DOWNLOAD PDF MATHEMATICAL METHODS IN RISK THEORY.

Chapter 1 : Mathematical methods in risk theory (Book,) [blog.quintoapp.com]

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Monte Carlo methods vary, but tend to follow a particular pattern: Define a domain of possible inputs Generate inputs randomly from a probability distribution over the domain Perform a deterministic computation on the inputs Aggregate the results For example, consider a quadrant inscribed in a unit square. In this procedure the domain of inputs is the square that circumscribes the quadrant. We generate random inputs by scattering grains over the square then perform a computation on each input test whether it falls within the quadrant. There are two important points: If the points are not uniformly distributed, then the approximation will be poor. There are a large number of points. The approximation is generally poor if only a few points are randomly placed in the whole square. On average, the approximation improves as more points are placed. Uses of Monte Carlo methods require large amounts of random numbers, and it was their use that spurred the development of pseudorandom number generators , which were far quicker to use than the tables of random numbers that had been previously used for statistical sampling. History[edit] Before the Monte Carlo method was developed, simulations tested a previously understood deterministic problem, and statistical sampling was used to estimate uncertainties in the simulations. Monte Carlo simulations invert this approach, solving deterministic problems using a probabilistic analog see Simulated annealing. In the s, Enrico Fermi first experimented with the Monte Carlo method while studying neutron diffusion, but did not publish anything on it. In , physicists at Los Alamos Scientific Laboratory were investigating radiation shielding and the distance that neutrons would likely travel through various materials. Despite having most of the necessary data, such as the average distance a neutron would travel in a substance before it collided with an atomic nucleus, and how much energy the neutron was likely to give off following a collision, the Los Alamos physicists were unable to solve the problem using conventional, deterministic mathematical methods. Ulam had the idea of using random experiments. He recounts his inspiration as follows: The first thoughts and attempts I made to practice [the Monte Carlo Method] were suggested by a question which occurred to me in as I was convalescing from an illness and playing solitaires. The question was what are the chances that a Canfield solitaire laid out with 52 cards will come out successfully? After spending a lot of time trying to estimate them by pure combinatorial calculations, I wondered whether a more practical method than "abstract thinking" might not be to lay it out say one hundred times and simply observe and count the number of successful plays. This was already possible to envisage with the beginning of the new era of fast computers, and I immediately thought of problems of neutron diffusion and other questions of mathematical physics, and more generally how to change processes described by certain differential equations into an equivalent form interpretable as a succession of random operations. Later [in], I described the idea to John von Neumann , and we began to plan actual calculations. Though this method has been criticized as crude, von Neumann was aware of this: Monte Carlo methods were central to the simulations required for the Manhattan Project , though severely limited by the computational tools at the time. In the s they were used at Los Alamos for early work relating to the development of the hydrogen bomb , and became popularized in the fields of physics , physical chemistry , and operations research. The Rand Corporation and the U. Air Force were two of the major organizations responsible for funding and disseminating information on Monte Carlo methods during this time, and they began to find a wide application in many different fields. The theory of more sophisticated mean field type particle Monte Carlo methods had certainly started by the mids, with the work of Henry P. Harris and Herman Kahn, published in , using mean field genetic -type Monte Carlo methods for estimating particle transmission energies. Metaheuristic in evolutionary computing. The origins of these mean field computational techniques can be traced to and with the work of Alan Turing on genetic type mutation-selection learning machines [18] and the articles by Nils Aall Barricelli at the Institute for Advanced Study in Princeton, New Jersey. Resampled or Reconfiguration Monte Carlo methods for estimating ground state energies of quantum systems in reduced matrix models is due to Jack H. Hetherington in [27] In molecular chemistry, the use of genetic heuristic-like particle methodologies a. It was in , that Gordon et al. Particle filters were also developed in signal processing in the early by P. From to , all the publications on Sequential Monte Carlo methodologies including the pruning and resample Monte Carlo methods introduced in computational physics and molecular chemistry, present natural and heuristic-like algorithms applied to different situations without a single proof of their consistency, nor a discussion on the bias of the estimates and on genealogical and ancestral tree based algorithms. The mathematical foundations and the first rigorous analysis of these particle algorithms are due to Pierre Del Moral [32] [40] in For example, Ripley [47] defines most probabilistic modeling as stochastic simulation , with Monte Carlo being reserved for Monte Carlo integration and Monte Carlo statistical tests. Sawilowsky [48] distinguishes between a simulation , a Monte Carlo method, and a Monte Carlo simulation: Drawing one pseudo-random uniform variable from the interval [0,1] can be used to simulate the tossing of a coin: If the value is less than or equal to 0. This is a simulation, but not a Monte Carlo simulation. Pouring out a box of coins on a table, and then computing the ratio of coins that land heads versus tails is a Monte Carlo method of determining the behavior of repeated coin tosses, but it is not a simulation. Drawing a large number of pseudo-random uniform variables from the interval [0,1] at one time, or once at a large number of different times, and assigning values less than or equal to 0. Kalos and Whitlock [11] point out that such distinctions are not always easy to maintain. For example, the emission of radiation from atoms is a natural stochastic process. It can be simulated directly, or its average behavior can be described by stochastic equations that can themselves be solved using Monte Carlo methods. The Monte Carlo simulation is in fact random experimentations, in the case that, the results of these experiments are not well known. Monte Carlo simulations are typically characterized by a large number of unknown parameters, many of which are difficult to obtain experimentally. The only quality usually necessary to make good simulations is for the pseudo-random sequence to appear "random enough" in a certain sense. What this means depends on the application, but typically they should pass a series of statistical tests. Testing that the numbers are uniformly distributed or follow another desired distribution when a large enough number of elements of the sequence are considered is one of the simplest, and most common ones. Sawilowsky lists the characteristics of a high quality Monte Carlo simulation: Pseudo-random number sampling algorithms are used to transform uniformly distributed pseudo-random numbers into numbers that are distributed according to a given probability distribution. Low-discrepancy sequences are often used instead of random sampling from a space as they ensure even coverage and normally have a faster order of convergence than Monte Carlo simulations using random or pseudorandom sequences. Methods based on their use are called quasi-Monte Carlo methods. RdRand is the closest pseudorandom number generator to a true random number generator. No statistically-significant difference was found between models generated with typical pseudorandom number generators and RdRand for trials consisting of the generation of random numbers. Scenarios such as best, worst, or most likely case for each input variable are chosen and the results recorded. The results are analyzed to get probabilities of different outcomes occurring. The samples in such regions are called "rare events". Applications[edit] Monte Carlo methods are especially useful for simulating phenomena with significant uncertainty in inputs and systems with a large number of coupled degrees of freedom. Areas of application include:

Chapter 2 : Mathematical Methods in Risk Theory (Grundlehren der mathematischen

From the reviews: "The huge literature in risk theory has been carefully selected and supplemented by personal contributions of the author, many of which appear here for the first time. The result is a systematic and very readable book, which takes into account the most recent developments of the.

Understanding the role of exposure in the occurrence of cancer in the presence of modifying effects is a difficult problem. Contributing to the difficulty are the stochastic nature of cancer occurrence, both background and exposure related, and the fact that radiogenic cancers are indistinguishable from nonradiogenic cancers. This section summarizes the theory, principles, and methods of risk assessment epidemiology for studying exposure-disease relationships. The two essential components of risk assessment are a measure of exposure and a measure of disease occurrence. Measuring exposure to radiation is a challenging problem, and dosimetry issues are discussed in detail elsewhere in this report; the common epidemiologic measures of disease occurrence are reviewed in this section. Evaluation of the association between exposure and disease occurrence is aided by the use of statistical models, and the types of models commonly used in radiation epidemiology are described below, as are the methods for fitting the models to data. This section ends with a description of the use of fitted models for estimating probabilities of causation and certain measures of lifetime detriment associated with exposure to ionizing radiation. Rates, Risks, and Probability Models Some individuals exposed to environmental carcinogens e. Thus, cancer is not a necessary consequence of exposure, and exposure is not necessary for cancer. However, the greater incidence of cancer in individuals exposed to known carcinogens indicates that the probability or risk of developing cancer is increased by exposure. Compared to unexposed individuals, the elevated risks of exposed individuals are manifest by increased cancer rates in the latter group. Risks and rates are the basic measures used to compare disease occurrence in exposed and unexposed individuals. This section describes rates and risks and their relationship to one another as a prelude to the sections on modeling and model fitting. Incidence Rate A common measure of disease occurrence used in cancer epidemiology is the incidence rate. Incidence refers to new cases of disease occurring among previously unaffected individuals. The population incidence rate is the number of new cases of the disease occurring in the population in a specified time interval divided by the sum of observation times, in that interval, on all individuals who were disease free at the beginning of the time interval. In general an incidence rate is time dependent and depends on both the starting point and the length of the interval. Let nj denote the number of individuals who are disease free and still under observation at time tj, and dj the number of new diagnoses during the jth interval. An estimate of the incidence rate at time tj is obtained by dividing dj by the product of nj and Lj: The denominator in is an approximation to the sum of observation times on the nj population members in the jth interval and in practice is usually replaced by the actual observation time, which accounts for the fact that the dj diagnoses of disease did not occur exactly at time tj. Page Share Cite Suggested Citation: The National Academies Press. As with the incidence rate, risk is time dependent and depends on both the starting point and the length of the interval. In a longitudinal follow-up study as described above, the proportion of new occurrences dj among nj disease-free individuals still under observation at time tj, is an estimate of the risk or probability of disease occurrence in the jth time interval. For the longitudinal follow-up study estimates defined above, the relationship is manifest by the equation Probability Models The description of rates and risks in terms of estimates from a longitudinal follow-up study is informative and clearly indicates the relevance of these numerical quantities to the study of disease. However, the development of a general theory of risk and risk estimation requires definitions of rates and risks that are not tied to particular types of studies or methods of estimation. Probability models provide a mathematical framework for studying incidence rates and risks and also are used in defining statistical methods of estimation depending on the type of study and the data available. Models for studying the relationship between disease and exposure are usually formulated in terms of the instantaneous incidence rate, which is the theoretical counterpart of the incidence rate estimate defined below. The instantaneous incident rate is defined in terms of the probability distribution function F t of the time to disease occurrence. That is, F t represents the probability that an individual develops the disease of interest in the interval of time 0, t. Two functions derived from F t are used to define the instantaneous incidence rate. The instantaneous incidence rate, also known as the hazard function, is the ratio Integrating the instantaneous incident rate yields the cumulative incidence rate The cumulative incidence rate and the distribution function satisfy the relationship from which it follows that the instantaneous incidence rate completely determines the first-occurrence distribution F t. This approximation is the theoretical counterpart of the relationship between risks and rates described in the discussion of risk. In the remainder of this chapter, incidence rate means instantaneous incidence rate unless explicitly noted otherwise. Incidence Rates and Excess Risks It is clear that the incidence rate plays an important role in the stochastic modeling of disease occurrence. Consequently, models and methods for studying the dependence of disease occurrence on exposure are generally formulated in terms of incidence rates. In the following it is assumed that individuals have been stratified on the basis of age, sex, calendar time, and possibly other factors related to disease occurrence, and that incidence rates are stratum specific. A common measure of discrepancy between incidence rates is the difference which by convention is called the excess absolute risk EAR even though it is, technically, a difference in rates. A second common measure of discrepancy is the relative risk RR , defined as Rearranging terms shows that so that RR t describes the multiplicative increase in incidence rate associated with exposure. These measures enable the study of differences in disease occurrence in relationship to time, by studying either EAR t or ERR t between unexposed and exposed groups. For most carcinogens, exposure is not a simple dichotomy unexposed, exposed but occurs on a continuum. For all carcinogens it is generally agreed that sufficiently large doses increase the risk of cancer. Thus, for many carcinogens the only open or unresolved issue is the dependence of risk on small or low doses. Low-dose ranges are often the most relevant in terms of numbers of exposed individuals. They are also the most difficult ranges for which to obtain unequivocal evidence of increased risk. These difficulties result from the fact that small increases in risk associated with low levels of exposure are difficult to detect using statistical methods in the presence of background risks. Even in the favorable situation in which the baseline risk is relatively well estimated compared to the risk of the exposed group when nj,U is large relative to nj,E , the ability to reliably detect small increases in risk associated with exposure requires a large number of exposed individuals at risk. For example, using the usual criterion for statistical testing in order to detect with probability. A key objective of this report is the calculation of quantitative estimates of human health risks e. In theory, such estimates could be derived by identifying a large group of individuals having common exposure profiles within each stratum and following the groups over a long period of time. As described above, the proportion of individuals in each group who develop cancer in specific time periods provides the desired estimates of risk. However, this approach is not feasible because sufficient data are not available. At low levels of exposure, cancer risks associated with exposure are small relative to baseline or background risks. The increases in observed cancer rates associated with exposure are small relative to the natural random fluctuations in baseline cancer rates. Thus, very large groups of individuals would have to be followed for very long periods of time to provide sufficiently precise estimates of risk associated with exposure. Consequently, direct estimates of risk are not possible for stratified subpopulations. The alternative is to use mathematical models for risk as functions of dose and stratifying variables such as sex and age. Estimation via Mathematical Models for Risk Model-based estimation provides a feasible alternative to direct estimation. Model-based estimates efficiently exploit the information in the available data and provide a means of deriving estimates for strata and dose profile combinations for which data are sparse. This is accomplished by exploiting assumptions about the functional form of a risk model. Of course, the validity of estimates derived from models depends on the appropriateness of the model; thus model choice is important. Biologically based and empirically derived mathematical models for risk are discussed in the next two sections. Biologically Based Risk Models Biologically based risk models are designed to describe the fundamental biological processes involved in the transformation of somatic cells into malignant cancer cells. The use of biologically based risk models in epidemiologic analyses can result in a greater understanding of the mechanisms of carcinogenesis. These models can also help to expose the complex interrelationships between different time- and age-dependent exposure patterns and cancer risk. Biologically based risk models provide an analytical method that is complementary to the traditional, well-established, empirical approaches. Armitage and Doll observed that for many human cancers the log-log plot of age-specific incidence rates versus age is nearly linear, up to moderately old ages. This observation has led to the development of models for carcinogenesis. These models have been fit to various data sets, leading to the observation that most cancers arise after the occurrence of five to seven stages. Comprehensive reviews of the mathematical theory of carcinogenesis have been given by Armitage and Doll , Whittemore , and Armitage In response to the multiplicity of parameters produced by their earlier models, Armitage and Doll proposed a simpler two-stage model designed to avoid parameters not readily estimable from available data. A major limitation of these early two-stage models is their failure to address the multiplication and death of normal cells, which was known to occur in tissues undergoing malignant change Moolgavkar and Knudson A revised two-stage model was later proposed by Moolgavkar and colleagues, which allowed for the growth of normal tissue and the clonal expansion of intermediate cells Moolgavkar and Knudson Numerous two-stage models have since been described in the literature Fisher ; Moolgavkar ; Sielken and others ; Luebeck and others ; Heidenreich and others , a, b; Moolgavkar and others ; Heidenreich and Paretzke ; Moolgavkar and Luebeck The two-stage clonal expansion TSCE model assumes a normal stem cell population of fixed size X and a rate of first mutation of v d , depending on the dose d of the carcinogen. The number of initiated cells arising from the normal cell pool is described by a Poisson process with a rate of vX. The initiated cells then divide either symmetrically or nonsymmetrically. Symmetrical division results in two initiated cells, while nonsymmetrical division results in an initiated cell and a differentiated cell. TSCE models for radiation carcinogenesis have now been applied successfully to a number of important data sets, including atomic bomb survivors Kai and others and occupational groups such as nuclear power plant workers and miners Moolgavkar and others ; Luebeck and others ; Sont and others A study of atomic bomb survivors illustrates the usefulness of the two-stage model in radiation epidemiology Kai and others Findings from this analysis include the observation of a high excess risk among children that may not be explained by enhanced tissue sensitivity to radiation exposure. The temporal patterns in cancer risk can be explained in part by a radiation-induced increase in the pool of initiated cells, resulting in a direct dose-rate effect Kai and others This database contains personal dosimetry records for workers exposed to ionizing radiation since , with current records for more than , Canadians Ashmore and others Application of the TSCE model to the NDR suggests an explanation of the apparently high excess relative risk observed, relative to the A-bomb data Sont and others In addition to the TSCE model, the Armitage-Doll model of carcinogenesis has evolved into several other analytic methods, including the general mutagen model Pierce The basic assumption of this model is that a malignant cell results from the accumulation of mutations, with k mutations required for malignancy. Although this model applies to both recessive and dominant mutations, it does not explicitly allow for selective proliferation of cells having only some of the required mutations. The general mutagen model has been applied successfully to A-bomb survivor data Pierce and Mendelsohn ; Pierce and Preston and to underground miners exposed to radon Lubin and others The parameters created by modern biologically based risk models have direct biological interpretation, provide insight into cancer mechanisms, and generate substantive questions about the pathways by which exposure to ionizing radiation can increase cancer risk. These models also provide a way of describing temporal patterns of exposure and risk. Although biologically based risk models have many strengths, some general limitations are associated with their use. Such models can only approximate biological reality and require an understanding of the complex mechanisms of radiation carcinogenesis for interpretation. In addition, it is difficult to distinguish among alternative models that yield similar dose-response curves without direct information on the fundamental biological processes represented by the model, which are often unknown. Biologically based risk models are generally more complex than empirical models and may require richer databases to develop properly. Despite these limitations, biologically based models have found many applications for important epidemiologic data sets, and the successes achieved to date afford support for the continual development of such models for future analyses that will directly inform the association between radiation exposure and human cancer risk. Biologically based models have not been employed as the primary method of analysis in this report for several reasons. The mechanisms of radiation carcinogenesis are not fully understood, which makes the development of a fully biologically based model difficult. The data required for a biologically based model, such as rates of cell proliferation and mutation, are also generally not available. The availability of empirical risk models that provide a good description of the available data on radiation and cancer permits the preparation of useful risk projection.

Chapter 3 : COMPUTATIONAL FINANCE & RISK MANAGEMENT

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The question of pricing and hedging a given contingent claim has a unique solution in a complete market framework. When some incompleteness is introduced, the problem becomes however more difficult. Several approaches have been adopted in the literature to provide a satisfactory answer to this probl Several approaches have been adopted in the literature to provide a satisfactory answer to this problem, for a particular choice criterion. Among them, Hodges and Neuberger [72] proposed in a method based on utility maximization. The price of the contingent claim is then obtained as the smallest resp. Since then, many authors have used this approach, the exponential utility function being most often used see for instance, El Karoui and Rouge [51], Becherer [11], Delbaen et al. In this chapter, we also adopt this exponential utility point of view to start with in order to nd the optimal hedge and price of a contingent claim based on a non-tradable risk. But soon, we notice that the right framework to work with is not that of the exponential utility itself but that of the certainty equivalent which is a convex functional satisfying some nice properties among which that of cash translation invariance. One of the fundamental characteristics of an insurance policy design problem is the sign constraint imposed on the risk, that should We develop a methodology to optimally design a financial issue to hedge non-tradable risk on financial markets. The modeling involves a minimization of the risk borne by issuer given the constraint imposed by a buyer who enters the transaction if and only if her risk level remains below a given thres The modeling involves a minimization of the risk borne by issuer given the constraint imposed by a buyer who enters the transaction if and only if her risk level remains below a given threshold. Both agents have also the opportunity to invest all their residual wealth on financial markets but they do not have the same access to financial investments. The problem may be reduced to a unique inf-convolution problem involving some transformation of the initial risk measures. Santomero - Risk Finance , " Besides these more general issues, specific questions were recently discussed in papers like Gerber and Shiu The new Basel Capital Accord has opened up a discussion concerning the measurement of operational risk for banks. In our paper we do not take a stand on the issue of whether or not a quantitatively measured risk capital charge for operational risk is desirable; however, given that such measurement In our paper we do not take a stand on the issue of whether or not a quantitatively measured risk capital charge for operational risk is desirable; however, given that such measurement will come about, we review some of the tools which may be useful towards the statistical analysis of operational loss data. We also discuss the relevance of these tools for foreign reserves risk management of central banks. General Aspects and Applications special issue , Statistics and Decisions , " Risk measures have been studied for several decades in the actuarial literature, where they appeared under the guise of premium calculation principles. Risk measures and properties that risk measures should satisfy have recently received considerable attention in the financial mathematics literature Risk measures and properties that risk measures should satisfy have recently received considerable attention in the financial mathematics literature. Mathematically, a risk measure is a mapping from a class of random variables defined on some measurable space to the extended real line. Economically, a risk measure should capture the preferences of the decision-maker. Building on the actuarial equivalent utility pricing principle, broad classes of risk measures are generated, of which most classical risk measures appear to be particular cases. This approach shows that most risk measures studied recently in the financial literature disregard the utility concept i. Some alternatives proposed in the literature are discussed, based on exponential utilities. Key words and phrases: Utility theories, risk measures, coherence, exponential utility, comonotonicity. This paper develops a unifying framework for allocating the aggregate capital of a financial firm to its business units. This enables the association of alternative allocation rules to specific decision criteria and thus provides the risk manager with flexibility to meet specific target objectives. The underlying general framework reproduces many capital allocation methods that have appeared in the literature and allows for several possible extensions. An application to an insurance market with policyholder protection is additionally provided as an illustration. Mathematics and Economics , "

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Chapter 4 : Download Mathematical Methods In Risk Theory

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Chapter 5 : Operations research - Wikipedia

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In the decades after the two world wars, the techniques were more widely applied to problems in business, industry and society. Since that time, operational research has expanded into a field widely used in industries ranging from petrochemicals to airlines, finance, logistics, and government, moving to a focus on the development of mathematical models that can be used to analyse and optimize complex systems, and has become an area of active academic and industrial research. This revealed unappreciated limitations of the CH network and allowed remedial action to be taken. In the World War II era, operational research was defined as "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control". About operational research scientists worked for the British Army. Early in the war while working for the Royal Aircraft Establishment RAE he set up a team known as the "Circus" which helped to reduce the number of anti-aircraft artillery rounds needed to shoot down an enemy aircraft from an average of over 20, at the start of the Battle of Britain to 4, in 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. Their conclusion was that a few large convoys are more defensible than many small ones. As most of them were from Bomber Command they were painted black for night-time operations. At the suggestion of CC-ORS a test was run to see if that was the best colour to camouflage the aircraft for daytime operations in the grey North Atlantic skies. Other work by the CC-ORS indicated that on average if the trigger depth of aerial-delivered depth charges DCs were changed from feet to 25 feet, the kill ratios would go up. Blackett observed "there can be few cases where such a great operational gain had been obtained by such a small and simple change of tactics". All damage inflicted by German air defences was noted and the recommendation was given that armour be added in the most heavily damaged areas. This recommendation was not adopted because the fact that the aircraft returned with these areas damaged indicated these areas were not vital, and adding armour to non-vital areas where damage is acceptable negatively affects aircraft performance. Their suggestion to remove some of the crew so that an aircraft loss would result in fewer personnel losses, was also rejected by RAF command. They reasoned that the survey was biased, since it only included aircraft that returned to Britain. The untouched areas of returning aircraft were probably vital areas, which, if hit, would result in the loss of the aircraft. When Germany organised its air defences into the Kammhuber Line , it was realised by the British 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 minimise RAF losses. By comparing the number of flying hours put in by Allied aircraft to the number of U-boat sightings in a given area, it was possible to redistribute aircraft to more productive patrol areas. Comparison of exchange rates established "effectiveness ratios" useful in planning. The ratio of 60 mines laid per ship sunk was common to several campaigns: They analysed, among other topics, the effectiveness of artillery, aerial bombing and anti-tank shooting. You can help by adding to it. March With expanded techniques and growing awareness of the field at the close of the war, operational research was no longer limited to only operational, but was extended to encompass equipment procurement, training, logistics and infrastructure. Operations Research also grew in many areas other than the military once scientists learned to apply its principles to the civilian sector. With the development of the simplex algorithm for linear programming in [26] and the development of computers over the next three decades, Operations Research can now "solve problems with hundreds of thousands of variables and constraints. Moreover, the large volumes of data required for such problems can be stored and manipulated very efficiently.

Chapter 6 : Monte Carlo method - Wikipedia

Actuarial mathematics originated toward the end of the 17th century, when E. Halley's famous mortality table permitted the mathematical treatment and calculation of annuity values for the first time.

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