1. Operations Research

To define anything non-trivial — like beauty or mathematics — is very difficult indeed. Here is a reasonably good definition of Operations Research:

1.1.1 Definition.

Operations Research (OR) is an interdisciplinary branch of applied mathematics and formal science that uses methods like mathematical modeling, statistics, and algorithms to arrive at optimal or near optimal solutions to complex problems. Definition 1.1.1 is problematic: to grasp it we already have to know, e.g., what is formal science or near optimality. From a practical point of view, OR can be defined as an art of optimization, i.e., an art of finding minima or maxima of some objective function, and — to some extend — an art of defining the objective functions. Typical objective functions are

- profit,
- assembly line performance,
- crop yield,
• bandwidth,
• loss,
• waiting time in queue,
• risk.

From an organizational point of view, OR is something that helps management achieve its goals using the scientific process. The terms OR and Management Science (MS) are often used synonymously. When a distinction is drawn, management science generally implies a closer relationship to Business Management. OR also closely relates to Industrial Engineering. Industrial engineering takes more of an engineering point of view, and industrial engineers typically consider OR techniques to be a major part of their tool set. Recently, the term Decision Science (DS) has also be coined to OR.

1.1.2 History of Operations Research*

Prehistory

Some say that Charles Babbage (1791–1871) — who is arguably the “father of computers” — is also the “father of operations research” because his
research into the cost of transportation and sorting of mail led to England’s universal “Penny Post” in 1840.

**OR During World War II**

The modern field of OR arose during World War II. Scientists in the United Kingdom including Patrick Blackett, Cecil Gordon, C. H. Waddington, Owen Wansbrough-Jones and Frank Yates and in the United States with George Dantzing looked for ways to make better decisions in such areas as logistics and training schedules.

Here are examples of OR studies done during World War II:

Britain introduced the convoy system to reduce shipping losses, but while the principle of using warships to accompany merchant ships was generally accepted, it was unclear whether it was better for convoys to be small or large. Convoys travel at the speed of the slowest member, so small convoys can travel faster. It was also argued that small convoys would be harder for German U-boats to detect. On the other hand, large convoys could deploy more warships against an attacker. It turned out in OR analysis that the losses suffered by convoys depended largely on the number of escort vessels present, rather than on the overall size of the
convoy. The conclusion, therefore, was that a few large convoys are more defensible than many small ones. In another OR study a survey carried out by RAF Bomber Command was analyzed. For the survey, Bomber Command inspected all bombers returning from bombing raids over Germany over a particular period. All damage inflicted by German air defenses was noted and the recommendation was given that armor be added in the most heavily damaged areas. OR team instead made the surprising and counter-intuitive recommendation that the armor be placed in the areas which were completely untouched by damage. They reasoned that the survey was biased, since it only included aircraft that successfully came back from Germany. The untouched areas were probably vital areas, which, if hit, would result in the loss of the aircraft. When the Germans organized their air defenses into the Kammhuber Line, it was realized that if the RAF bombers were to fly in a bomber stream they could overwhelm the night fighters who flew in individual cells directed to their targets by ground controllers. It was then a matter of calculating the statistical loss from collisions against the statistical loss from night fighters to calculate how close the bombers should fly to minimize RAF losses.
1.1.3 Phases of Operations Research Study

An OR project can be split in the following seven steps:

**Step 1: Formulate the problem** The OR analyst first defines the organization’s problem. This includes specifying the organization’s objectives and the parts of the organization (or system) that must be studied before the problem can be solved.

**Step 2: Observe the system** Next, the OR analyst collects data to estimate the values of the parameters that affect the organization’s problem. These estimates are used to develop (in Step 3) and to evaluate (in Step 4) a mathematical model of the organization’s problem.

**Step 3: Formulate a mathematical model of the problem** The OR analyst develops an idealized representation — i.e. a mathematical model — of the problem.

**Step 4: Verify the model and use it for prediction** The OR analyst tries to determine if the mathematical model developed in Step 3 is an accurate representation of the reality. The verification typically includes observing the system to check if the parameters are correct. If the model does not
represent the reality well enough then the OR analyst goes back either to Step 3 or Step 2.

**Step 5:** Select a suitable alternative given a model and a set of alternatives, the analyst now chooses the alternative that best meets the organization’s objectives. Sometimes there are many best alternatives, in which case the OR analyst should present them all to the organization’s decision-makers, or ask for more objectives or restrictions.

**Step 6:** Present the results and conclusions The OR analyst presents the model and recommendations from Step 5 to the organization’s decision-makers. At this point the OR analyst may find that the decision makers do not approve of the recommendations. This may result from incorrect definition of the organization’s problems or decision-makers may disagree with the parameters or the mathematical model. The OR analyst goes back to Step 1, Step 2, or Step 3, depending on where the disagreement lies.

**Step 7:** Implement and evaluate recommendation finally, when the organization has accepted the study, the OR analyst helps in implementing the recommendations. The system must be constantly monitored and updated dynamically as the environment changes.
1.2 Goal Programming:

1.2.1 INTRODUCTION

In many important real-world decision-making situations, it may not be feasible, or desirable to reduce all the goals of an organization into a single objective. For example, instead of focusing only on optimizing profits, the organization may simultaneously be interested in maintaining a stable workforce, increasing its share of market and limiting price increases. Goal programming is an extension of linear or nonlinear programming involving an objective function with multiple objectives. While developing a goal programming model, the decision variables of the model are to be defined first. Then the managerial goals related to the problems are to be listed down and ranked in order of priority. Since it may be very difficult to rank these goals on a cardinal scale, an ordinal ranking is usually applied to each of the goals. It may not always be possible to fully achieve every goal specified by the decision-maker. Thus, goal programming is often referred to as a lexicographic procedure in which the various goals are satisfied in order of their relative importance.
Example: An office equipment manufacturer produces two kinds of products: computer covers and floppy boxes. Production of either a computer cover or a floppy box requires 1 hour of production capacity in the plant. The plant has a maximum production capacity of 10 hours per day. Because of the limited sales capacity, the maximum numbers of computer covers and floppy boxes that can be sold are 6 and 8 per day, respectively. The gross margin from the sale of a computer cover is Rs. 80, and Rs. 40 for a floppy box. The overtime hour should not exceed 2 hours/day. The plant manager has set the following goals arranged in order of importance.

1. To avoid any underutilization of production capacity.

2. To limit the overtime hours to 2 hours.

3. To sell as many computer covers and floppy boxes as possible. Since the gross margin from the sale of a computer cover is set at twice the amount of profit from a floppy box, he has twice as much desire to achieve the sales goal for computer covers as for the floppy boxes.

4. To minimize the overtime operation of the plant as much as possible.
Variants

The initial goal programming formulations ordered the unwanted deviations into a number of priority levels, with the minimization of a deviation in a higher priority level being infinitely more important than any deviations in lower priority levels. This is known as lexicographic or pre-emptive goal programming. Ignizio gives an algorithm showing how a lexicographic goal programme can be solved as a series of linear programmes. Lexicographic goal programming should be used when there exists a clear priority ordering amongst the goals to be achieved.

If the decision maker is more interested in direct comparisons of the objectives then Weighted or non pre-emptive goal programming should be used. In this case all the unwanted deviations are multiplied by weights, reflecting their relative importance, and added together as a single sum to form the achievement function. It is important to recognize that deviations measured in different units cannot be summed directly due to the phenomenon of incommensurability.
Hence each unwanted deviation is multiplied by a normalization constant to allow direct comparison. Popular choices for normalization constants are the goal target value of the corresponding objective (hence turning all deviations into percentages) or the range of the corresponding objective (between the best and the worst possible values, hence mapping all deviations onto a zero-one range). For decision makers more interested in obtaining a balance between the competing objectives, Chebyshev goal programming should be used. Introduced by Flavell in 1976, this variant seeks to minimize the maximum unwanted deviation, rather than the sum of deviations. This utilizes the Chebyshev distance metric, which emphasizes justice and balance rather than ruthless optimization.

**Strength and weakness**

A major strength of goal programming is its simplicity and ease of use. This accounts for the large number of goal programming applications in many and diverse fields. Linear Goal programmes can be solved using linear programming software as either a single linear programme, or in the case of the lexicographic variant, a series of connected linear programmes.
Goal programming can hence handle relatively large numbers of variables, constraints and objectives. A debated weakness is the ability of goal programming to produce solutions that are not Pareto efficient. This violates a fundamental concept of decision theory that is no rational decision maker will knowingly choose a solution that is not Pareto efficient. However, techniques are available to detect when this occurs and project the solution onto the Pareto efficient solution in an appropriate manner.

The setting of appropriate weights in the goal programming model is another area that has caused debate, with some authors suggesting the use of the Analytic Hierarchy Process or interactive methods for this purpose.

1.3 Theory of Game

1.3.1 Introduction

Game theory is a study of strategic decision making. More formally, it is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers." An alternative term suggested "as a more descriptive name for the discipline" is interactive decision theory. Game theory is mainly used in economics, political science, and
psychology, as well as logic and biology. The subject first addressed zero-sum games, such that one person's gains exactly equal net losses of the other participant(s). Today, however, game theory applies to a wide range of class relations, and has developed into an umbrella term for the logical side of science, to include both human and non-humans, like computers. Classic uses include a sense of balance in numerous games, where each person has found or developed a tactic that cannot successfully better his results, given the other approach.

Modern game theory began with the idea regarding the existence of mixed-strategy equilibrium in two-person zero-sum games and its proof by John von Neumann. Von Neumann's original proof used Brouwer's fixed-point theorem on continuous mappings into compact convex sets, which became a standard method in game theory and mathematical economics. His paper was followed by his 1944 book Theory of Games and Economic Behavior, with Oskar Morgenstern, which considered cooperative games of several players. The second edition of this book provided an axiomatic theory of expected utility, which allowed mathematical statisticians and economists to treat decision-making under uncertainty.
This theory was developed extensively in the 1950s by many scholars. Game theory was later explicitly applied to biology in the 1970s, although similar developments go back at least as far as the 1930s. Game theory has been widely recognized as an important tool in many fields. Eight game-theorists have won the Nobel Memorial Prize in Economic Sciences, and John Maynard Smith was awarded the Crafoord Prize for his application of game theory to biology.

1.3.2 Types of games

Cooperative or non-cooperative: A game is *cooperative* if the players are able to form binding commitments. For instance the legal system requires them to adhere to their promises. In non-cooperative games this is not possible. Often it is assumed that *communication* among players is allowed in cooperative games, but not in non-cooperative ones. However, this classification on two binary criteria has been questioned, and sometimes rejected (Harsanyi 1974).

Of the two types of games, non-cooperative games are able to model situations to the finest details, producing accurate results. Cooperative
games focus on the game at large. Considerable efforts have been made to link the two approaches. The so-called Nash-programme has already established many of the cooperative solutions as non-cooperative equilibrium.

*Hybrid* games contain cooperative and non-cooperative elements. For instance, coalitions of players are formed in a cooperative game, but these play in a non-cooperative fashion.

- Symmetric and asymmetric: A symmetric game is a game where the payoffs for playing a particular strategy depend only on the other strategies employed, not on who is playing them. If the identities of the players can be changed without changing the payoff to the strategies, then a game is symmetric. Many of the commonly studied 2×2 games are symmetric. The standard representations of chicken, the prisoner's dilemma, and the stag hunt are all symmetric games. Some *scholars* would consider certain asymmetric games as examples of these games as well. However, the most common payoffs for each of these games are symmetric
Zero-sum and non-zero-sum: Zero-sum games are a special case of constant-sum games, in which choices by players can neither increase nor decrease the available resources. In zero-sum games the total benefit to all players in the game, for every combination of strategies, always adds to zero (more informally, a player benefits only at the equal expense of others). Poker exemplifies a zero-sum game (ignoring the possibility of the house's cut), because one wins exactly the amount one's opponents lose. Other zero-sum games include matching pennies and most classical board games including Go and chess.

Many games studied by game theorists (including the infamous prisoner's dilemma) are non-zero-sum games, because the outcome has net results greater or less than zero. Informally, in non-zero-sum games, a gain by one player does not necessarily correspond with a loss by another.

Constant-sum games correspond to activities like theft and gambling, but not to the fundamental economic situation in which there are potential gains from trade. It is possible to transform any game into a (possibly
asymmetric) zero-sum game by adding an additional dummy player (often called "the board"), whose losses compensate the players' net winnings.

**General and applied uses**

- Description and modeling
- Prescriptive or normative analysis
- Economics and business
- Political science
- Biology
- Computer science and logic
- Philosophy

1.4 **Queueing Theory**

1.4.1 **Introduction:**

Queueing theory is the mathematical study of waiting lines, or queues.\[1\] In queueing theory a model is constructed so that queue lengths and waiting times can be predicted. Queueing theory is generally considered a branch of operations research because the results are often used when making business decisions about the resources needed to provide service.
Queueing theory started with research by Agner Krarup Erlang when he created models to describe the Copenhagen telephone exchange. The ideas have since seen applications including telecommunications, traffic engineering, computing\cite{3} and the design of factories, shops, offices and hospitals.

**Etymology**

The word *queue* comes, via French, from the Latin *cauda*, meaning tail. The spelling "queueing" over "queuing" is typically encountered in the academic research field. In fact, one of the flagship journals of the profession is named Queueing Systems.

**Single queueing nodes**

Single queueing nodes are usually described using Kendall's notation in the form $A/B/C$ where $A$ describes the time between arrivals to the queue, $B$ the size of jobs and $C$ the number of servers at the node.

Agner Krarup Erlang, a Danish engineer who worked for the Copenhagen Telephone Exchange, published the first paper on what would now be called queueing theory in 1909. He modeled the number of telephone calls
arriving at an exchange by a Poisson process and solved the M/D/1 queue in 1917 and M/D/k queueing model in 1920. In Kendall’s notation

- M stands for Markov and means arrivals occur according to a Poisson process
- D stands for deterministic and means jobs arriving at the queue require a fixed amount of service
- \( k \) describes the number of servers at the queueing node (\( k = 1, 2,... \)). If there are more jobs at the node than there are servers then jobs will queue and wait for service.

The M/M/1 queue is a simple model where a single server serves jobs that arrive according to a Poisson process and have exponentially distributed service requirements. In an M/G/1 queue the G stands for general and indicates an arbitrary probability distribution. The M/G/1 model was solved by Felix Pollaczek in 1930, a solution later recast in probabilistic terms by Aleksandr Khinchin and now known as the Pollaczek–Khinchine formula. After World War II queueing theory became an area of research interest to mathematicians.
Work on queueing theory used in modern packet switching networks was performed in the early 1960s by Leonard Kleinrock

**Application to telephony**

The public switched telephone network (PSTN) is designed to accommodate the offered traffic intensity with only a small loss. The performance of loss systems is quantified by their grade of service, driven by the assumption that if sufficient capacity is not available, the call is refused and lost. Alternatively, overflow systems make use of alternative routes to divert calls via different paths — even these systems have a finite traffic carrying capacity.

However, the use of queueing in PSTNs allows the systems to queue their customers' requests until free resources become available. This means that if traffic intensity levels exceed available capacity, customer's calls are not lost; customers instead wait until they can be served. This method is used in queueing customers for the next available operator.

A queueing discipline determines the manner in which the exchange handles calls from customers. It defines the way they will be served, the
order in which they are served, and the way in which resources are divided among the customers. Here are details of four queueing disciplines:

First in first out

This principle states that customers are served one at a time and that the customer that has been waiting the longest is served first.

Last in first out

This principle also serves customers one at a time, however the customer with the shortest waiting time will be served first, also known as a stack.

Processor sharing

Service capacity is shared equally between customers.

Priority

Customers with high priority are served first. Queueing is handled by control processes within exchanges, which can be modeled using state equations. Queueing systems use a particular form of state equations
known as a Markov chain that models the system in each state. Incoming traffic to these systems is modeled via a Poisson distribution and is subject to Erlang’s queueing theory assumptions viz.

- **Pure-chance traffic** – Call arrivals and departures are random and independent events.
- **Statistical equilibrium** – Probabilities within the system do not change.
- **Full availability** – All incoming traffic can be routed to any other customer within the network.
- **Congestion is cleared as soon as servers are free.**

Classic queueing theory involves complex calculations to determine waiting time, service time, server utilization and other metrics that are used to measure queueing performance.

### 1.4.2 Queueing System Classification

With Little’s Theorem, we have developed some basic understanding of a queueing system. To further our understanding we will have to dig deeper into characteristics of a queueing system that impact its performance. For
example, queueing requirements of a restaurant will depend upon factors like:

* How do customers arrive in the restaurant? Are customer arrivals more during lunch and dinner time (a regular restaurant)? Or is the customer traffic more uniformly distributed (a cafe)?

* How much time do customers spend in the restaurant? Do customers typically leave the restaurant in a fixed amount of time? Does the customer service time vary with the type of customer?

* How many tables does the restaurant have for servicing customers?

The above three points correspond to the most important characteristics of a queueing system. They are explained below:

**Arrival Process**

* The probability density distribution that determines the customer arrivals in the system.

* In a messaging system, this refers to the message arrival probability distribution.
Service Process

* The probability density distribution that determines the customer service times in the system.

* In a messaging system, this refers to the message transmission time distribution. Since message transmission is directly proportional to the length of the message, this parameter indirectly refers to the message length distribution.

Number of Servers

* Number of servers available to service the customers.

* In a messaging system, this refers to the number of links between the source and destination nodes.

Based on the above characteristics, queueing systems can be classified by the following convention:

\[ A/S/n \]

Where A is the arrival process, S is the service process and n is the number of servers. A and S are can be any of the following:
Examples of queueing systems that can be defined with this convention are:

* M/M/1: This is the simplest queueing system to analyze. Here the arrival and service time are negative exponentially distributed (Poisson process). The system consists of only one server. This queueing system can be applied to a wide variety of problems as any system with a very large number of independent customers can be approximated as a Poisson process. Using a Poisson process for service time however is not applicable in many applications and is only a crude approximation. Refer to M/M/1 Queueing System for details.

* M/D/n: Here the arrival process is Poisson and the service time distribution is deterministic. The system has n servers. (e.g. a ticket
booking counter with n cashiers.) Here the service time can be assumed to be same for all customers)

* G/G/n: This is the most general queueing system where the arrival and service time processes are both arbitrary. The system has n servers. No analytical solution is known for this queueing system.

**Queueing networks**

Networks of queues are systems a number of queues are connected by customer routing. When a customer is serviced at one node it can join another node and queue for service, or leave the network. For a network of m the state of the system can be described by an m–dimensional vector (x₁, x₂,..., xₘ) where xᵢ represents the number of customers at each node. The first significant results in this area were Jackson networks, for which an efficient product-form stationary distribution exists and the mean value analysis which allows average metrics such as throughput and sojourn times to be computed.

If the total number of customers in the network remains constant the network is called a closed network and has also been shown to have a
product–form stationary distribution in the Gordon–Newell theorem. This result was extended to the BCMP network where a network with very general service time, regimes and customer routing is shown to also exhibit a product-form stationary distribution.

Networks of customers have also been investigated, Kelly networks where customers of different classes experience different priority levels at different service nodes.

**Mean field limits**

Mean field models consider the limiting behavior of the empirical measure (proportion of queues in different states) as the number of queues \(m\) goes to infinity. The impact of other queues on any given queue in the network is approximated by a differential equation. The deterministic model converges to the same stationary distribution as the original model.

**Fluid limits**

Fluid models are continuous deterministic analogs of queueing networks obtained by taking the limit when the process is scaled in time and space, allowing heterogenous objects. This scaled trajectory converges to a
deterministic equation which allows us stability of the system to be proven. It is known that a queueing network can be stable, but have an unstable fluid limit.

**Heavy traffic/diffusion approximations**

Under a so-called heavy traffic regime, where occupancy rates are high (utilization near 1) a reflected Brownian motion, Ornstein–Uhlenbeck process or more general diffusion process can be used to approximate the queueing model. The number of dimensions of the RBM is equal to the number of queueing nodes and the diffusion is restricted to the non-negative orthant.

**Utilization**

Utilization is the proportion of the system's resources which is used by the traffic which arrives at it. It should be strictly less than one for the system to function well. It is usually represented by the symbol $\rho$. If $\rho \geq 1$ then the queue will continue to grow as time goes on. In the simplest case of an M/M/1 queue (Poisson arrivals and a single Poisson server) then it is given by the mean arrival rate over the mean service rate, that is,
\[
\rho = \frac{\lambda}{\mu}
\]

where \( \lambda \) is the mean arrival rate and \( \mu \) is the mean service rate. More generally:

\[
\rho = \frac{\lambda}{\mu \times c}
\]

where \( \lambda \) is the mean arrival rate, \( \mu \) is the mean service rate, and \( c \) is the number of servers, such as in an M/M/c queue.

In general, a lower utilization corresponds to less queueing for customers but means that the system is more idle, which may be considered inefficient.

1.4.3 Role of Poisson process, exponential distributions

A useful queueing model represents a real-life system with sufficient accuracy and is analytically tractable. A queueing model based on the Poisson process and its companion exponential probability distribution often meets these two requirements. A Poisson process models random events (such as a customer arrival, a request for action from a web server,
or the completion of the actions requested of a web server) as emanating from a memory less process. That is, the length of the time interval from the current time to the occurrence of the next event does not depend upon the time of occurrence of the last event. In the Poisson probability distribution, the observer records the number of events that occur in a time interval of fixed length. In the (negative) exponential probability distribution, the observer records the length of the time interval between consecutive events. In both, the underlying physical process is memory less.

Models based on the Poisson process often respond to inputs from the environment in a manner that mimics the response of the system being modeled to those same inputs. The analytically tractable models that result yield both information about the system being modeled and the form of their solution. Even a queueing model based on the Poisson process that does a relatively poor job of mimicking detailed system performance can be useful. The fact that such models often give "worst-case" scenario evaluations appeals to system designers who prefer to include a safety factor in their designs. Also, the form of the solution of models based on
the Poisson process often provides insight into the form of the solution to a queueing problem whose detailed behavior is poorly mimicked. As a result, queueing models are frequently modeled as Poisson processes through the use of the exponential distribution.

1.4.4 Limitations of queueing theory

The assumptions of classical queueing theory may be too restrictive to be able to model real-world situations exactly. The complexity of production lines with product-specific characteristics cannot be handled with those models. Therefore specialized tools have been developed to simulate, analyze, visualize and optimize time dynamic queueing line behavior.

For example; the mathematical models often assume infinite numbers of customers, infinite queue capacity, or no bounds on inter-arrival or service times, when it is quite apparent that these bounds must exist in reality. Often, although the bounds do exist, they can be safely ignored because the differences between the real-world and theory is not statistically significant, as the probability that such boundary situations might occur is remote compared to the expected normal situation. Furthermore, several
studies show the robustness of queueing models outside their assumptions. In other cases the theoretical solution may either prove intractable or insufficiently informative to be useful.

Alternative means of analysis have thus been devised in order to provide some insight into problems that do not fall under the scope of queueing theory, although they are often scenario-specific because they generally consist of computer simulations or analysis of experimental data. See network traffic simulation.

1.5 Inventory management

1.5.1 Introduction

Inventory management is primarily about specifying the shape and percentage of stocked goods. It is required at different locations within a facility or within many locations of a supply network to precede the regular and planned course of production and stock of materials.

The scope of inventory management concerns the fine lines between replenishment lead time, carrying costs of inventory, asset management, inventory forecasting, inventory valuation, inventory visibility, future
inventory price forecasting, physical inventory, available physical space for inventory, quality management, replenishment, returns and defective goods, and demand forecasting. Balancing these competing requirements leads to optimal inventory levels, which is an on-going process as the business needs shift and react to the wider environment.

Inventory management involves a retailer seeking to acquire and maintain a proper merchandise assortment while ordering, shipping, handling, and related costs are kept in check. It also involves systems and processes that identify inventory requirements, set targets, provide replenishment techniques, report actual and projected inventory status and handle all functions related to the tracking and management of material. This would include the monitoring of material moved into and out of stockroom locations and the reconciling of the inventory balances. It also may include ABC analysis, lot tracking, cycle counting support, etc. Management of the inventories, with the primary objective of determining/controlling stock levels within the physical distribution system, functions to balance the need for product availability against the need for minimizing stock holding and handling costs.
Definition

Inventory management is primarily about specifying the size and placement of stocked goods. Inventory management is required at different locations within a facility or within multiple locations of a supply network to protect the regular and planned course of production against the random disturbance of running out of materials or goods. The scope of inventory management also concerns the fine lines between replenishment lead time, carrying costs of inventory, asset management, inventory forecasting, inventory valuation, inventory visibility, future inventory price forecasting, physical inventory, available physical space for inventory, quality management, replenishment, returns and defective goods and demand forecasting.

Or can be defined as the left out stock of any item used in an organization.

1.5.2 Business inventory

The reasons for keeping stock

There are three basic reasons for keeping an inventory:
1. **Time** - The time lags present in the supply chain, from supplier to user at every stage, requires that you maintain certain amounts of inventory to use in this lead time. However, in practice, inventory is to be maintained for consumption during 'variations in lead time'. Lead time itself can be addressed by ordering that many days in advance.

2. **Uncertainty** - Inventories are maintained as buffers to meet uncertainties in demand, supply and movements of goods.

3. **Economies of scale** - Ideal condition of "one unit at a time at a place where a user needs it, when he needs it" principle tends to incur lots of costs in terms of logistics. So bulk buying, movement and storing brings in economies of scale, thus inventory.

4. **Appreciation in Value** - In some situations, some stock gains the required value when it is kept for some time to allow it reach the desired standard for consumption, or for production. For example; beer in the brewing industry.

All these stock reasons can apply to any owner or product.
REFERENCES


5. Italian Notebook.com [1]"Who moved my parmigiano?" 24 February 2009


8. TU Berlin: Technische Universität Berlin


10. Schlechter, Kira (Monday March 02, 2009). "Hershey Medical Center to open redesigned emergency room". *The Patriot-News*.


37. SM Lee (1972) Goal programming for decision analysis, Auerback, Philadelphia


44. RB Flavell (1976) A new goal programming formulation, Omega, 4, 731-732.
45. EL Hannan (1980) Non-dominance in goal programming, INFOR, 18, 300-309

46. M Tamiz, SK Mirrazavi, DF Jones (1999) Extensions of Pareto efficiency analysis to integer goal programming, Omega, 27, 179-188.
