one and the process is repeated until either no further improvement is possible or the cost of further computations cannot be justified.
- ✓ *Deductive Methods* – these are classical methods which include calculus, finite differences which are used for solving an OR model. The kind of mathematics required depends upon the nature of the model. For example, the area indicated by the mathematical function may be evaluated through the use of integral calculus.
- ✓ *Monte Carlo Methods* – these methods use the concept of ' probability and sampling '. various steps involved in Monte Carlo methods are as given,

Step-I for a system, make simple observations and determine the probability distribution (for variable of interest);

Step-II convert probability distribution to cumulative distribution;

Step-III select the sequence of random numbers with the help of random number table;

Step-IV determine the sequence of values of variables with the sequence of random numbers so obtained;

Step-V fit the appropriate standard mathematical function to the values obtained in Step-IV.

From above points, we may conclude that Monte Carlo Method is essentially a simulation technique in which statistical distribution functions are created by generating a series of random numbers

(This technique shall be coved in detail separately in a dedicated chapter in later part of this book).

Methodology of Operations Research

In view of the already referred phases – Judgement, Research and Action, the methodology of OR generally involves following six steps:

Step – I ***Define*** *the problem of interest and gather relevant data;*

Step – II ***Formulate*** *a mathematical model to represent the problem;*

Step – III ***Develop*** *a computer-base procedure for deriving the solution to the problem from the model;*

Step – IV ***Test*** *the model and refine it as needed;*

Step – V ***Prepare*** *for the ongoing application of the model as prescribed by the management;*

Step – VI ***Implement*** *the model to the system as prescribed by the management.*

Now let us discuss the above mentioned steps in details so as to have a better understanding of the working of Operations Research Study.

Step – I: Define the Problem and Gather Data

Most practical problems encountered by operations research teams are usually described vaguely. Therefore, the first step is to study the relevant system and develop a well-defined statement of the problem to be considered. This includes – the appropriate objective; the constraints on what can be done; interrelationships between the area of study and other areas of the organization; possible alternate courses of action; and finally time limits for making the decision.

The operations research team is normally working in an advisory capacity, that is, advising the management decision making process. The team performs a detailed technical analysis and then presents the recommendations to the management. The report of the operations research team usually will identify a number of alternatives under different assumptions or over different range of values of some policy parameters that can be evaluated only by the management, such as, trade-off between costs and benefits. The management evaluates the study report and its recommendations taking into account a variety of intangible factors and make the final decision based upon its best judgment.

Ascertaining the appropriate objectives is a very important aspect of problem definition. Operations research is concerned with the welfare of the entire organization rather than for only certain components. An operations research team / study seeks optimum solutions for the overall organization rather than sub-optimal solutions that are best only for one or few components when applied to. However, many problems primarily concern only a portion of the organization, in such cases the objectives stated should not be too general. Instead the objectives should be as specific as possible and consistent with the higher level objectives of the organization.

Operations research team spends a lot of time gathering relevant information / data related to the problem. Much data are needed both to gain an accurate understanding of the problem and to provide the needed input for the mathematical model being formulated for the next phase of the study. Frequently much of the needed data will not be available when the study begins. Therefore, it often is necessary to install a new computer based MIS (management information system), so as to collect relevant data on an ongoing basis and in the desired format.

Step – II: Formulate a mathematical Model

After defining the problem, the problem is reformulated in a form that is convenient for analysis. The operations research approach is to construct a mathematical model that represents the essence of the problem. Mathematical models are expressed in terms of mathematical symbols and expressions. A mathematical model of a business problem is the system of equations and related mathematical expressions that describe the essence of the problem.

If there are ‘n’ related quantifiable decisions to be made, they are represented as *decision variables*, whose respective values are to be determined. The appropriate measure of performance is then expressed as a mathematical function of these decision variables, this function is referred to as *objective function*. Any restrictions on the values that can be assigned to these decision variables are expressed by means of inequalities or equations, such mathematical expressions for restrictions are referred to as *constraints*. The constants in the constraints, that is coefficients and right hand sides, and the objective function are called as *parameters* of the models. The mathematical model represents the problem to choose the values of the decision variables so as to maximize or minimize the objective function, subject to the specified constraints.

Step – III: Deriving Solutions from the Model

After a mathematical model is formulated for the problem under consideration, the next phase is to develop a procedure for deriving solutions to the problem from this model. One of the standard algorithms of operations research is applied on a computer using one of a number of readily available software packages.

It is common in operations research study to search for a *optimum* or *best solution*. But since the models in operations research are idealistic in nature rather than exact representations of the real problems, thus there cannot be any surety that the optimum solution for the model shall provide the best possible solution that could be implemented for the real problem.

However, if the model is well formulated and tested, the resulting solution should tend to be a good approximation to an ideal course of action for the real problem. Since an optimum solution may not be feasible always, thus the managers need to seek a solution that is *good enough* for the problem under study. In other words of operations research leader Samuel Eiron *"optimizing is the science of the ultimate, satisfying is the art of the feasible"*. The goal of the operations research study should be to conduct the study in an optimum manner, regardless of whether this involves finding an optimal solution for the model. Thus in addition to pursuing the science of the ultimate, the OR team should also consider the cost of the study and the disadvantages of delaying its completion and then attempt to maximize the net benefits and minimize the losses of the study problem. Therefore, OR teams occasionally uses only *heuristic procedures* to find a good *sub-optimal solution*.

Step – IV: Testing the Model

The first version of a large mathematical model inevitably contains many flaws. Therefore, before the model is used it must be thoroughly tested to try and correct as many flaws as possible. After a long succession of improved models, the current model gives reasonably valid results. The major flaws have been sufficiently eliminated and the model now can be reliably used. This process of testing and improving a model to increase its validity is commonly referred to as *model validation*.

Step – V: Preparing to Apply the Model

After the testing phase has been completed and an acceptable model has been developed, for the model to be used repeatedly, a well documented system has to be established for applying the model as prescribed by the management. This system includes the model, solution procedure and operating procedures for its implementation. This system thus is usually computer based. A considerable number of computer programs often need to be used and integrated. Databases and MIS may provide up-to-date input for the model whenever it is used. In such cases, interface programs are needed. After a solution procedure is applied to the model, additional computer programs may trigger the implementation of the results automatically. In other cases, an interactive computer-based system Decision Support System (DSS) is installed to help the managers use data and models to support their decision making as required.

Step – VI: Implementation

After a system is developed for applying the model, the last phase of OR study is to implement this system as prescribed by the management. It is here important to note that the operations research team participates in launching this phase both to ensure that the model solutions are accurately translated to an operating procedure and to rectify any errors in the solution that needs to be uncovered.

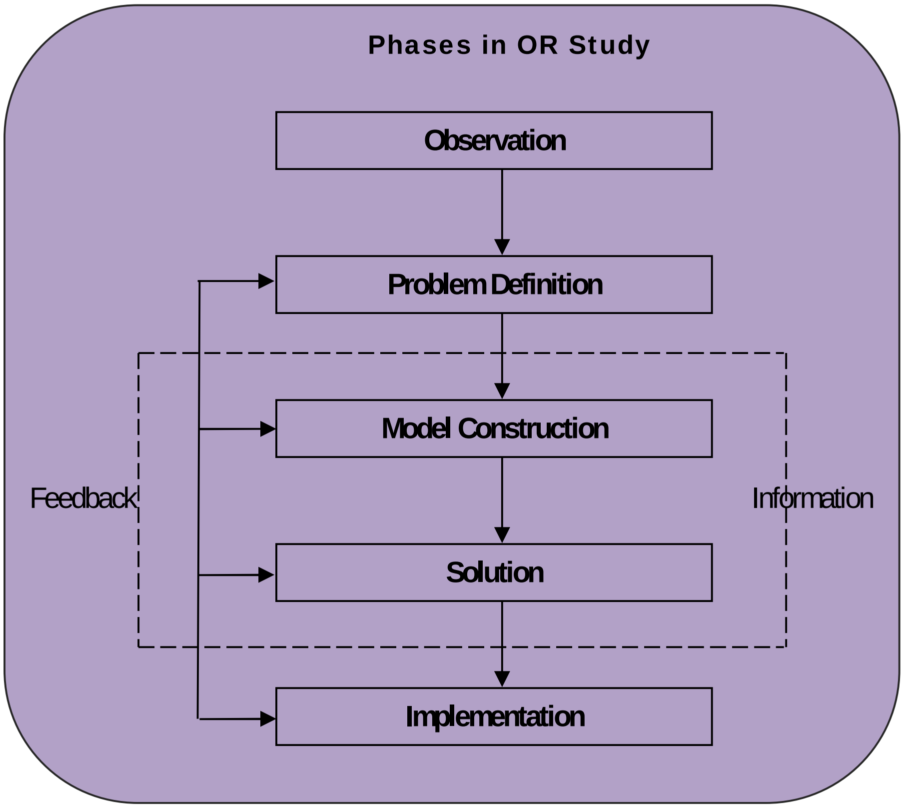
The implementation phase involves several steps for its proper and efficient results, which may be summed as below,

- The operations research team gives operating management a careful explanation of the new system to be adopted and its direct relation with the operating realities;
- These two sides share the responsibility for developing the procedures required to put this new system into effective usage and operation;

- Operating management sees that a detailed indoctrination is given to the personnel involved and a new course of action is initiated in this regard;
- The OR team monitors the initial experience with the course of action taken and seeks to identify any modifications that should be made in the future.

Throughout the entire phases during which the new system is being used, it is important to continue to obtain feedback regarding as to how well the system is responding and working. Also if the assumptions of the model continue to satisfy when significant deviations from the original assumptions occur. Also it is necessary to examine and determine any modifications that may be required in the system for its efficient and effective working.

In short from above we may conclude that, management science consists of a logical and systematic approach towards problem solving which resembles the scientific method of problem solving. The above described phases can be illustrated diagrammatically as given below,



Operations Research Modeling Techniques

Operations Research techniques can be categorized as follows:

- ***Linear Mathematical Programming***
  - *Linear Programming Models*
  - *Graphical Analysis*
  - *Simplex method*

- *Sensitivity Analysis*
- *Transportation Problem Models*
- *Assignment Problem Models*
- *Integer Linear Programming*
- *Goal Programming*
- *Dynamic Programming*

✓ ***Probabilistic Techniques***

- *Decision Analysis*
- *Game Theory*
- *Markov Analysis*
- *Queuing Models*
- *Forecasting*

✓ ***Network Techniques***

- *Network Flow Diagrams*
- *PERT & CPM*

✓ ***Other Techniques***

- *Non-linear programming*
- *Inventory Models*
- *Simulation Techniques*
- *Analytical Hierarchy Process*

A brief overview of some of the OR modeling techniques as given above is as presented below,

- **Linear Programming.** Linear Programming (LP) is a mathematical technique of assigning a fixed amount of resources to satisfy a number of demands in such a way that some objective is optimized and other defined conditions are also satisfied.
- **Transportation Problem.** The transportation problem is a special type of linear programming problem, where the objective is to minimize the cost of distributing a product from a number of sources to a number of destinations.
- **Assignment Problem.** Succinctly, when the problem involves the allocation of *n* different facilities to *n* different tasks, it is often termed as an assignment problem.

- **Queuing Theory.** The queuing problem is identified by the presence of a group of customers who arrive randomly to receive some service. This theory helps in calculating the expected number of people in the queue, expected waiting time in the queue, expected idle time for the server, etc. Thus, this theory can be applied in such situations where decisions have to be taken to minimize the extent and duration of the queue with minimum investment cost.

- **Game Theory.** It is used for decision making under conflicting situations where there are one or more opponents (i.e., players). In the game theory, we consider two or more persons with different objectives, each of whose actions influence the outcomes of the game. The game theory provides solutions to such games, assuming that each of the players wants to maximize his profits and minimize his losses.
- **Inventory Control Models.** It is concerned with the acquisition, storage, handling of inventories so as to ensure the availability of inventory whenever needed and minimize wastage and losses. It help managers to decide reordering time, reordering level and optimal ordering quantity.
- **Goal Programming**. It is a powerful tool to tackle multiple and incompatible goals of an enterprise.
- **Simulation.** It is a technique that involves setting up a model of real situation and then performing experiments. Simulation is used where it is very risky, cumbersome, or time consuming to conduct real study or experiment to know more about a situation.
- **Nonlinear Programming.** These methods may be used when either the objective function or some of the constraints are not linear in nature. Non-Linearity may be introduced by factors such as discount on price of purchase of large quantities.
- **Integer Programming.** These methods may be used when one or more of the variables can take only integral values. Examples are the number of trucks in a fleet, the number of generators in a power house, etc.
- **Dynamic Programming.** Dynamic programming is a methodology useful for solving problems that involve taking decisions over several stages in a sequence. One thing common to all problems in this category is that current decisions influence both present & future periods.
- **Sequencing Theory.** It is related to Waiting Line Theory. It is applicable when the facilities are fixed, but the order of servicing may be controlled. The scheduling of service or sequencing of jobs is done to minimize the relevant costs. For example, patients waiting for a series of tests in a hospital, aircrafts waiting for landing clearances, etc.
- **Replacement Models**. These models are concerned with the problem of replacement of machines, individuals, capital assets, etc. due to their deteriorating efficiency, failure, or breakdown.
- **Markov Process.** This process is used in situations where various states are defined and the system moves from one state to another on a probability basis. The probability of going from one state to another is known. This theory helps in calculating long run probability of being in a particular state.
- **Network Scheduling-PERT and CPM.** Network scheduling is a technique used for planning, scheduling and monitoring large projects. Such large projects are very common in the field of construction, maintenance, computer system installation, research and development design, etc. Projects under network analysis are broken down into individual tasks, which are arranged in a logical sequence by deciding as to which activities should be performed simultaneously and which others sequentially.
- **Symbolic Logic.** It deals with substituting symbols for words, classes of things, or functional systems. It incorporates rules, algebra of logic, and propositions. There have been only limited attempts to apply this technique to business problems; however, it is extensively used in designing computing machinery.
- **Information Theory.** It is an analytical process transferred from the electrical communications field to operations research. It seeks to evaluate the effectiveness of information flow within a given system and helps in improving the communication flow.

Advantages of OR

- **Better Control:** The management of large organizations recognize that it is a difficult and costly affair to provide continuous executive supervision to every routine work. An O.R. approach may provide the executive with an analytical and quantitative basis to identify the problem area. The most frequently adopted applications in this category deal with production scheduling and inventory replenishment.
- **Better Systems:** Often, an O.R. approach is initiated to analyze a particular problem of decision making such as best location for factories, whether to open a new warehouse, etc. It also helps in selecting economical means of transportation, jobs sequencing, production scheduling, replacement of old machinery, etc.
- **Better Decisions:** O.R. models help in improved decision making and reduce the risk of making erroneous decisions. O.R. approach gives the executive an improved insight into how he makes his decisions.
- **Better Co-ordination:** An operations-research-oriented planning model helps in coordinating different divisions of a company.

Limitations of OR

- **Dependence on an Electronic Computer:** O.R. techniques try to find out an optimal solution taking into account all the factors. In the modern society, these factors are enormous and expressing them in quantity and establishing relationships among these require voluminous calculations that can only be handled by computers.
- **Non-Quantifiable Factors:** O.R. techniques provide a solution only when all the elements related to a problem can be quantified. All relevant variables do not lend themselves to quantification. Factors that cannot be quantified find no place in O.R. models.
- **Distance between Manager and Operations Researcher:** O.R. being specialist's job requires a mathematician or a statistician, who might not be aware of the business problems. Similarly, a manager fails to understand the complex working of O.R. Thus, there is a gap between the two.
- **Money and Time Costs:** When the basic data are subjected to frequent changes, incorporating them into the O.R. models is a costly affair. Moreover, a fairly good solution at present may be more desirable than a perfect O.R. solution available after sometime.
- **Implementation:** Implementation of decisions is a delicate task. It must take into account the complexities of human relations and behavior.

Application Areas of OR

Some problems that can be analyzed by Operations Research approach are classified as follows:

- **Finance, Budgeting and Investments**
  - ✓ Credit policy analysis.
  - ✓ Cash flow analysis.

- ✓ Dividend policies.
- ✓ Investment portfolios.

- **Marketing**

  - ✓ Product selection, timing, etc.
  - ✓ Advertising media, budget allocation.
  - ✓ Number of salesman required.
  - ✓ Selection of product mix.

- **Purchasing, Procurement and Exploration**

  - ✓ Optimal buying and reordering.
  - ✓ Replacement policies

- **Production Management**

  - ✓ Location and size of warehouses, factories, retail outlets, etc.
  - ✓ Distribution policy.
  - ✓ Loading and unloading facilities for trucks, etc.
  - ✓ Production scheduling.
  - ✓ Optimum product mix.
  - ✓ Project scheduling and allocation of resources.

- **Personnel Management**

  - ✓ Selection of suitable personnel.
  - ✓ Recruitment of employees.
  - ✓ Assignment of jobs.
  - ✓ Skills balancing.

- **Research and Development**

  - ✓ Project selection.
  - ✓ Control of R&D projects.
  - ✓ Reliability and alternative design.