Decision Analytics Journal 8 (2023) 100284

Contents lists available at ScienceDirect

Decision Analytics Journal

journal homepage: www.elsevier.com/locate/dajour

The origins of forward-looking decision making: Cybernetics, operational research, and the foundations of forecasting

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ARTICLE INFO

Keywords:
Decision making
Cybernetics
Operational research
Business analytics
Forecasting
Artificial intelligence
Machine learning

ABSTRACT

The massive explosion of literature, theory, and methods on all aspects of decision-analytics, machine learning and artificial intelligence, over the past 20 or so years has brought a rapid specialization in each of the substrata of the fields that are using them. The sharp focus on empirical usage of these methods across applications, and the consequent trivialization from data only-driven improvements and multiple method comparisons, have diverted attention from foundational and epistemological concerns and questions, leading to pure empiricism — due to, but not exclusively, increases and availability of computing power. Tapping into the, equally massive, history and literature of the earliest developments from pioneers in the fields of cybernetics, operations research, and forecasting, we re-establish the links to the past on the origins of business and predictive analytics. Using interdisciplinary-sourced material we bring attention to the significance of these early developments and to the need for a return to these early sources in re-establishing our connection with the fundamental principles and questions that define meaningful, forward-looking, decision-making.

1. Introduction

In the current era of machine learning (ML) and its now pretentious, prodigy artificial intelligence (AI), we are often faced with some sort of awe in terms of the rapidity of developments and the potential that these developments hold for the future. Still, the ability to think and to work on intuition and insight, to mend together empirical observations and to offer induction via the measurement and management of uncertainty, are knotted to our human nature. However, these abilities are not new and neither do the works of the current day tend to answer much different questions that those that we have been asking in days past.

(Re)establishing our links to the past might appear irrelevant, unimportant, impractical or a waste of time, but what we will show in this paper is the exact opposite: what we today call business and predictive analytics, fields that heavily depend (with their various definitions) on big data, cloud computing, ML and AI, are nothing more than technologically pumped-up versions of questions, ideas, approaches, materials and methods that can be found in the (near or distant) past. Not only that, but we shall also attempt to briefly illustrate that there is a wealth of forgotten and unexplored *innovative* ideas that either are just repeated today (with modern methods in applications) but also that we have to acknowledge all the works of the past, not just as relevant but as *pioneering* to what is now being achieved in business and predictive analytics.

Here is a simple example of why we possibly want to get in touch with the past. The term "financial engineering", referring to the methodological union of advanced statistics, quantitative finance and investment technology and a field that hails from the early 1990's might appear as a new term, a modern term — and in part it is, at least for its current content. But the name "financial engineering" is not new. There is a 1920s book with this exact same title and with some, now possibly obvious but still good, advice:

> *A (financial) engineer must know the properties of all material with which he comes in contact, and he must understand thoroughly the action and limitations of all (methods and practices) and instruments which he is called upon to use or test, as well as the proper application of the same. More than this, he should know how to translate (financial) engineering factors into dollars and cents. This is Financial Engineering.*
>
> [Goldman [1]]

Is this passage of fundamental importance to today's world? Should it not hold true and be widely known and implemented, while at the same time a reference is made to the original source? There is a wealth of examples that can illustrate a similar line of arguments, especially in the field of finance (which heavily uses predictive analytics) and business administration (which heavily uses business analytics). What is it that we ask from an ML (or AI, depending on your take) assistant

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https://doi.org/10.1016/j.dajour.2023.100284
Received 18 June 2023; Received in revised form 2 July 2023; Accepted 5 July 2023
Available online 8 July 2023

like ChatGPT: information gathering and processing for a question and, if possible, a prediction for the future based on statistical observations and correlations — but the final decision on how to use this information rests with us. Even if there is a suggestion from the machine we still have to abide by, exercise our judgment and manage the unpredictable as in:

> *The successful speculator will always look ahead and watch the signs of the times. Scanning the distant horizon in the commercial and financial world, he will foresee "coming events which cast their shadows before" and be the first the field to profit by them. In a general way the result of speculation will depend upon the exercise of good judgment, but in some instances will be governed by circumstances over which we have no control.*
>
> [J. Hickling and Co. [2]]

This is from an 1874 book about the art of speculation (we now call it investment management) which uses business analytics of those days. Does it not define the dear need of human monitoring of events, of grasping the novelty of the times, of the necessity of practicing good judgment and to accept some, small or large, degree of uncertainty in outcomes? The technical works on methods for speculation in the stock and commodity markets are documented in many books for the 50-year period of around 1875 to 1925, and most of them definitively define and operate with concepts that today are taught as "revelations" of the post-Markovitz era. Similarly, the ideas of economic crises and their management, crises which are vastly disrupting of the globalized economy, are neither new nor the ideas connected with them are new — and one would venture to say that their solutions are therefore not new. Even in terms of business ethics, a field of epistemology on its own, ideas are not new. Take for example the concept of financial literacy, much *en vogue* after the 2008 global financial crisis. Is the need for financial literacy new? Here is an excerpt from a 1902 paper in the *International Journal of Ethics*:

> *Only those who have expert knowledge of market conditions can, in the long run, make money on the exchanges. These are the prominent professional speculators, the "big operators", as they are often called. The great majority of all the others who speculate, namely, the outside public, either know nothing of the intricacies of the market, or rely on "inside information" that is worse than useless because misleading. Out of the losses of this class comes the greater part of the gains of the big operators.*
>
> [Ryan [3]]

In the fields of business administration and human resource management, also users of business and predictive analytics, some notions that appear strictly modern are, unsurprisingly, not. Take for example the idea of "stakeholder capitalism" espoused by the World Economic Forum: "*That is the core of stakeholder capitalism: it is a form of capitalism in which companies do not only optimize short-term profits for shareholders, but seek long term value creation, by taking into account the needs of all their stakeholders, and society at large.*"[1] But this idea, attributed to the mid-1950's and onwards to its final form in the mid-1970's, is again not new and we can find a definition similar, if not superior, in spirit in this 1922 quote:

> *What is industry? It is more than a division of labor, or a use of capital, or a production of goods, or a distribution of profits. It is an art of life: its inevitable product some sort of character. It is a daily relation of human beings, who are richly endowed with sensibilities, and who possess a pathetic capacity for indifference, shortsightedness, and brutality, and for enthusiasm, loyalty, and sacrifice. An industrial establishment should be a company of brothers banded together for mutual aid and the public good and sustaining each other with sympathy in a process of self-expression. The most significant thing about industry is that it is a process of dealing with human nature. For people of talent, it is chiefly an opportunity for leadership.*
>
> [Marshall [4]]

This is from Leon Marshall's book Business Administration; Marshall was the 4th Dean of the Booth School of Business at the University of Chicago. See how his definition is both modern and conformable to what we discuss today. "Art of life", "daily relation of human beings", "mutual aid" and "public good", "human nature" and even the notion of sustainability appears. Marshall's excerpt *is* about stakeholders, all of us. Marshall's volume is much worth reading, along with his previous book *"Readings in Industrial Society"* (1918) which is another foundational work in the crossroads of economics, management, and cybernetics [5].

These examples are just a glimpse of the books and papers that have been published in the late 19th and early 20th centuries about the subject matters that are, directly or indirectly, related to this work. But one can find ample motivation for the use, and necessity, of understanding the historical foundations of fields like forecasting and technology, in more recent years as well. In the late 1970's here are two excerpts that point towards this fundamental notion of historical understanding. Here is Harold A. Linstone, senior editor of *Technological Forecasting and Social Change* in a 1980 editorial:

> *Yet history provides the only laboratory or models we have for studying complex interactions between technology, the individual, and society… The suspicion grows that there is a rich lode of insights in history that is going unmined…*
>
> [Linstone [6]]

A year later, in 1981, George E. Brown Jr., Chairman of the House of Representatives Subcommittee on Science, Research and Technology, said on history and policy analysis, published as a short note again in *Technological Forecasting and Social Change*:

> *…An important contribution of history to policy analysis is simply that of broadening our understanding. History can inform our comprehension of why things are the way they are, and thus help us make more intelligent judgments.*
>
> [Brown [7]]

For the remainder of the paper, we will focus more on the foundations of three methodological pillars of the evolution of business and predictive analytics: cybernetics, operational research (OR), and forecasting. All three of these pillars have been and are still used extensively and expansively in solving real world problems, supported by technological innovation and, without a doubt, have shaped the design of public policy and technological cooperation (and competition) at the international level. In Section 2 we present the origins and early history of cybernetics and OR and their immediate and close connection; in Section 3 we illustrate the early development of the concepts and methods for machine learning and artificial intelligence, while in Section 4 we discuss the origins of the concept and the meaning of modern business and predictive analytics. In Section 5 we offer an extended historical review of ideas, questions, methods and applications from the early foundations and applications of forecasting, while in Section 6 we discuss the importance for a return to fundamentals in predictive analytics. Section 7 offers some concluding remarks.

2. A precursor to AI: the origins of cybernetics & operational research

The period immediately following the end of the 2nd World War was loaded with new methods and applications, many of which had their origins in the war effort. Forecasting, Operational Research and Cybernetics were all gestated in the pre-war laboratories that were converted for military operations, and then re-converted for civilian use. The 1942 report of the father of modern cybernetics, Norbert Wiener, was a major technical work on the field of time series analysis and forecasting, being published in his 1949 book on stationary time series [8] (see also Section 5). The wartime effort, Wiener's own scientific

[1] See What is stakeholder capitalism? Its History and Relevance | World Economic Forum (weforum.org)

explorations and the advancements in "creative technology"[2], were all conducive to the culmination of his other major work *"Cybernetics: Control and Communication in Animal and The Machine"* — the first foundational exploration of what came to be called artificial intelligence [12]. The early impact of cybernetics was considerable, as we shall see.[3]

At the same time the field of operational research would be "released" for peacetime applications and would follow an intertwined path with that of cybernetics. The first reference to the term "operational research" (OR) can be found in the 1942 memorandum of W. B. Leach and W. E. Davidson "Operational Research in England" followed by a number of other references and mid to early post-war publications on the definition and usage of the term OR [13],[4]. Charles Kittel in 1947 published in *Science* a summary article on the usages of OR, while William J. Horvath claims in a 1948 piece for the *American Statistician* that OR is a scientific basis for executive decision making; also, in 1948 and again in the *American Statistician*, R. L. Anderson writes about the peacetime implications of OR [16–18]. In the paper of Kittel, the definition of OR is given as *"a scientific method for providing executive departments with a quantitative basis for decisions"* — talk about the idea of business analytics then, back in 1947. In a 1950 issue of the *Operational Research Quarterly*, P. M. S. Blackett also gave a short summary paper for the business usage and potential of OR methods developed during the war and rapidly expanding at that time. Here is what Blackett had to say about the qualifications of OR workers:

> *As has been said, operational research is scientific, and training in some scientific disciplines may be regarded as essential, although it need not necessarily be in the exact sciences. The most important qualification is the ability to take a broad view of a problem, so that important factors will not be missed. Some knowledge of statistical methods will be required, at least within an operational research group, even if not in every worker in the group. Specialist knowledge (technical, industrial, economic, or social) appropriate to the field of application is desirable but is usually acquired on the job. A high degree of general intelligence and enthusiasm for the work are important.*
>
> [Blackett [19]]

Note the importance placed on a well-rounded approach to OR and compare this to the overspecialization of data science and data scientists of today. In 1951 we find an article by J. Knox, published in *Operational Research Quarterly*, about applications of OR in the building industry [20]. In 1953 in the *Harvard Business Review*, Cyril C. Hermann, and John F. Magee write about the use of OR in Management, while also in the same year Robert H. Roy pointed to the usefulness of OR in industrial engineering, in a *Scientific Monthly* publication [21,22]. Also, in 1953 we find a paper by Gerard Hindrichs about the philosophy of OR, published in *Philosophy of Science* [23].

After the publication of the volume on Cybernetics by Wiener, Stafford Beer produced a number of works attempting to link (not always successfully by some of the reviews of his work) OR to Cybernetics and Management, pushing through the idea of business analytics even. Beer took his cue from the much broader and visionary work of Wiener and tried to offer a multitude of applications of cybernetics and OR in management. In 1954 Beer writes the opening article for *Operational Research Quarterly* titled "Operational Research and Accounting", and also in 1954 he writes in *Business* a short article about how operational research aids production control [24,25]. In 1956 he presented in the *International Congress of Cybernetics* a paper titled "Process Control and Automation", while in 1959 he writes in *Operational Research Quarterly* a paper titled "What has Cybernetics to do with Operational Research" and he also published his book *"Cybernetics and Management"* [26–28]. In 1955 John A. Howard published in the *Journal of Marketing* about the use of OR in market research, while in 1956 Russell Ackoff published his paper in *Operations Research* on the development of OR as a science [29,30]. Finally, in 1958 Herbert Simon and Allen Newell published in *Operations Research* a paper suggesting heuristic programming as the next advances in operational research — which brings us to the next topic that involves programming: machine learning and artificial intelligence [31].

3. The beginnings of machine learning & artificial intelligence

Possibly the very early reference to the ideas used in ML, the neural networks of the human brain, can be found in W. S. McCulloch and W. Pitts, in their 1943 paper titled "A Logical Calculus of the Ideas Immanent in Nervous Activity", published in the *Bulletin of Mathematical Biophysics* [32]. In a 1964 paper about computers and perception, published in the *Proceedings of the American Philosophical Society*, Herman H. Goldstine thus writes for the results of McCullogh and Pitts:

> *McCulloch and Pitts succeeded in showing that any statement or series of statements, e.g., any conceivable phase of human behavior such as the recognition of the triangularity of a geometrical figure, which can be expressed completely and unambiguously in a finite number of words can be realized by such a formal neural network. Moreover, the converse is also true: Given a neural network it is always possible to give a complete and unambiguous description of its behavior in a finite number of words.*
>
> [Goldstine [33]]

The results of McCullogh and Pitts were used by John Von Neumann in constructing in 1945 the logical details for the design of the second high-speed computer, the EDVAC, and were later incorporated in the pioneering work of Frank Rosenblatt who introduced in 1958 the first neural network for ML, the single layer perceptron [34].[5]

But 1958 was more than a decade away from the late 1940's, so here is another piece of early ML. In 1948 Guy Orcutt presents a "new regression analyzer" in a *Journal of the Royal Statistical Society* paper filled with equations, flow diagrams, electrical switches, and the prototype itself in several photos [35]. This was "creative technology" at its best (see footnote 3) at its best. This paper, clearly another early version of ML, data science and technology fused together, is a prime example of the origins of ML as we now know it.[6,7]

[2] See Mervin J. Kelly "The Bell Telephone Laboratories — An Example of An Institute of Creative Technology", *Proceedings of the Royal Society of London*, 1950 [9]. For the same concept of "creative technology" see also Earl P. Stevenson "Creative Technology", *The Scientific Monthly*, 1953 [10]. A re-introduction to the idea of "creative enterprise" can be found in the paper by Groen and Welsh [11], published in *Technological Forecasting and Social Change*.

[3] The term cybernetics comes from the ancient Greek word *kybernetikos* (good at steering), referring to the art of the helmsman. Cybernetics is interdisciplinary in nature and can be considered as the foundation of modern decision-making.

[4] See also Mark A. Gallagher and Donald L. Allen "75 Years (1942–2017) of Operational Research in the United States Air Force", *Military Operational Research* 2017, and Leroy A. Brothers "Operational Analysis in the United States Air Force", *Journal of the Operational Research Society of America*, 1954 [14,15].

[5] It is interesting to note that the title of that paper included the words "information storage" and "organization in the brain". Rosenblatt's paper was published in the *Psychological Review*.

[6] His work on the regression analyzer was based in his 1944 doctoral dissertation. Guy Orcutt has produced a significant amount of early work in the field of econometrics and time series analysis with particular emphasis on the uses of technology for improved computations and understanding. In 1949 Orcutt and Donald Cochrane published in the *Journal of the American Statistical Association* their classic paper on autoregressive estimation of regression errors and its implications on modeling and prediction [36]. In 1952 Orcutt published an early paper concerned with causality in the *Review of Economics and Statistics* [37].

[7] Guy Orcutt was also a pioneer of computer simulations in economics and econometrics, see for example his 1960 paper in the *American Economic Review* The 1960 bibliographic review of Martin Shubik in the *Journal of the American Statistical Association* has an extensive list of references on the use of simulation, gaming, AI, and business decision making up to that date [38,39].

The concept of ML as evolved along with the available technology for performing quantitative and statistical computations and has now drifted towards the application of algorithms into computing platforms — the focus being more on developing the algorithmic structures than to interface them with the hardware. But what was the early use of the term "machine learning"? The references we found are mostly post 1950s but are very interesting. In a 1955 paper in the *Library Quarterly*, Lester Asheim writes about the future of the book and extensively quotes Wiener's work on the impact of machines in all aspects of human life. Intelligent machines that can "learn":

> *Already designers and users of these machines speak of machine "memory", machine "judgment", and machine "learning" and describe the mechanisms as perceptive, responsive, purposive, and capable of making decisions. Since these machines carry out calculations hitherto performed only by minds, it is probably only natural that their functions should be described in mental terms, although the scientists usually try to point out that it is not the machine itself which is mechanistically analogous to the brain but rather the operation of the machine plus the instructions fed into it. But when respectable scientists tell us: "No one can say with rational certainty that the world championship in chess will never be held by a machine. No one can say with rational certainty that no machine will ever compose a sonnet fit to be included in a good anthology", the layman cannot be blamed if he begins to fear that the machine will one day take over with a will of its own.*
>
> [Asheim [40]]

Prophetic, right? We now have ML that does beat humans in chess championships and have machine learning that composes music and paints works of art.

In a 1956 paper, published in the *Arithmetic Teacher*, Howard F. Fehr, George McMeen and Max Sobel, use the term "machine learning" to illustrate the usage of hand-held calculators in classes [41].[8] In a 1957 discussion of another paper, published in *Philosophy*, A. D. Ritchie and W. Mays make an apt remark for the idea of ML: *"In short the "learning" of the machine is a partial and clumsy imitation of something far more complex, done by different means and done better. The machine is a toy; its performance does not show that it thinks, but that its inventor thinks too little"* [42]. Although it sounds polemical, this remark was in tune with the times and the discussion going on about machine learning and "thinking machines". But it is also very relevant today, for we do know that despite the complexity of modern ML models they are still imitations of something more complex (the human brain and human mind) — but they do perform better than us quite frequently now. In another 1957 paper about data processing, automation, and calculations, by Charles Wrigley and published in the *Review of Educational Research*, we find a very detailed literature review of the machines used for learning and for ML — see in particular the referenced 1952 paper by Anthony Oettigner, published in the *Philosophical Magazine*, about programming computers to learn [43,44].

Many early efforts in machine learning involved the work done at IBM. For example, two sequential papers on a "learning machine" were published in the *IBM Journal of Research and Development in* 1958, one by R. M. Friedberg and its follow-up by R.M. Friedberg, B. Dunham, and J. H. North [45,46]. Also in 1958, and in the same journal, Allen Newell, J. C. Shaw and Herbert Simon addressed ML and the problem of complexity, while in 1959 and in the same journal, A. L. Samuel published certain studies in ML using the game of checkers [47–49]. Samuel also published, in the *Annals of the American Academy of Political and Social Science*, a 1962 paper on AI as the frontier of automation [50].

These ideas on ML were developed along with ideas focusing on AI. While today ML is a foundation of AI, the lines between the two were blurred in those pioneering efforts. Focusing on the use of the term "artificial intelligence" we can trace it back to very early work by E. G. Boring in 1946, published in the *American Journal of Psychology* [51]. The work of G. P. Dineen, of B. G. Farley and W. A. Clark, and of O. G. Selfridge, are three very early papers on programming pattern recognition, all published in 1955 in the *Proceedings of the Western Joint Computer Conference, IRE* [52–54]. Marvin Minsky has made significant contributions to the topic, with his 1956 and 1959 *Group Reports* at MIT and his 1961 *Proceedings of the IRE* paper [55–57]. Minsky considered the general problem of AI and worked in models of ML. Allen Newell, J. C. Shaw and Herbert Simon considered problem solving in humans and computers, simulation of human thought and the process of creating thinking in a series of *RAND Corporation* reports, from 1956 to 1959 [47,48,58,59]. In 1959 also A. M. Pierce published a bibliography on the then available literature on AI, at the Air Force Cambridge Research Center [60]. In 1960 Mary E. Murphy writes a paper, published by the *Journal of the Academy of Management*, about computer developments in the, then, Soviet Union, describing the early efforts of the Soviets in the same fields of machine learning and artificial intelligence [61].[9]

4. The (re)emergence of modern-day business & predictive analytics

Analytics (or *business analytics*) is considered as the successor of OR.[10] There has been great buzz throughout the business world in recent years about the importance of incorporating analytics into managerial decision making. The primary impetus for this buzz is associated with Thomas Davenport, a renowned thought-leader who has helped hundreds of companies worldwide to revitalize their business practices [67]. So, what is analytics? The short (but oversimplified) answer is that it is basically OR by another name [68]. However, there are differences in their relative emphases. Analytics fully recognizes that we have entered into the era of *big data*, where massive amounts of data now are available to many businesses and organizations to support managerial decision making.

As indicated by the following definition, a primary focus of analytics is on how to make the most effective use of all these data: *Analytics is the scientific process of transforming data into insight for making better decisions* (definition developed by the Institute for Operational Research & the Management Sciences, INFORMS). It has been stressed that business analytics are tightly connected with big data, i.e., any set of data that is too large or too complex to be handled by standard data-processing techniques and typical desktop software [69]. IBM describes the phenomenon of big data through the four Vs: *volume* (data at rest), *velocity* (data in motion), *variety* (data in many forms), and *veracity* (data in doubt).

The application of analytics can be divided into three overlapping categories. The first, *descriptive (or reporting) analytics*, encompasses innovative techniques to locate the relevant data and identify the interesting patterns to better describe and understand what has happened in the past and what is going on now. Examples are data queries, descriptive statistics, data visualization, dashboards, data mining techniques, and fundamental if–then spreadsheets. A second (and more advanced) category is *predictive analytics*, which involves using the data to predict

[8] Here is an interesting teaching quote from that paper, related to the importance and usefulness of machine learning: *"Always make the paper and pencil work a little harder than previous machine computation. This shows the value of the machine and also encourages paper and pencil learning before machine learning".* One cannot possibly appreciate the value of machine learning if one does not understand the first principles of its related field.

[9] There is a separate strand of the literature on Soviet cybernetics as well, see for example the bibliography by Comey [62] on Soviet publications on cybernetics in *Studies of Soviet Thought*, and also [63] in the *Slavic Review* and [64] in *Science Studies*. For a short history of forecasting in the Soviet Union from 1927 up to the early 1990's, see the paper by Bestuzhev-Lada [65] in *Technological Forecasting and Social Change*.

[10] See the 1958 paper of Martin Shubik, published in the *Administrative Science Quarterly*, on an early reference of studies and theories of decision making, where he reviews the then available methods and approaches for *decision making analytics* [66], and also see footnote 8.

what will happen in the future or ascertain the impact of one variable on another. Regression analysis, time series, and statistical forecasting are prominently used here. The final (and most advanced) category is *prescriptive analytics*, which involves using the data to prescribe what should be done in the future. More specifically, prescriptive analytics indicates a course of action to take. Thus, the output of a prescriptive model is a decision. The powerful optimization techniques of OR generally are utilized here, along with simulation, expert systems, decision modeling etc.

According to [68], OR analysts often deal with all three of these categories, but not very much with the first one, somewhat more with the second one, and heavily with the last one. Thus, OR can be thought of as focusing mainly on *advanced analytics*, predictive and prescriptive activities, whereas analytics professionals might get more involved than OR analysts with the entire business process, including what is associated with the first category (*identifying a need*) and what follows the last category (*implementation*). Looking to the future, the two approaches should tend to merge over time. Because the term analytics is more meaningful to most people than the term OR, it is concluded that *analytics* may eventually replace OR, as the common name for this integrated discipline.

Although analytics was initially introduced as a key tool mainly for business organizations, it also can be a powerful tool in other contexts. As one example, analytics, together with OR, played a key role in the 2012 presidential campaign in the US [68]. The Obama campaign management hired a multi-disciplinary team of statisticians, predictive modelers, data-mining experts, mathematicians, software programmers, and OR analysts. It eventually built an entire analytics department five times as large as that of its 2008 campaign. With all this analytics input, the Obama team launched a full-scale and all-front campaign, leveraging massive amounts of data from various sources to directly micro-target potential voters and donors with tailored messages.

5. The foundations of prognosis: the art & science of forecasting

The art of "prognosis" (foreknowledge) is as old as humanity itself. Attempting to gain foreknowledge about what the future holds is pervasive in history and society. From the earliest attempts of divination and interpretation of natural signs and the organization of specialized oracles, e.g., the Delphic Oracle, to the foundations of probability to modern machine learning methods, all these are attempts to foreknowledge, attempts to forecasting and prediction.[11] There is thus a rich history of the art and science of forecasting, and, in this section, we will only briefly outline some of the earliest attempts on inductive forecasting and decision making, going up to the period of the 2nd world war.[12]

Plutarch in one of his works (*"The E at Delphi"*) defines the process of forecasting as follows:

The god, moreover, is prognostikos (a forecaster), and the art of prognosis (forecasting) concerns the future that is to result from things present and past. For there is nothing of which either the origin is without cause or the foreknowledge thereof without reason; but since all present events follow in close conjunction with past events, and all future events follow in close conjunction with present events, in accordance with a regular procedure which brings them to fulfillment from beginning to end, he who understands, in consonance with Nature, how to fathom the connections and interrelations of the causes one with another knows and can declare: what now is, and in future shall be, and has been of aforetime.

This is an accurate and surprisingly modern definition, accurate to even contemporary models and approaches to forecasting. For it defines the forecasting process clearly:

(a) via an information set: "*the future that is to result from things present and past, "since all present events follow in close conjunction with past events, and all future events follow in close conjunction with present events"*,
(b) via the use of some model: "*in accordance with a regular procedure", which uses the information set,*
(c) via the understanding that successful forecasting is linked with some notion of causality: "*For there is nothing of which either the origin is without cause or the foreknowledge thereof without reason", "how to fathom the connections and interrelations of the causes one with another".*

Is it not the case that even machine learning models of today attempt to do the same by their use of "big data" as their information set, their use of many different machine learning approaches as models and by their attempts to uncover why these models work by understanding causal relationships among variables?

Fast forwarding from the time of Plutarch to the mid and late 19th and, mostly, early to mid-20th century, we find a number of periodical and book publications that are devoted to the art and science of forecasting. One significant difference of these old publications was their intent and focus on using forecasts for actual decision making. The areas of focus on forecasting back then were three-fold: forecasting the weather, forecasting population trends, and forecasting the stock market and business and economic conditions — it should come at no surprise that we still forecast the same topics with equal fervor but various degrees of success.

An 1840 publication in the *Journal of the Royal Agricultural Society of England* presents a forecast evaluation of past weather forecasts [71]. Samual Benner, an Ohio farmer, begins publishing in 1876 a series of commodity forecasts in his books dubbed "*Benner's Prophecies*" for the very practical purposes of both speculation and using his predictions for running agricultural activities [72]. Benner has been publishing and (significantly) evaluating his forecasts for more than 30 years! In 1889 Simon N. Patten discusses forecasting implicitly in his paper about the stability of prices, published in the *Publications of the American Statistical Association* [73]. Although not directly related to forecasting (but related to data analysis), we must mention the work of August Meitzen (translated by Roland Falkner) on the history and methods of statistics that was published as a two-part supplement in 1891 in the *Annals of the American Academy of Political and Social Science* [74,75]. James Stevens writes in 1900 in the *American Mathematical Monthly* forecasting the census returns, and his analysis includes a mini robustness check on his results too [76]. G. C. Selden writes in a 1902 paper, published in the *Quarterly Journal of Economics*, about trade cycles and the effort to anticipate (i.e., to forecast) [77]. In 1910 Warren Persons publishes a paper in the *Publications of the American Statistical Association* on the correlation of economic statistics [78]. In 1911 we have a paper by Roger Babson in the *Annals of the American Academy of Political and Social Science* discusses factors that affect the path of commodity prices while a 1912 paper by the same author in the *Publications of the American Statistical Association* is about forecasting business conditions

[11] In a speech he gave in 1913 in the Royal Institution Herbert George Wells said that *"Until a scientific theory yields confident forecasts you know it is unsound and tentative; it is mere theorizing, as evanescent as art talk or the phantoms politicians talk about"* [70]. The quote can be found in H. G. Wells' short book *"The Discovery of the Future"*, published in the same year. It is critical to note that the importance of forecasting for decision making and scientific progress was strongly embedded in the period of time that we are examining in this section.

[12] Going after the 1940's will get us into a rich and diverse universe of contributions to forecasting that will take us beyond the scope and size for the current paper. Note that our review of these earliest attempts of forecasting methods and applications are focused on published works that dealt almost exclusively on forecasting and not the more general topics of probability, of time series analysis and early studies on the business cycle. It is also of interest to note that the earliest references of forecasting precede those of cybernetics and operational research by at least 25+ years.

with the study of statistics. Also, in 1912 we have another paper by T. E. Burton on the cause of high prices published in Science [79–81]. In 1912 Irving Fisher discusses a structural forecast based on the quantity theory of money and published in the *American Economic Review*, while in 1913 we another paper by James Brookmire, again in the *American Economic Review*, discussing methods of business forecasting [82,83]. In 1912 we also have the first publication of Seabury Colum Gilfillan, a pioneer of future studies, who has made contributions in that aspect of technological forecasting. That first paper was titled "Housekeeping in the future", published in the *Independent*.[13]

Nat Murray presents an analysis on the trend of agricultural prices in a 1921 publication in the *Journal of Farm Economics* and W. F. Callander and Joseph Becker publish in 1923, also in the *Journal of Farm Economics*, about forecasting crop production [86,87]. A number of other papers published in the same journal in 1924 are also about agricultural forecasting (Henry Taylor, Warren Waite, F. A. Pearson, G. F. Warren and Frederick Waugh). Raymond B. Prescott writes in 1922 about the law of growth and forecasting demand, published in the *Journal of the American Statistical Association* [88]. The trend of prices is discussed in a 1923 paper by Allyn A. Young, published in the *American Economic Review*, while E. C. Snow discusses trade forecasting and prices also in 1923 in a paper published by the *Journal of the Royal Statistical Society* [89,90]. We find again Roger Babson in 1924 with a paper on business forecasting and its relation to modern selling, published in the *Annals of the American Academy of Political and Social Science*, while Winthrop M. Daniels in a 1924 paper in the *Quarterly Journal of Economics* writes about a forecast of the future of the American railroads [91,92]. Charles F. Sarle writes in 1925 about the forecasting of the price of hogs, published in the *American Economic Review* and in the same year Bradford B. Smith writes about forecasting the acreage of cotton, published in the *Journal of the American Statistical Association* [93,94]. In 1927 we have a roundtable discussion in the *Journal of the American Statistical Association* about forecasting the volume of orders or sales. In the same year, 1927, Holbrook Working writes in the *Journal of Farm Economics* about forecasting the price of wheat [95]. In 1928 Edmund E. Day writes about the role of statistics in business forecasting, published by the *Journal of the American Statistical Association* and, in the same year, Charles P. White writes about industrial forecasting [96,97]. In 1929 E. M. Burns writes about statistics and economic forecasting in the same journal, while Seymour Andrew and Harold Flinn write in 1930 about the appraisal of economic forecasts, published again in the *Journal of the American Statistical Association* – the topic of forecasting evaluation is starting at that time to be treated quite seriously, but then again it was Samuel Benner that has introduced a rigorous forecasting evaluation of his "prophecies" 30-years before! [98,99]

In 1928 Oskar Morgenstern (of Von Neumann and Morgenstern, game-theory fame) publishes and important (and still unrecognized) book on economic forecasting "*Wirtschaftsprognose*" which contains a wealth of material on the theory and practice of forecasting that are highly relevant today (e.g., his very early understanding of structural change as a cause for forecast failure) [100]. The book is reviewed in 1929 by Arthur Marget in a paper in the *Journal of Political Economy* [101]. It should be noted that Morgenstern was very well aware of the limitations of economic forecasting, and he carefully structures his arguments in this book as well as in his subsequent 1937 book on the limits of economics [102]. It is, however, precisely because he warns us of the problems that might arise in economic forecasting (and the problem of forecast failure in general) that his book is a treasure trove of information.

[13] For an excellent review of the contributions of Gilfillan in the field of future studies see the 2020 paper by Matthieu Ballandonne, published in *Technological Forecasting and Social Change* [84]. Of particular note, and related to the foundational aspects of technological forecasting, is Gilfillan's 1952 paper "The Prediction of Technical Change", published in the *Review of Economics and Statistics* [85].

Continuing with our timeline, the book of Lincoln W. Hall "*An Approach to Definite Forecasting*" is published in 1929 by the University of Pennsylvania Press while Donald R. G. Cowan writes in 1930 on the commercial application of forecasting methods, published in the *Journal of Farm Economics* [103,104]. In the same year, 1930, Garfield Cox writes about the evaluation of economic forecasts, published in the *Journal of American Statistical Association* – and that paper (also a monograph from Cox) is discussed in a follow-through paper by Donald Tucker, Arthur Marget and John G. Thompson [105,106]. Willford I. King writes in 1931 about what groups of stocks will lead the next bull market, in the Journal of the American Statistical Association, while Donald B. Woodward writes in the same journal about forecasts of commodity prices in 1932 [107,108]. In the same year, 1932, Willford I. King writes again about forecasting methods that were successfully used since 1928, and in 1932 also R. G. Glenday writes in the *Journal of the Royal Statistical Society* about business forecasting in terms of the influence of money on trade development [109,110]. In 1933 we find Alfred Cowles (of the well-known Cowles Foundation) to ask the (still very relevant) question as to whether stock market forecasters are able to forecast, and the paper is published in *Econometrica* [111]. We find again Willford I. King in 1934 writing about technical methods of forecasting stock prices, published in the Journal of the American Statistical Association, while in the same year Erwin Graue writes about the evaluation of forecasts of the general price level from 1919 to 1931 [112,113]. The notion of long vs. short-time forecasting (discussed extensively in Oskar Morgnestern's book mentioned before) is taken up two papers by E. W. Pettee published in 1936 in the *Journal of the American Statistical Association*, where he evaluates long-term commodity forecasting from 1850 to 1930, and in the *Journal of Business*, where he evaluates short-term price forecasting from 1920 to 1929 [114,115].

Alfred Kaehler writes in 1939 about forecasting the business cycle, published in *Social Research*, while Merrill Flood writes in 1940 about recursive methods in business cycle analysis and on the importance of having a "training/testing" set of observations for proper measurement of the accuracy of forecasts, with his work being published in *Econometrica* [116,117]. Marion Clawson, Carl P. Heisig and Edgar B. Hurd write in 1941 about long-term forecasting of fruit and nut production in the *Journal of Farm Economics*, while in 1942 L. C. Wilcoxen discusses the market forecasting significance of market movements and published in the *Journal of the American Statistical Association* [118,119]. Also in 1942, J. E. Gates writes about forecasting the demand for electric energy that is published in the *Journal of Land & Public Utility Economics*, while Richard V. Gilbert and Victor Perlo write in Econometrica about the investment-factor method of forecasting business activity [120,121]. In 1944 Alfred Cowles publishes, also in *Econometrica*, his paper on stock market forecasting, as a follow-through to his earlier 1933 paper mentioned before [122].

During the 1920's, 1930's and the 1940's we can also find some of the most critical and advanced works on the foundations of stochastic processes that were subsequently used for developing advanced methods in forecasting. The pioneering work of Udny Yule on time series analysis laid the groundwork for further developments, with papers like his 1921 on the time correlation problem, published in 1921 in the *Journal of the Royal Statistical Society* or his paper on the (critical) understanding of non-sense correlations among time series, published in the same journal in 1926 [123,124]. The early papers of Joseph Leo Doob also form part of these foundations, as for example his 1934 paper on probability and statistics published in the *Transactions of the American Mathematical Society*, his paper on stochastic processes and statistics on the same year published in the *Proceedings of the National Academy of Sciences*, and his 1942 paper on Brownian motion and stochastic equations published in the Annals of Mathematics [125–127]. Harald Cramer (of the familiar Cramer–Rao lower bound) writes in 1940 in the *Annals of Mathematics* on the theory of stationary random processes, while Herman Wold published his book "A Study in Analysis of Stationary Time Series" also in 1938 — his 1948 paper, published in the *Annals of Mathematical Statistics*, on the prediction of stationary time series must also be here noted [128–130]. C. Whelden Jr. writes in 1926 on the trend-seasonal analysis in time series, published in the *Journal of the American Statistical Association*, while Simon Kuznets (of the curve with the same name) writes a 1928 paper on the analysis of time series, published in the same journal [131,132]. In 1937 Herbert Jones addressed the nature of regression functions in the correlation analysis of time series, published in *Econometrica*, while in 1940 Gerhard Tintner writes about the analysis of economic time series published in the *Journal of the American Statistical Association* [133,134]. M. G. Kendall pioneers the discussion, in 1941, about the impact of the elimination of trend on oscillation in time series, published in the *Journal of the Royal Statistical Society*, while in 1944 he writes about autoregressive time series, published in Biometrika [135,136]. The father of cybernetics, Norbert Wiener, writes during the 2nd world war, in 1942, the report on forecasting stationary time series (which later become the foundational 1949 book "*Extrapolation, Interpolation and Smoothing of Stationary Time Series"*) concretely introducing many of the tools and algorithms that were to dominate the field of time series analysis and forecasting for years to come.[14]

6. The return to fundamentals in forecasting & predictive analytics

The reader must have noticed that there are many earlier references in forecasting than are on cybernetics, OR or AI. This is only natural, for the desire to forecast was not necessarily constrained by lack of technological know-how. Events and data could be predicted via various ways, heuristically, by theory, hand calculations and so on. It was the advent of new technologies after the 2nd World War that brought the new topics of cybernetics and OR into the foreground; still though, they would try to answer similar questions in forward-looking decision making, expanding the field, models and applications used to tackle predictability.

But why bother with all these papers on the historical foundations of forecasting? Are they not just of, well, historical interest, if at all? We shall make the argument that the answer is a resounding no. Not only are these, and other related technical papers and books of that era, of practical significance for today, they do allow us to view modern developments from a proper, less exuberant, and more humble perspective. For although the methods and computational power of today is nothing short of amazing, compared to the past, the decision-making process, the structure of experimentation, the benchmarking of methods, models and ideas still follows the thought process of that past era. Furthermore, these early references collectively tell an important story: it was the desire to foreknowledge, be it in peace or in war, the desire to forecast and predict that was driving developments in many fronts that lead to attempts for their automation, the idea of predictive systems then the groundbreaking work of Wiener on cybernetics to end-up today with machine learning and AI.

The element of the, possibly, highest importance that can be garnered from the references and story of the previous section is this: fundamental questions of today are essentially the same as the fundamental questions back then, as is the thought process of arriving at the questions and their answers; only the methods might differ. This is abundantly clear from even the most cursory look inside the historical material: the questions being asked back them were about the exact same issues we ask today for our predictive analytics methods and tools. Here is what Oskar Morgenstern had to say on his 1937 book "*The Limits of Economics*" about the importance of setting up afront the right questions: "*One of the essential preliminaries to progress is to know exactly what the questions at issue are".* The presence of big data in our era should not be seen as a current novelty; it is novel because the technology allows for more storage and thus new methods had to be found to address the faster analysis of big data, but the questions remain the same: discovering relationships and obtaining accurate predictions. And lest the reader thinks that computing power was not available back then, one should look at the 1922 book of Irving Fisher *"The Making of Index Numbers"*, which was about the most comprehensive attempts for index construction: chapter XV is devoted to the topic of "speed of calculation" using "a computer" (human computer that is.) [138] A whole chapter is devoted to the methodological approach for computation even if that computation was done by hand. The completeness of this particular work is of significant note, as is the style and clarity of presentation of the book.

The second element of significance is the scope of application of forecasting, and we can see from the references that was everywhere: economic production and the state of the business cycle, general prices, commodity prices and production, electric demand, the stock market, population, sales and order volume, agriculture, railroad expansion, monetary economics, inflation, short-term forecasting, long-term forecasting, forecasting for planning, forecasting for investing, evaluation of forecasts, ability of forecasters. And we do stress that there are other early references on the need for forecasting scattered in the early literature of management studies, economics and risk and insurance.

The third element of significance is that they offer foundational perspective that can be used to formulate benchmarks for performance evaluation, be that in forecasting or elsewhere. For example, the papers of the previous section on forecast evaluation are critical because they offered a transparent evaluation of past real-time forecasts, and they were judged on their merits or none thereof. These days they were not afraid to forecast and fail and try again. Today we offer a lot of pseudo-evaluations of many methods in academic papers but we rarely, if ever, convene to judge publicly made, real-time forecasts on important variables and judge them accordingly. True, they might be proprietary models and forecasting competitions, but the real litmus test is only when forecasts are openly produced, recorded, kept, and regularly evaluated that they might make a difference in decision making.

The last, but not least, element of significance is this: simplicity comes before complexity. Reading these early references, we find that there is a rational progression in argument and method that rests on one (or a few) fundamental questions being addressed. In these papers and books, explanation, and scope of analysis (or storytelling) comes before technique and methods, standard methods are used exhaustively before advanced ones are offered, there is a rather complete understanding of the problems the methods might face (before implanting them) and winning a forecasting competition is not the end product — understanding how to solve a problem is. In a sense, the pioneers of the early 20th century were genuine problem solvers, at the same time data-scientists, business analysts, forecasters, consultants and (when in industry) actual decision makers. Their emphasis on the "why" things might work (or not) and not on the "how" to analyze the data or "learn to code" (which they would have done anyhow should programming code was available back then!)

As modern predictive analytics is tied, inexorably, with the machine that offers the vast computing power to the end user, we might want to keep in mind the ways and means of the past, suitably adjusted to the present of machine learning and AI:

> *"The thinker is prior to the machine. Machines or formulae can only help in our study; they cannot initiate or direct an investigation. Only the thinker can do that. We must admit, even insist, that certain techniques or formulae make it possible for the scientist to achieve things that would otherwise be impossible. These aids, however, are only of value when directed by the thinker".*
>
> [Kantor [139]]

[14] We have omitted for space considerations but not forgotten the significant impact of the work of the Russian and Soviet school of research in time series analysis and forecasting. An excellent review of the impact of this school can be found in the paper of Shiryaev [137] on the life and creative activities of the most representative worker of that school, Andrey Kolmogorov.

7. Conclusions

The primacy of human creativity and invention glows through the formative years of business and predictive analytics. The "creative technology" concept was formed during the 2nd World War years and then in the 1950s, a concept that was fused with both an excitement about technological evolution and its prospects and with a deep understanding of its implications and complications. The search for better methods and approaches for business management and improved predictability was being laid on top of strong foundations of the early years of work in forecasting, time series analysis, statistics, neuroscience, and electrical and mechanical engineering. As we have seen, most of the pioneers in the field had an excellent grasp, if not more, of all the connecting elements of their craft — they had too: it was then impossible to move on without having a "global" understanding of the theory and how the theory can be efficiently implemented.

On one hand, today's specialization is exciting for its opportunities to quickly create and implement a variety of *useful tools*. On the other hand, is an obstacle to global thinking, to the foundational thinking of these pioneers of the past, that leads beyond replication, improvement and possibly "revelation" to "emergence", invention, and the creation of *true innovation* – for replication and improvement of what is already known do not constitute innovation.[15] [141]

All concepts of decision-making are forward looking, it always has been and always will be this way.[16] In any field of human endeavor, the explanation–induction–prediction–innovation sequence forms the basis of any method of decision-making. Knowing and understanding the past, exploring the fundamental questions, with the dual perspective then and now, should again form the basis of decision analytics. On top of this foundation, we should then add all the novelty, excitement, and broader knowledge of the day to make sure that these questions are clearly and definitively asked (and possibly answered): what is the nature of the problem we are examining? Is the problem truly new? Have we carefully studied the literature and methods of the past? If so and the problem is indeed new we have "emergence" and innovation; but if not, then we at most can look for improvements and "revelation" of a pre-existing but yet unknown pattern or solution — in either case we must acknowledge which one of the two are we offering as the end-product. There is a serious responsibility that the pioneers of the past have laid upon their successors, to make sure that we examine problems that are truly new and worthwhile of time, effort, and resources — we have a responsibility to permeate the information "noise" of big data and to arrive at structural explanations and open, transparent, and meaningful predictions. Predictions that one can act upon, and that the future evaluation will show to be accurate and consistent with observations.[17]

Understanding the past informs the present and the future — and this is neither new to say, nor ours:

> *"It takes discipline, not merely to abandon work that must be rejected, but not to abandon that which still merits consideration. Thus, I take my stand in support of innovation... We cannot with impunity act as if the bulk of literature and thought that represents the achievements and the speculations of past ages were not there".*
>
> [*Norbert Wiener (1950)*]

[15] See [140] in *Daedalus* for an excellent discourse of "revelation" vs. "emergence" when discussing the paradox of prediction. Norbert Wiener's 1950s unpublished work on invention can be found in the 1993 book *"Invention: The Care and Feeding of Ideas"*

[16] On the primacy of prediction in science and technology, see also [142]: "*But predicting the shape of future technological development and possible scientific advance is not an idle, academic exercise, suitable solely as an essay topic or as a party game. It is of vital importance...*". This vital importance, in historical perspective, can also be seen in the 1988 book of Michael H. Gorn "*Harnessing the Genie*", which is about real-time, real-life innovations and applications in forecasting in the US Air Force between 1944 and 1988 [143].

[17] For a relatively recent epistemological account on the importance of prediction vs. explanation see [144] in Philosophy of Science: "explanation needs prediction if we are to fully understand its strengths."

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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