

OPERATIONS RESEARCH

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BOOKS

1. **An Introduction to Management Science –Quantitative Approaches to Decision Making, David Anderson, Dennis J. Sweeney, Thomas A. Williams, West Publishing**
2. **Operations Research-Applications and Algorithms, Wayne Winston, Thomson, Brooks/Cole**
3. **Operations Research: An Introduction Hamdy A. Taha**
4. **Applied Management Science-A computer Integrated Approach for Decision Making, John A. Lawrence, Barry A. Pasternack, John Wiley.**
5. **Applied Mathematical Programming Using Algebraic Systems, Bruce Mc Carl. Thomas H. Spreen -Electronic Book**
6. **Linear Programming for Managerial Decisions, Ahmet Acar, METU.**
7. **Linear programming and Network Flows, Makhtar S.Bazaraa, John J. Jarvis, Hanif D. Sherali, Wiley**
8. **Network Optimization: Continuous and Discrete Models, Dimitri P. Bertsekas <http://www.athenasc.com>**

Applied Management Science : Making Good Strategic Decisions Hussein Arsham

<http://ubmail.ubald.edu/~harsham/opre640/opre640.html>

Business and Management Science

- Every enterprise has an objective it wishes to accomplish.
- Companies that operate for profit want to provide products or services to customers in order to make money for their owners or stockholders.
- A nonprofit organization such as a hospital may want to provide services to patients at minimum cost.
- In general, the goal of both for-profit and not-for-profit organizations is to optimize the use of available RESOURCES, given all the internal and external constraints placed them.
- Success is usually measured by how well they do so.

Thus, an organization is always looking for ways to run

- **More efficiently,**
- **More effectively,**
- **More profitably.**

WHAT IS MANAGEMENT SCIENCE?

- *Modern-day management science grew out of successful applications of the scientific approach to solving military operational problems during World War II.*
- *Hence it was originally dubbed “operational research”*
- *After the War as this approach found its into all areas of the military, government, and industry the term was shortened to “operations research” (OR).*
- *As managers in business began using operations research approaches to aid in decision making the term “management science” (MS) was coined.*
- *Today there is a little distinction between the terms, and they are used interchangeably in the literature.*

- ***OR/MS IS A DISCIPLINE THAT ADOPTS THE SCIENTIFIC APPROACH FOR PROBLEM SOLVING TO DECISION MAKING.***
- ***THE USE OF LOGIC AND MATHEMATICS IN SUCH A WAY AS TO NOT INTERFERE WITH COMMON SENSE.***

**MS/OR IS THE SCIENTIFIC
APPROACH TO EXECUTIVE DECISION
MAKING, WHICH CONSIST OF**

- 1.The art of mathematical modeling of complex situations**
- 2.The science of the development of solution techniques used to solve these models**
- 3.The ability to effectively communicate the results to the decision maker.**

MS/OR Time Line

1665 Newton's Method for Finding a Minimum Solution of a Function, I. Newton

1736 Königsberg Bridge Problem, L. Euler

1738 St. Petersburg Problem, D. Bernoulli

1763 Bayes' Rule, T. Bayes

1788 Lagrangian multipliers, *Mécanique Analytique*, J. L. Lagrange

1795 Method of Least Squares, C. F. Gauss, A. Legendre

1823 Solution of Inequalities, J. Fourier

1823 Principle of Utility, J. Bentham

1824 Kriegspiel (war gaming), von Reisswitz

1826 Solution of Linear Equations, C. F. Gauss

1833 Analytical Engine, C. Babbage

1873 Solution of Equations in Nonnegative Variables, P. Gordon

1880 [Markov Chains](#), A. Markov

1896 Pareto Optimal/Efficient Solution, V. Pareto

1896 Solution of Linear Equations as a Combination of Extreme Point Solutions,

H. Minkowski

1900 Time Studies/Scientific Management, F. Taylor

1900 Gantt Charts, H. Gantt, F. Taylor

1903 Solution of Inequality Systems, J. Farkas

1909 “The Theory of Probabilities and Telephone Conversations,” A. K. Erlang

1913 Inventory Economic Order Quantity (EOQ), F. W. Harris

1914 Lanchester's Equations, F. W. Lanchester

1915 Positive Solution to Linear Equations, E. Stiemke

1927 “Application of the Theory of Probability to Telephone Trucking Problems,”

E. C. Molina

1928 *Probability Theory and Its Engineering Uses*, T. C. Fry

1930 Econometric Society founded

1931 Quality Control Charts, W. Shewart

1933 Hypothesis Testing, J. Neyman, E. Pearson

1936 Transposition Theorem, Linear Inequalities, T. Motzkin

1936 Facility Location, E. Weiszfeld aka A.Vazsonyi

1937 Time Zero: British military applications – the term Operational Research first used

1939 “Mathematical Methods of Organization and Production,” L. Kantorovich

1939 Optimality Condition for Constrained Problems (Master’s thesis, U. Chicago),

W. Karush

1941 *The Structure of the American Economy* (Inter-industry Economics), W. W. Leontief

1941 Transportation Problem, F. Hitchcock

1942 USAF military OR

1942 Antisubmarine Warfare Operations Research Group (first U.S. civilian group engaged in military OR)

1942 UK Naval Operational Research, P. Blackett

1942 Search Theory, P. Morse, R. Rinehart, B. Koopman, G. Kimball

1943 Neural Networks, W. McCulloch, W. Pitts

1944 *Theory of Games and Economic Behavior*, J. von Neumann, O. Morgenstern

1944 Utility Theory, J. von Neumann, O. Morgenstern

1944 Exponential Smoothing, R. Brown

1945 Project RAND (Douglas Aircraft Co.)

1945 USN Operations Evaluation Group (OEG)

1945 “The Cost of Subsistence” (Diet Problem), G. Stigler

1946 “Methods of Operations Research” [OEG Report (Classified)], P. M. Morse, G. E. Kimball

1947 Linear Programming Model, G. B. Dantzig

1947 Simplex Method, G. B. Dantzig

1947 Project SCOOP (USAF Scientific Computation of Optimal Programs)

1947 *Theory of Games and Economic Behavior*, 2nd edition, J. von Neumann, O. Morgenstern

1948 The RAND Corporation

1948 Johns Hopkins US Army Operations Research Office (ORO)

1948 First courses in OR at MIT

1948 Operational Research Club of Great Britain

1949 Monte Carlo Simulation, S. M. Ulam, J. von Neumann

1949 “Programming of Inter-Dependent Activities I, General Discussion,” M. Wood, G. Dantzig.

1949 “Programming of Inter-Dependent Activities II, Mathematical Model,” G. Dantzig

1949 *Dynamic Equipment Policy*, G. Terborgh

1949 Cowles Commission Conference on “Activity Analysis of Production and Allocation”

1950 Quality Control, W. E. Deming

1950 *Operational Research Quarterly*, first OR journal, now the *Journal of Operational Research*

1950 Nash Equilibrium, J. Nash

1950 Simulation/War Games

1950 Decision Analysis, W. Edwards, R. Luce, H. Raiffa, R. Howard, R. Keeney

1950 Navy Operations Evaluation Group (OEG)

1950 Military Gaming

1950 *An Introduction to Probability Theory and Its Applications*, vol. I, W. Feller

1950 Dynamic Programming, R. Bellman

1950 Shortest Path Problem

1950 OR in Industrial Sector: British Iron and Steel Industry Research Association, C. Goodeve;

British National Coal Board, P. Rivett

1950 First Solution of the Transportation Problem on a Computer, SEAC, National Bureau of Standards

1951 Unclassified version of *Methods of Operations Research*, P. M. Morse, G. E. Kimball

1951 First computer-based simplex algorithm, SEAC, National Bureau of Standards

1951 First Symposium on “Linear Inequalities and Programming”

1951 *Activity Analysis of Production and Allocation*, Koopmans, T. C. (ed.)

1951 *The Structure of the American Economy*, (Inter-industry Economics) W. Leontief

1951 “Nonlinear Programming,” (optimality condition for constrained problems), H. Kuhn, A.

Tucker

1951 “Maximization of a Linear Function of Variables Subject to Linear Inequalities,” (Simplex Method), G. Dantzig

1951 “Some Problems in the Theory of Queues,” D. Kendall

1951 Naval Post Graduate School OR program

1951 “Study of Negro Manpower in Army,” Johns Hopkins Operations Research Office

1951 Primal-dual Linear Programs, J. von Neumann, G. Dantzig, A. Tucker

1951 OR group established at Courtland (UK fiber producer)

1951 “Application of the Simplex Method to a Transportation Problem,” G. Dantzig

1951 “A Proof of the Equivalence of the Programming Problem and the Game Problem,” G. Dantzig

1952 *Operations Research*, First OR journal in the United States

1952 Operations Research Society of America (ORSA) founded

1952 Portfolio Analysis, H. Markowitz

1952 First OR Application in Agriculture, C. Thornthwaite

1952 First degree program (MA and Ph.D.) formed at Case Institute of Technology, Cleveland, Ohio

1952 *Introduction to the Theory of Games*, J. McKinsey

1952 Product Form of the Inverse, A. Orden

1952 Blending Aviation Gasoline, A. Charnes , W. W. Cooper, B. Mellon

1952 UNIVAC I installed in The Pentagon to solve U.S. Air Force linear-programming problems

1953 *The Institute of Management Sciences (TIMS) founded*

1953 *The Theory of Inventory Management*, T. Whitin

1953 Operational Research Society (UK) founded

1953 *An Introduction to Linear Programming*, A. Charnes, W.W. Cooper, A. Henderson,

1953 Alternate Algorithm for the Revised Simplex Method: Using a Product Form of the Inverse,

G. Dantzig, W. Orchard-Hays

1954 “Traffic Delays at Toll Booths,” L. C. Edie
1954 Parametric Programming , S. I. Gass, T. L. Saaty
1954 *Operations Research for Management*, J. McCloskey, F. Trefethen
(eds.)
1954 *Naval Research Logistics Quarterly* established
1954 FORTRAN programming language, J. Backus, I. Ziller
1954 Sequencing and Scheduling (Johnson's Theorem), S. Johnson
1954 Dual Simplex Method, C. Lemke, E. Beale
1954 First ORSA Frederick W. Lanchester Prize to L. C. Edie
1954 *The Compleat Strategyst*, J. Williams
1955 Military Battle Models
1955 Traveling Salesman Problem, M. Flood
1955 Bounded Rationality/Satisficing, H. Simon
1955 Stochastic Programming, G. B. Dantzig
1955 Operations Research Center at MIT, P. Morse
1955 Hungarian Method for Transportation Problem, H. Kuhn, E.
Egerváry
1956 Trim (cutting stock) Problem, A. E. Paull
1956 PERT/CPM/MPM, J. Kelley, Jr., W. Walker/D. Malcolm, J.
Roseboom, C. Clark,
W. Fazar/B. Roy
1956 *The Theory of Games and Linear Programming*, S. Vajda
1956 Quadratic Programming, M. Frank, P. Wolfe
1957 First International Conference on OR (IFORS), Oxford
1957 Quadratic Assignment Problem, T. C. Koopmans, M. Beckmann
1957 *Introduction to Operations Research*, C. Churchman, E. Arnoff, R.
Ackoff
1957 Dynamic Programming, R. Bellman

1957 *Games and Decisions: Introduction and Critical Survey*, R. D. Luce, H. Raiffa

1957 Jackson Networks, J. Jackson

1957 *Proceedings of the First International Conference on Operational Research*, M. Davies, R. T. Eddison, T. Page (eds.)

1958 *Linear Programming and Associated Techniques: A Comprehensive Bibliography*, V. Riley, S. I. Gass

1958 SIMSCRIPT, H. Markowitz

1958 *Linear Programming: Methods and Applications*, S. I. Gass

1958 Integer Programming, R. Gomory

1958 *Readings in Linear Programming*, S. Vajda

1958 *Queues, Inventory and Maintenance*, P. M. Morse

1958 Linear Programming and Economic Analysis, R. Dorfman, P. A. Samuelson, R. Solow

1958 *Scientific Programming in Business and Industry*, A. Vazsonyi

1959 *Mathematical Methods and Theory in Games, Programming and Economics*, I, II, S. Karlin

1959 Chance-Constrained Programming, A. Charnes, W. Cooper

1959 Dantzig-Wolfe Decomposition, G. B. Dantzig, P. Wolfe

1959 *Mathematical Methods of Operations Research*, T. Saaty

1959 Shortest Route Problem, E. Dijkstra

1959 International Federation of Operational Research Societies (IFORS)

1960 Branch and Bound, A. Land, A. Doig, R. Dakin, J. Little, K. Murty, D. Sweeney, C. Karel

1960 Facility Location

1960 Cost Effectiveness Analysis

1960 Value Theory, P. Fishburn

1960 Planning, Programming and Budgeting (PPB)

1960 Artificial Intelligence and OR

1960 Airline Group of the International Federation of Operations Research Societies (AGIFORS)

1960 Decision Trees

1960 Vehicle Traffic Science, R. Herman, D. Gazis, G. Newell, R. Oliver, I. Prigogine

1960 Cost Effectiveness Analysis

1960 *Stochastic Processes*, L. Takács

1960 *Finite Markov Chains*, J. G. Kemeny, J. Laurie Snell

1960 *Dynamic Programming and Markov Processes*, R. A. Howard

1960 *Planning Production, Inventories, and Work Force*, C. Holt, F.

Modigliani, J. Muth, H. Simon

1961 International Abstracts in Operations Research (IAOR) established

1961 GPSS/Simulation Language, G. Gordon

1961 *Elements of Queueing Theory*, T. L. Saaty

1961 *Queues*, D. Cox and W. Smith

1961 Research Analysis Corporation (RAC)

1961 *Industrial Dynamics*, J. Forrester

1961 Little's Law, J. Little

1961 Packet Switching Theory, L. Kleinrock

1961 Geometric Programming , C. Zener

1962 Benders Partitioning Method, J. Benders

1962 Chinese Postman's Problem, M.- K. Kwan

1962 *Renewal Theory*, D. Cox

1962 *Flows in Networks*, L. Ford, Jr., D. Fulkerson

1962 *Smoothing, Forecasting and Prediction of Discrete Time Series*, R. Brown

1962 Fuzzy Set Theory, L. Zadeh

1962 Center for Naval Analyses

1963 *Analysis of Inventory Systems*, G. Hadley and T. Whitin

1963 *Linear Programming and Extensions*, G. Dantzig

1963 Delphi Method, N. Dalkey and O. Helmer

1963 Implicit Enumeration/Additive Algorithm, E. Balas, A. Geoffrion

1964 Social Welfare Function, Impossibility Theorem, K. Arrow

1964 *Analysis for Military Decisions*, E. S. Quade (ed.)

1964 Vehicle Routing Savings Algorithm, Clarke and Wright

1965 *Management Models and Industrial Applications of Linear Programming*, A. Charnes,
W. W. Cooper

1965 Complexity Theory; NP-Complete, J. Edmonds, R. Karp

1965 Goal Programming, A. Charnes, W. Cooper

1965 The Knapsack Problem, G. B. Dantzig

1965 Political Redistricting, S. Hess, J. Weaver, H. Seigfeldt, J. Whelan, P. Zitlau

1966 *A First Course in Stochastic Processes*, S. Karlin

1967 *Introduction to Operations Research*, F. Hillier, G. Lieberman

1967 *Theory of Scheduling*, R. Conway, W. Maxwell, L. Miller

1967 Criminal Justice: President's Crime Commission Science and Technology Task Force,
A. Blumstein, S. I. Gass, R. C. Larson

1967 *Geometric Programming*, R. Duffin, E. Peterson, C. Zener

1968 Surrogate constraints, F. Glover

1968 *Nonlinear Programming: Sequential Unconstrained Minimization Techniques*, A. Fiacco,
G. McCormick

1968 Metric (Multi-Echelon Technique for Recoverable Item Control), C. Sherbrooke

1968 Decision Analysis, R. Howard

1968 Outranking Procedure (ELECTRE) for Multi-Attribute Decision Making, B. Roy

1969 Advertising, J. Little, L. Lodish

1969 *Principles of Operations Research*, H. Wagner

1969 System Simulation, G. Gordon

1969 New York City RAND Institute

1969 First ARPANET/INTERNET site at UCLA, L. Kleinrock

1970 *Time Series Analysis*, G. Box, G. Jenkins

1971 *Marketing Decision Making: A Model Building Approach*, P. Kotler

1971 ORSA's journal *OR/SA Today* established

1971 *World Dynamics*, J. Forrester

1971 Computational Complexity, S. A. Cook, R. Karp

1972 *Limits to Growth*, D. Meadows et al.

1972 International Institute for Applied Systems Analysis (IIASA)

1972 Soft Systems Methodologies, P. Checkland

1972 Sweep Algorithm for Vehicle Routing, B. Gillett, L. Miller

1972 First Franz Edelman Award for Management Science Achievement presented to The Pillsbury Company

1972 Klee-Minty problem showed that the simplex method is not a polynomial-time algorithm,
V. Klee and G. J. Minty

1973 Decision Support Systems, P. Keen, S. Morton

1974 Computers and Operations Research established

1974 Hypercube Queueing Model, R. C. Larson

1974 OR established in Federal Express

1974 First joint ORSA and TIMS meeting

1974 *OR/MS Today* established (first joint ORSA/TIMS publication)

1974 TIMS's *Interfaces* becomes joint publication of TIMS and ORSA

1974 SLAM, GASP/Simulation Languages, A. Pritsker

1974 “*A Guide to Models in Governmental Planning and Operations*, S. I. Gass, R. Sisson (eds.)

1974 “*Fundamentals of Queueing Theory*,” D. Gross, C. Harris

1975 Multicriteria Decision Making, M. Zeleny, S. Zionts, J. Wallenius, W. Edwards, B. Roy

1975 First von Neumann Prize (ORSA) to George B. Dantzig

1975 Analysis for Public Decisions, E. Quade

1975 *Queueing Systems, Vol. I: Theory*, L. Kleinrock

1976 *Queueing Systems, Vol. II: Computer Applications*, L. Kleinrock

1976 *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, R. Keeney, H. Raiffa

1976 *Models in the Public Policy*, M. Greenberger, M. Crenson, B. Crissey

1976 Quality Control, G. Taguchi

1977 *Models for Public Systems Analysis*, E. Beltrami

1977 Anti-Cycling Rules for Linear-Programming Problem, R. Bland

1977 *Manpower Planning*, R. Grinold, K. Marshall

1978 Data Envelopment Analysis (DEA), A. Charnes, W. Cooper, E. Rhodes

1978 Lagrangian Relaxation, A. Geoffrion

1979 Ellipsoid Method, L. Khachian

1979 “Airline Safety: An Empirical Study,” A. Barnett, M. Abraham, V. Schimmel

1980 Spreadsheet OR add-in software

1980 Constraint Programming

1980 *The Analytic Hierarchy Process*, T. Saaty

1980 Parallel Computing

1980 LINDO, L. Schrage

1980 Conflict Analysis

1980 Revenue (Yield) Management, American Airlines, T. Cook

1981 *Urban Operations Research*, R. C. Larson, A. Odoni

1982 Expert systems, A. Barr, E. Fiegenbaum

1982 Simulated Annealing, W. Metropolis

1982 Average Running Time of Simplex Method Shown to be Polynomially Bounded,

K.-H. Borgwardt

1984 Neural Networks, J. Hopfield

1984 Interior Point Methods, N. Karmarkar

1984 *What's Best*, S. Savage, K. Cunnigham, G. Link

1984 PROMETHE Method for Multi-Attribute Decision Making, J.-P. Brans, B. Mareschal,

P. Vinke

1985 Flexible Manufacturing Systems

1985 Airline Crew and Aircraft Scheduling

1985 *Handbook of Systems Analysis: Craft Issues and Procedural Choices*, H. Miser, E. Quade

1986 Burger King receives OR practice award

1988 American Airlines Decision Technologies, T. Cook

1988 General Algebraic Modeling System/GAMS, A. Meeraus

1989 Tabu Search, F. Glover

1990 Desert Shield military airlift

1990 Supply Chain Management

1990 Financial Engineering, W. Ziemba, S. Zenios, J. Mulvey

1990 Geographical Information Systems

1990 Evolutionary Algorithms

1991 American Airlines and Federal Express receive the INFORMS Prize

1991 OR and Persian Gulf War

1992 San Miguel Corporation receives the INFORMS Prize

1993 NYC's Office of Management and Budget and United Airlines receive the INFORMS Prize

1994 Network-Enabled Optimization System (NEOS)

1994 AT&T and US West Technologies receive the INFORMS Prize

1995 Data Mining

1995 INFORMS formed by merger of ORSA and TIMS

1995 Bellcore receives the INFORMS Prize

1995 Online Analytical Processing (OLAP)

1995 Enterprise Resource Planning (ERP)

1995 INFORMS OnLine

1996 *Encyclopedia of Operations Research and Management Science*, S. Gass, C. Harris

1996 e-Commerce

1996 Center for Excellence in Aviation Operations Research (Berkeley, MIT, U of MD, VPI&SU)

1996 Pfizer, Inc. receives the INFORMS Prize

1997 Merrill Lynch Private Client Group receives the INFORMS Prize

1998 Lucent Technologies receives the INFORMS Prize

1999 IBM receives the INFORMS Prize

2000 50th anniversary of the publication of the *Journal of Operational Research*

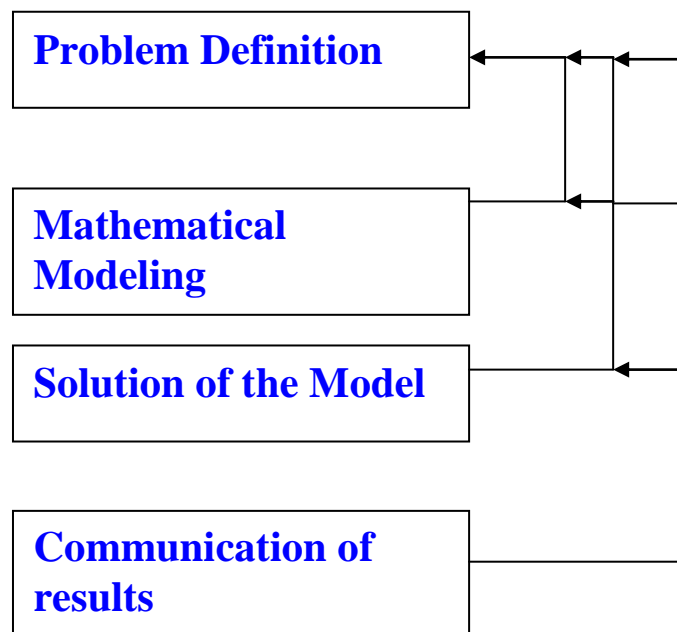
2001 50th anniversary of the OR program at the Naval Post Graduate School

2002 50th anniversary of the founding of ORSA

2002 50th anniversary of the publication of *Operations Research*

Management Science Process

Management science is a discipline that adopts the scientific method to provide management with key information for executive decision-making. In its simplest form, management-science can be thought of as a four step procedure as shown in the following figure.



Problem Definition

- 1.Observe operations**
- 2.Ease into complexity**
- 3.Recognize political realities**
- 4.Decide what is really wanted**
- 5.Identify constraints**
- 6.Seek continuous feedback**

The Methodology of Operations Research

- 1. Formulate the problem**
- 2. Observe the system**
- 3. Formulate a Mathematical model of the problem**
- 4. Verify the model and use the model for prediction**
- 5. Select a suitable alternative**
- 6. Present the results and conclusions of the study to the organization**
- 7. Implement and evaluate recommendations**

Classification of Mathematical Models

By the Purpose of the Model

- **Optimization Models**
- **Prediction Models**

By the degree of the certainty

- **Deterministic models**
- **Probabilistic models or Stochastic Models**

MS/OR IS GENERALLY APPLIED IN THREE SITUATIONS

- 1.Designing and implementing new operations or procedures**
- 2.Evaluating an ongoing set of operations or procedures**
- 3.Determining and recommending corrective action for operations and procedures that are producing unsatisfactory results.**

Management is also applied when a company has experienced significant or repetitious **failures** or **shortfalls**.

An analyst is typically faced with some or all of the following factors.

- 1. “Fuzzy”, incomplete or conflicting data,**
- 2. “Soft” constraints,**
- 3. Differing opinions among and between workers and management,**
- 4. Very limited budgets for analyses,**
- 5. Narrow time frames for solutions and recommendations**
- 6. Political “turf wars”,**
- 7. No firm idea by management of exactly what is wanted.**

MANAGEMENT SCIENCE

TECHNIQUES

Linear Programming: *Linear programming is a problem-solving approach that has been developed for situations involving maximizing or minimizing a linear function subject to linear constraints that limit the degree to which the objective can be pursued.*

Integer Linear Programming: *Integer linear programming is an approach used for problems that can be set up as linear programs with the additional requirement that some or all of the decision recommendations be integer values.*

Network Models: *A network is a graphical description of a problem consisting of circles called nodes that are interconnected by lines called arcs. Specialized solution procedures exist for these types of problems, enabling us to quickly solve many managerial problems in such areas as transportation system design, information system design, and project scheduling.*

Project Management: PERT/CPM In many situations managers assume the responsibility for planning, scheduling, and controlling projects that consist of numerous separate jobs or tasks performed by a variety of departments, individuals, etc. PER and CPM are techniques for helping managers carry out their project management responsibilities.

Inventory Models: Inventory models are used to help managers faced with the dual problems of maintaining sufficient inventories to meet demand for goods and, at the same time, incurring the lowest possible inventory holding costs.

Waiting Line or Queuing Models: Waiting line or queuing models have been developed to help managers understand and make better decisions concerning the operation of systems involving waiting lines.

Computer Simulation: Computer simulation is a technique used to model the operation of a system over time. This technique employs a computer program to model the operation and perform simulation computations.

Decision Analysis: *Decision analysis can be used to determine optimal strategies in situations involving several decision alternatives and an uncertain or risk-filled pattern of events.*

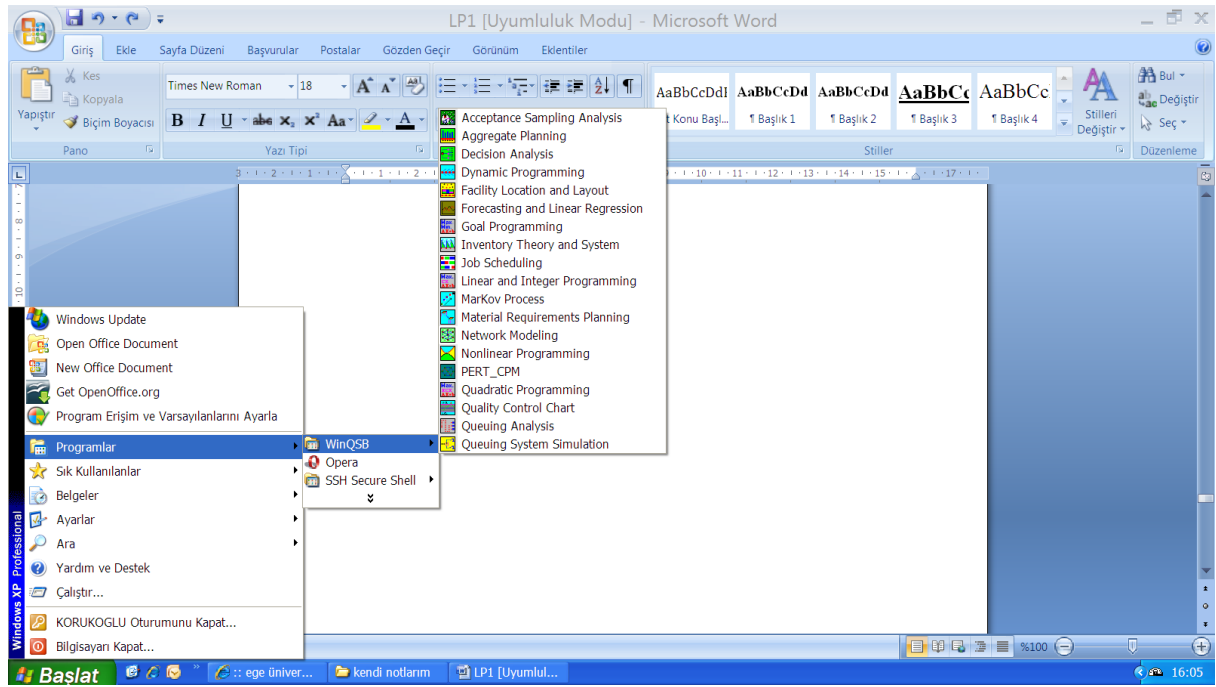
Goal Programming: *Goal programming is a technique for solving multi-criteria decision problems, usually within the framework of linear programming.*

Analytic Hierarchy Process: *A multi-criteria decision-making technique that permits the inclusion of subjective factors in arriving at a recommended decision.*

Forecasting: *Forecasting methods are techniques that can be used to help predict future aspects of a business operation.*

Markov Process Models: *Markov process models are useful in studying the evolution of certain systems over repeated trials. For example, Markov processes have been used to describe the probability that a machine that is functioning in one period will continue to function or break down in another period.*

Dynamic Programming: *Dynamic programming is an approach that allows us to break up a large problem in such a fashion that once all the smaller problems have been solved, we are left with an optimal solution to large problem.*



The utilization of Management Science and Operations Research Methodologies*

Frequency of use % of respondents

	Never	Moderate	Frequent
Statistical	1.6	38.7	59.7
Computer Simulation	12.9	53.2	33.9
PERT/CPM	25.8	53.2	21.0
Linear Programming	25.8	59.7	14.5
Queuing Theory	40.3	50.0	9.7
Nonlinear Programming	53.2	38.7	8.1
Dynamic Programming	61.3	33.9	4.8
Game Theory	69.4	27.4	3.2

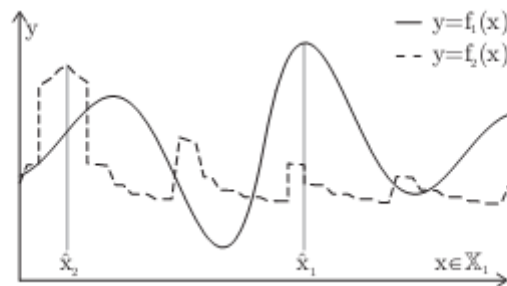
Familiarity with and use of various quantitative methods by management science practitioners*

	Familiarity Rank	Usage (%)
Linear Programming	1	83.8
Simulation	2	80.3
Network Analysis	3	58.1
Queuing Theory	4	54.7
Decision Trees	5	54.7
Integer Programming	6	38.5
Dynamic Programming	7	32.5
Nonlinear Programming	8	30.7
Markov Processes	9	31.6
Replacement analysis	10	38.5
Game Theory	11	13.7
Goal Programming	12	20.5

*C.L. Morgan, "A survey of MS/OR Surveys, Interfaces 19.no 6.

OPTIMIZATION CLASSIFICATION

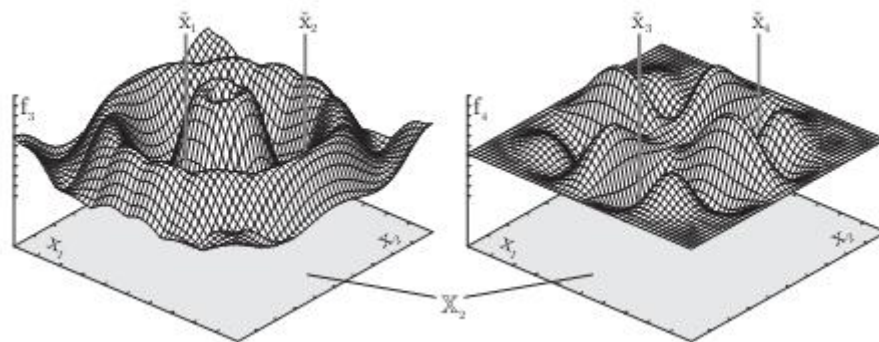
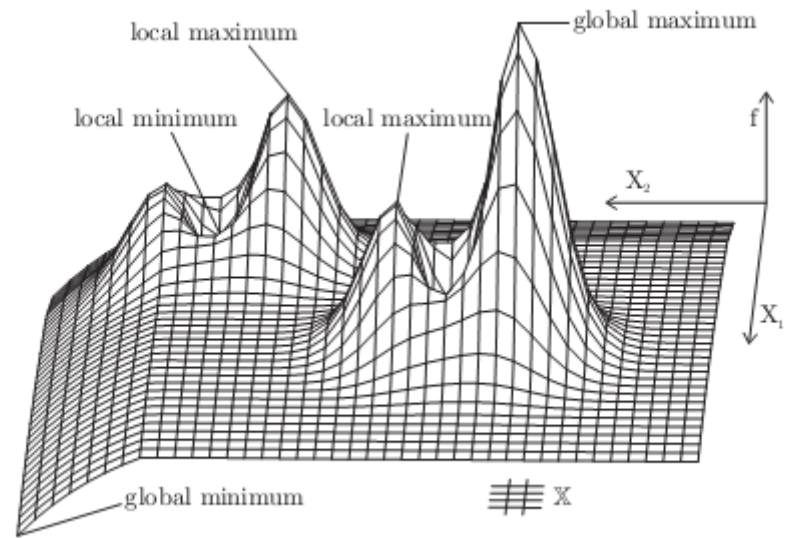
Optimization may be defined as the process by which an optimum is achieved.



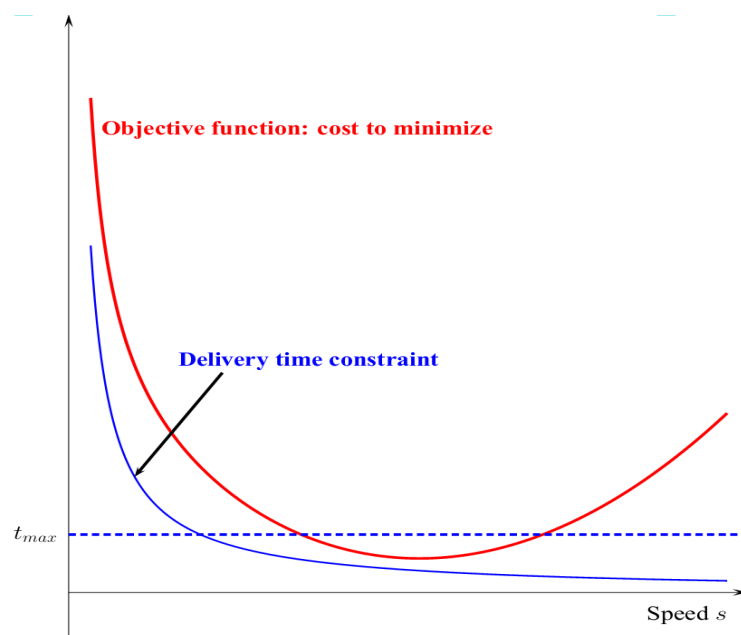
✓ **Optimization of Univariate Functions**

✓ **Optimization of Multivariate Functions**

Optimizations may be performed for obtaining local and global optima.



- ✓ The optimum may be that of an industrial institution or an objective function that models a similar entity.
- ✓ The factors that define the optimum will vary with the situation to which the optimization process is applied.
- ✓ Some examples of factors that may be optimized are cost, raw materials used, time required and pollution caused.



- ✓ **Optimization without constraints**
- ✓ **Optimization with constraints**

Unconstrained Optimization

- ✓ **Classical Methods**
 - **Functions of one variable**
 - **Functions of n Variables**
- ✓ **Search Methods-Functions of one variable**
 - **Fibonacci Search**
 - **Golden Section Search**
 - **The Curve Fitting Approaches**
 - **Quadratic Interpolation**
 - **Cubic Interpolation**
- ✓ **Direct Search Methods-Functions of n variables**
 - **The Method of Hooke and Jeeves**
 - **Nelder and Mead's Method**
- ✓ **Gradient Methods**
 - **Steepest Descent Method**
 - **Quadratic Functions**
 - **The Davidon-Fletcher-Powell Method**
 - **The Fletcher-Reeves Method**

Constrained Optimization

✓ Classical Methods

- Equality Constraints
- Inequality Constraints
- Convexity and Concavity

✓ Search Methods

- Modified Hook and Jeeves
- The complex Method

✓ Nonlinear Constraint Optimization

The standard form of the constrained optimization problem is as follows:

$$\begin{array}{ll} \text{Minimize} & f(x) \\ \text{Subject to} & g_j(x) \leq 0, \quad i = 1, \dots, p \\ & h_i(x) = 0, \quad j = 1, \dots, m \end{array}$$

where x has dimensions $n \times 1$, $f(x)$ is the objective function to be minimized, $g(x)$ are a set of inequality constraints, and $h(x)$ are a set of equality constraints.

Lagrange multipliers

If $F(x, y)$ is a (sufficiently smooth) function in two variables and $g(x, y)$ is another function in two variables, and we define $H(x, y, z) := F(x, y) + zg(x, y)$, and (a, b) is a relative extremum of F subject to $g(x, y) = 0$, then there is some value $z = \lambda$ such that $\frac{\partial H}{\partial x}|_{(a,b,\lambda)} = \frac{\partial H}{\partial y}|_{(a,b,\lambda)} = \frac{\partial H}{\partial z}|_{(a,b,\lambda)} = 0$.

Example of use of Lagrange multipliers

Find the extrema of the function $F(x, y) = 2y + x$ subject to the constraint $0 = g(x, y) = y^2 + xy - 1$.

Solution

Set $H(x, y, z) = F(x, y) + zg(x, y)$. Then

$$\begin{aligned}\frac{\partial H}{\partial x} &= 1 + zy \\ \frac{\partial H}{\partial y} &= 2 + 2zy + zx \\ \frac{\partial H}{\partial z} &= y^2 + xy - 1\end{aligned}$$

Solution, continued

Setting these equal to zero, we see from the third equation that $y \neq 0$, and from the first equation that $z = \frac{-1}{y}$, so that from the second equation $0 = \frac{-x}{y}$ implying that $x = 0$. From the third equation, we obtain $y = \pm 1$.

Nonlinear constraint optimization software

Name	Model	Global Method	Interfaces
ALGENCAN	Aug. Lag.	augmented	AMPL, CUTEr, Java, MATLAB, Octave, Python, R
CONOPT	GRG/SLQ	line-search	AIMMS, GAMS
CVXOPT	IPM	only convex	Python
FilterSQP	SQP	filter/trust region	AMPL, CUTEr,
GALAHAD	Aug. Lag.	nonmonotone/ augmented	CUTEr, Fortran
IPOPT	IPM	filter/line search	AMPL, CUTEr, C, C++,
KNITRO	IPM	penalty-barrier/ trust region	AIMMS, AMPL, Mathematica, MATLAB, MPL, C, C++, f77, Excel
KNITRO	SLQP	penalty/trust region	s.a.
LANCELOT	Aug. Lag.	augmented trust region	SIF, AMPL, f77
LINDO	GRG/SLP	only convex	C, MATLAB, LINGO
LOQO	IPM	line search	AMPL, C, MATLAB
LRAMBO	SQP	1 exact penalty/ line search	C
MINOS	Aug. Lag.	augmented	AIMMS, AMPL, MATLAB, C, C++, f77
NLPQLP	SQP	augmented line-search	C, f77, MATLAB
NPSOL	SQP	penalty Lagrangian/ line search	AIMMS, AMPL, MATLAB, C, C++, f77
PATH	LCP	line search	AMPL
PENNON	Aug. Lag.	line search	AMPL, MATLAB
SNOPT	SQP	penalty Lagrangian/ line search	AIMMS, AMPL, MATLAB, C, C++, f77
SQPlab	SQP	penalty Lagrangian/ line search	MATLAB

Optimization Tasks

✓ By Solving Method

- Linear Programming
- Quadratic Programming
- Nonlinear Programming
- Dynamic Programming
- Integer Programming
 - Binary Programming
- Mixed Integer Programming

✓ By number of Criteria

- Single Criterion
- Multi Criterion

Definition of a multi-objective optimization problem

The general multi-objective optimization problem is posed as follows:

$$\begin{aligned} & \underset{\mathbf{x}}{\text{Minimize}} \quad \mathbf{F}(\mathbf{x}) = [F_1(\mathbf{x}), F_2(\mathbf{x}), \dots, F_k(\mathbf{x})]^T \\ & \text{subject to } g_j(\mathbf{x}) \leq 0, \quad j = 1, 2, \dots, m, \end{aligned} \tag{1}$$

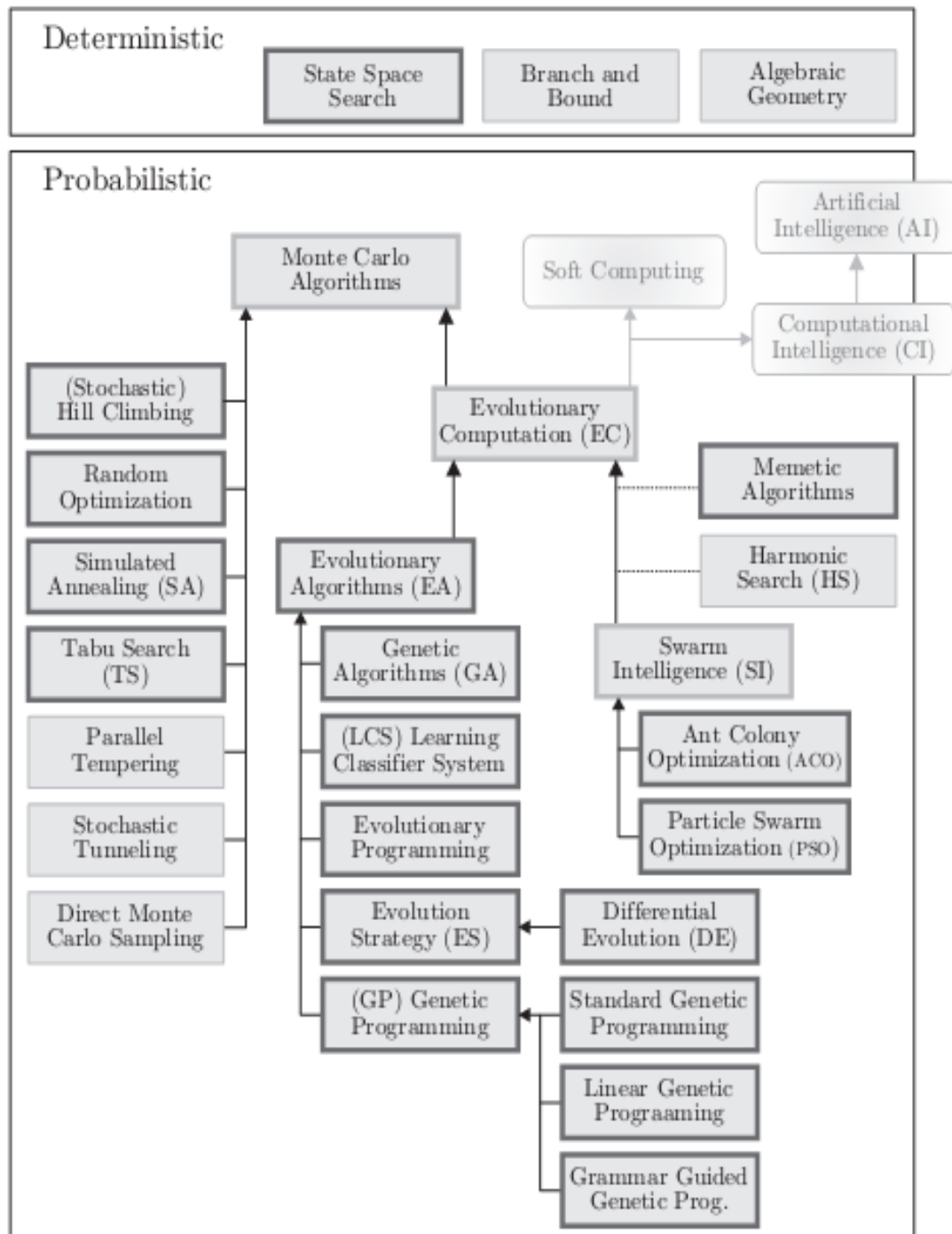
$$h_l(\mathbf{x}) = 0, \quad l = 1, 2, \dots, e,$$

where k is the number of objective functions, m is the number of inequality constraints, and e is the number of equality constraints. $\mathbf{x} \in E^n$ is a vector of *design variables* (also called *decision variables*), where n is the number of independent variables x_i . $\mathbf{F}(\mathbf{x}) \in E^k$ is a vector of objective functions $F_i(\mathbf{x}) : E^n \rightarrow E^1$. $F_i(\mathbf{x})$ are also called objectives, *criteria*, *payoff functions*, *cost functions*, or *value functions*. The gradient of $F_i(\mathbf{x})$ with respect to \mathbf{x} is written as $\nabla_{\mathbf{x}} F_i(\mathbf{x}) \in E^n$. \mathbf{x}_i^* is the point that minimizes the objective function $F_i(\mathbf{x})$. Any comparison (\leq, \geq , etc.) between vectors applies to corresponding vector components.

Multi-objective optimization often means to compromise conflicting goals.

- ✓ **Minimize the time between an incoming order and the shipment of the corresponding product,**
- ✓ **Maximize profit,**
- ✓ **Maximize product quality**
- ✓ **Minimize negative impact on environment,**
- ✓ **Minimize cost for advertising,**
- ✓ **Minimize cost for personal,**
- ✓ **Minimize cost for raw materials,**
- ✓ **.**

The taxonomy of global optimization algorithms



Simulated Annealing

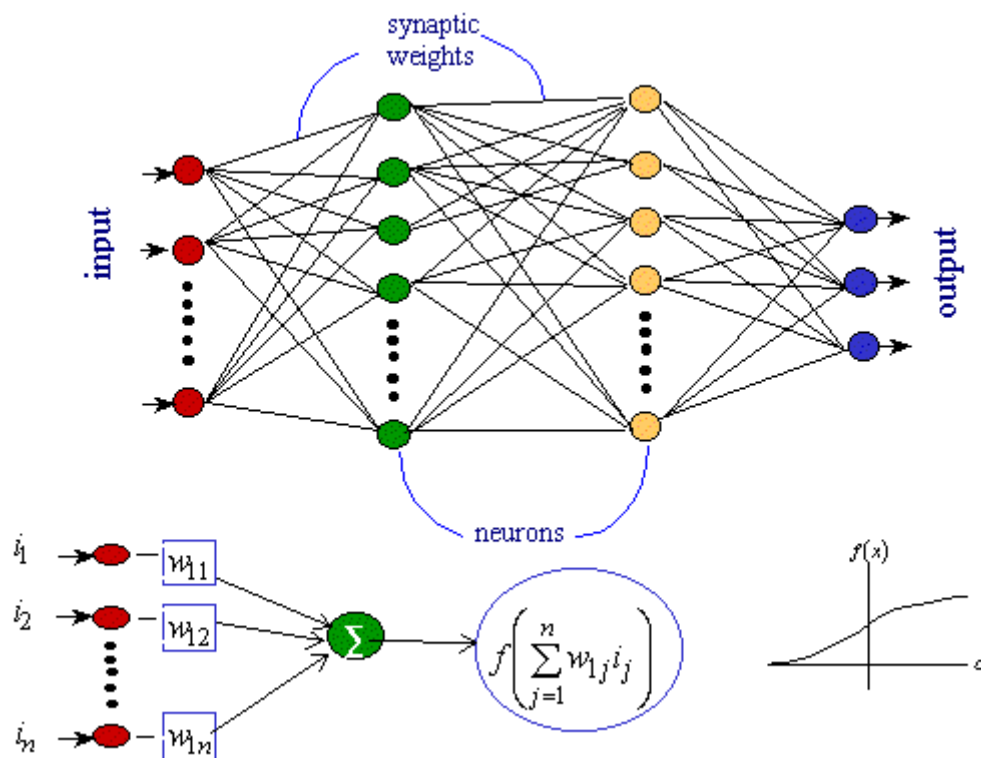
This technique draws its inspiration from the annealing process that many substances undergo while changing state. Typically, a substance, such as iron for example, when heated gains energy. This energy is gradually dissipated due to cooling. The temperature is thus a measure of the disorder in the iron. As it cools its molecules gradually, loose energy and gain order. This process continues until the system can achieve thermodynamic equilibrium. In the case of annealing a piece of iron, thermodynamic equilibrium would occur when the temperature of the iron is the same as the temperature of the surroundings. Simulated Annealing tries to mimic this process and therefore gets its name.

One of the difficulties in using Simulated Annealing is that it becomes very difficult to choose the rates of cooling and the initial temperatures for the system that is being optimized. This occurs primarily because of the absence of any rules for selecting them. The selection of these parameters depends on heuristics and varies with the system that is being optimized.

Neural Networks

Neural networks derive their inspiration from biological neuron systems and the brain. A neural network consists of a number of sub-units called neurons.

There has been an explosion of interest in Neural Networks. They have been applied to modeling as well as to interpretation. The major reason for the universal appeal and utility of neural networks is that they are universal approximators.



Genetic Algorithms

These algorithms draw their inspiration from various hypotheses of biological evolution. Historically, such hypotheses have proposed that species evolve through a process of survival of the fittest.

- A population of a species (set of possible solutions in this case) is created.
- The members of this species are allowed to reproduce and recombine to produce new offspring.
- The fittest offspring are then selected to go on to the next stage namely, recombining and producing new offspring (or new solutions).

Initialize the population

Evaluate initial population

Repeat

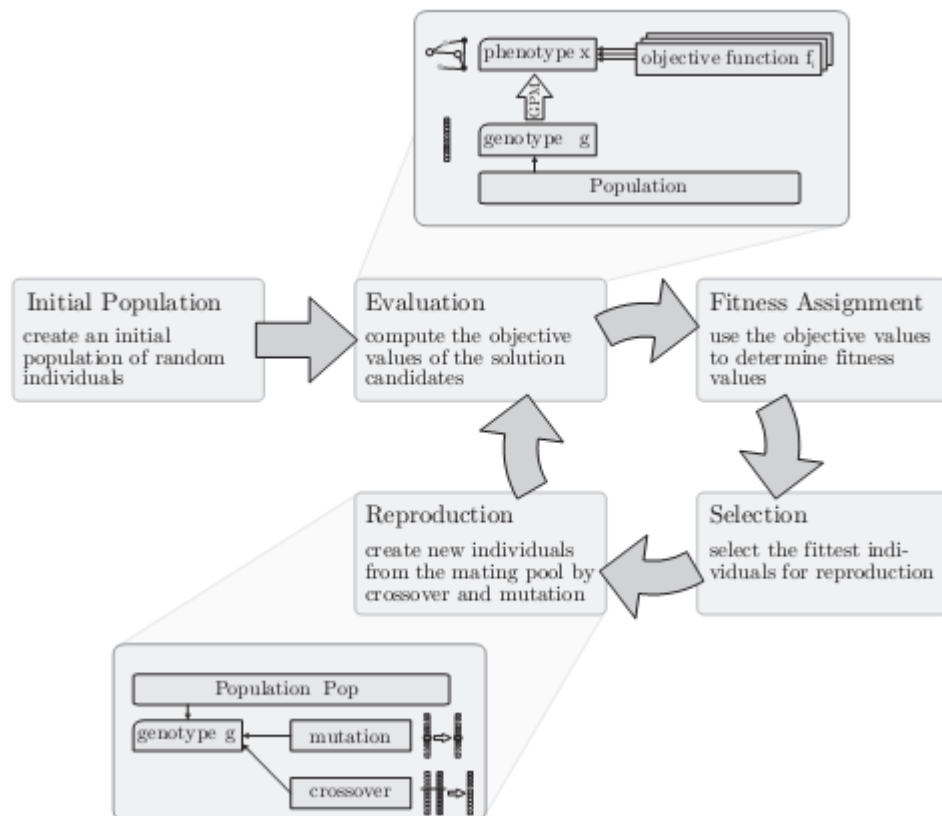
Perform competitive selection

Apply genetic operators

to generate new solutions Evaluate solutions in the population

Until some convergence criteria is satisfied

The basic cycle of genetic algorithms



Tabu Search

This technique is based on the idea that humans behave in a seemingly random manner given the same learning environment. The correct behavior or solution is discovered over time by performing a given action, determining its consequences and using those consequences in performing future actions. Hence, Tabu search must keep a track or 'list' of the paths it as traversed.

Tabu search has two main stages.

- *In the first stage it explores the state space coarsely and determines probable solutions.*
- *In the second stage, it searches in the environs of these probable solutions to determine which solution is the best.*

Institute for operations research and management science

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Master's and PhD Programs in Operations Research

The screenshot shows the PhD.org Graduate School Guide website. The left sidebar contains search filters for Location, Type of location, Cost, Outcomes, Size, Diversity, and Undergraduate selectivity. The main content area displays a list of programs, including:

- Operations Research, Cornell University, Ithaca, NY
- Operations Research (M.S. only), CUNY Bernard M. Baruch College, New York, NY
- Operations Research, DePaul University, Chicago, IL
- Operations Research, Florida Institute of Technology-Melbourne, Melbourne, FL
- Operations Research, George Mason University, Fairfax, VA
- Operations Research, George Washington University, Washington, DC
- Operations Research, Georgia Institute of Technology-Main Campus, Atlanta, GA
- Operations Research, Georgia State University, Atlanta, GA
- Operations Research, Iowa State University, Ames, IA
- Operations Research, Kansas State University, Manhattan, KS
- Operations Research, Kent State University-Kent Campus, Kent, OH
- Operations Research, Massachusetts Institute of Technology, Cambridge, MA
- Operations Research, Michigan State University, East Lansing, MI
- Operations Research, Naval Postgraduate School, Monterey, CA
- Operations Research, New York University, New York, NY
- Operations Research, North Carolina State University at Raleigh, Raleigh, NC
- Computer Science & Operations Research, North Dakota State University-Main Campus, Fargo, ND
- Operations Research, Northeastern University, Boston, MA
- Operations Research, Oregon State University, Corvallis, OR
- Operations Research & Financial Engineering, Princeton University, Princeton, NJ
- Operations Research, Rensselaer Polytechnic Institute, Troy, NY
- Operations Research, Rutgers University-Newark, Newark, NJ
- Operations Research, Rutgers University-New Brunswick/Pliscataway, New Brunswick, NJ
- Operations Research, Southern Methodist University, Dallas, TX
- Operations Research, Stanford University, Stanford, CA
- Operations Research, St. John's University-New York, Queens, NY
- Operations Research, Syracuse University, Syracuse, NY
- Operations Research, Temple University, Philadelphia, PA
- Operations Research, Texas A & M University, College Station, TX
- Operations Research, The University of Texas at Austin, Austin, TX
- Operations Research, The University of Texas at Dallas, Richardson, TX
- Operations Research, Union College, Schenectady, NY
- Operations Research, University of Alabama in Huntsville, Huntsville, AL
- Industrial Eng. & Operations Research, University of California, Berkeley, Berkeley, CA
- Operations Research, University of Delaware, Newark, DE
- Operations Research, University of Minnesota-Twin Cities, Minneapolis, MN
- Industrial Eng. & Operations Research, University of New Haven, West Haven, CT
- Operations Research, University of North Carolina at Chapel Hill, Chapel Hill, NC

- [Operations Research, Air Force Institute of Technology](#), Wright-Patterson AFB, OH
- ☐ [Applied Statistics & Operations Research, Bowling Green State University-Main Campus](#), Bowling Green, OH
- ☐ [Management Science/Operations Research, California State University-Fullerton](#), Fullerton, CA
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- ☐ [Operations Research, Yale University](#), New Haven, CT