# Nominal science without data – the artificial Cold War content of Game Theory and Operations Research

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**Abstract**
Expanding upon literature on early digital computers, this paper shows the role mathematicians have undertaken in founding the academic fields of Game Theory and Operations Research, and details how they were supported by the mathematics departments of military agencies in branches of the US Armed Services. This paper claims that application is only decoration. Other than astronomy, physics and engineering, where experiments generate data analysed with the aid of models and appropriate software on computers, Game Theory and Operations Research are not data driven but method driven and remain a branch of applied mathematics. They use the method of "abstractification" in economy and society to derive their models but lack a layer of empirical research needed to generate data and to apply their methods in economics and society. Therefore, their models were only nominal mathematics without application.

## Introduction

Since 1945, the United States had experienced a unique innovation push with the computer, the nuclear weapon, new air combat weapons and the transistor within just a few years. These innovations were accompanied by Game Theory and Operations Research in the academic field. Widely–held is the view that computers supplemented the mathematical concepts of Game Theory and Operations Research and gave these fields a fresh impulse. Together, they established the view of the world as a space of numbers and introduced quantitative methods in economics, political science and in sociology. A series of conferences on these subjects settled this new view. They imparted Cold War science and technology policy with a unique flavour of progress, superiority and modernity.

Whereas the history of quantitative methods has been mainly written as a history of digital computers, the history of Game Theory and Operations Research has had only a small number of contributions. In the issue 83 of Real World Economics Review Bernard Guerrien and Lars Pålsson Syll published 2018 critical contributions to the current state of Game Theory: Syll criticised the rational choice theory and Guerrien doubts whether Game Theory could be applied to real world problems.[1] My approach here is a history of science approach that reveals the artificial content of Game Theory and Operations Research in the Cold War science context. In addition as a sociology of science approach, I characterize these theories as an expert movement of mathematicians. This paper deconstructs the current success stories and shows that Game Theory and Operations Research were not only related to the Cold War scenario in the nominal sense, but lacked substantiated applications in social,

[1] Florencia Garcia-Vicente, Daniel D. Garcia-Swartz, Martin Campbell-Kelly, "The History, Geography, and Economics of America's Early Computer Clusters." *Information and Culture*, issue 4, 2016, pp. 445-478. William Aspray*, John von Neumann and the Origins of Modern Computing,* Cambridge, Mass., *1990*. Thomas Haigh, Mark Priestley and Crispin Rope, *ENIAC in Action – Making and Remaking the Modern Computer*, Cambridge, Mass., 2016. Lars Pålsson Syll, "Why Game Theory never will be anything but a footnote in the history of social science." *Real-World Economics Review*, issue no. 83, 20 March 2018, pp. 45-64. Bernard Guerrien, "On the current state of Game Theory." *Real-World Economics Review*, issue no. 83, 20 March 2018, pp. 35-44. Roy Weintraub (ed.), *Toward a History of Game Theory*, London, 1992.

political and economic fields, and remained a branch of applied mathematics. To regard Game Theory and Operations Research within the context of digital computers opens up the view that these strands of science and technology came about through the same institutions, at the same time and using the same proponents and funding agencies which have John Von Neumann at the centre.[2] Mathematicians in the branches of the Armed Services strongly supported the development of analogue and digital computers and related research in Game Theory and Operations Research. The U.S. Army's Ballistic Research Laboratory at Aberdeen, Md., was led by mathematicians and funded the development of the ENIAC computer at the Moore School of the University of Pennsylvania in Philadelphia. The Navy maintained their Office of Naval Research in Washington D.C., which included a mathematics department and supported several R&D projects.[3] The Air Force employed the RAND Corporation with the department of mathematics and the National Bureau of Standards (located in Washington D.C.) as R&D laboratories and agencies for financing research and the development of digital computers. Established in 1948 in Santa Monica, California, RAND was the think tank of the Air Force and had great influence in shaping academic debates during the Cold War. But its research on future air warfare and strategic bombing systems did not meet the expectations of the Air Force. RAND's plan to attack the Soviet–Union using a fleet of bombers, in which most of the pilots would have been put at risk, was refused by the Air Force.[4] So RAND focussed very successfully on academic attitudes toward research on Game Theory. It organized conferences and edited books. Every leading economist and mathematician held a consulting contract with RAND – these were very well-paid.[5]

The history of Cold War discourse at RAND has already been the subject of critical accounts. Stephen Johnson and Philip Mirowski covered the rise of Game Theory and Operations Research at RAND and their impact on neoclassical economics.[6] Judy Klein explored the emergence of quantitative methods in the field of time series and of the theory of Dynamic Programming in the Cold War and contributed to the critical study on the role of Game Theory in Cold War discourses. She also contributed to the book "How Reason Almost Lost Its Mind" (2013), the result of a summer seminar on Game Theory at the Max–Planck–Institute Berlin in 2010 (in the following MPI–group).[7] This book also contains a critical account of Operations

[2] William Aspray*, John von Neumann and the Origins of Modern Computing,* (cf. note 1).
[3] Mina Rees, "The Computing Program of the Office of Naval Research, 1946-1953." *Annals of the History of Computing,* issue No. 2 - April-June (1982 vol. 4), pp. 102-120. As R&D is research and development meant. Richard Vahrenkamp, "The Computing Boom in the US Aeronautical Industry, 1945–1955." *ICON – The Journal of the International Committee for the History of Technology*, volume 25, 2019, pp. 2–25.
[4] Stephen Johnson, *The United States Air Force and the culture of innovation, 1945-1965*, Washington D.C. 2002, Air Force History and Museum Program, p. 42.
[5] Charles Shrader, *History of Operations Research in the United States Army*, Washington D.C., 2006, p. 60. On the role of the RAND Corporation in decision theory see Paul Edwards, *The closed world. Computers and the Politics of Discourse on Cold War America*, Cambridge (Mass.), 1996, pp. 114-116. George Dantzig, "Impact of Linear Programming on Computer Development", Lecture at ORSA/TIMS meeting on April 30, 1985, typewriter manuscript Stanford University, Document ADA157659, 1985 (Internet source).
[6] Stephen Johnson, "Three Approaches to Big Technology: Operations Research, Systems Engineering, and Project Management." *Technology and Culture*, Vol. 38, No. 4 (Oct., 1997), pp. 891-919, here p. 898. Philip Mirowski, *Machine Dreams – Economics becomes a Cyborg Science*, Cambridge (Mass.), Cambridge Univ. Press 2002. See also Jennifer Light, *From Warfare to Welfare: Defense Intellectuals and Urban problems in Cold War America*, Baltimore 2003, on the influence of RAND on urban planning in New York.
[7] Paul Erickson, Judy Klein, Lorraine Daston, Rebecca Lemov, Thomas Sturm and Michael Gordin, *How Reason Almost Lost Its Mind*, Chicago UP, 2013. Judy Klein, *Statistical Visions in Time: A History of Time Series Analysis, 1662 – 1938*. Cambridge (Mass.), 1997. Judy Klein, "Cold War, Dynamic Programming, and the Science of Economizing: Bellman Strikes Gold in Policy Space", lecture at First Annual Conference on the History of Recent Economics (HISRECO), University of Paris X -Nanterre,

Research. Paul Erickson's book on Game Theory followed in 2015. My paper continues these studies and will introduce the new concept of "abstractification". With this approach, the results of the MPI–group will be developed further to show the artificial content of Cold War discourses on Game Theory and Operations Research.

Atsushi Akera and Brent Jesiek have already explained the leading role mathematicians assumed in the development of the digital computer.[8] I will expand this reasoning and show that mathematicians also developed Game Theory and Operations Research and introduced a particular view of society as a space of numbers. The method applied in Game Theory and Operations Research is the "abstractification" of social reality in order to get a mathematical model. In engineering, astronomy and meteorology, mathematical models serve to structure the data measured and to make better predictions. Computers are fed with data to test the models. Scholars work inside the triangle data-model-computer, making this approach data-driven.[9] The scientists had personal experience with the material which they studied, as Nathan Ensmenger showed with the example of a laboratory in biological research.[10] Another is the approach of Game Theory and Operations Research. These fields use social, economic and political relations in firms and in society to derive mathematical models for their own sake, but not to derive solutions for social or economic problems. They stripped their models of social and political relations and gained simple models as material for academic purposes. Both were not driven by data, but rather by new mathematical methods. Empirical data was not particularly interesting for the scholars, and therefore the triangle of data-model-computer remained blank. The method of abstractification leads into the space of numbers with no way back to the real world, as will be shown with the examples of mixed strategies in Game Theory and the Transportation Model of Operations Research.

To regard Game Theory and Operations Research as an expert movement of mathematicians is not extraordinary in a twentieth century that witnessed various expert movements: the efficiency movement in the US around 1910, the rationalization movement in European industry around 1925, and the automation movement in the US and Europe around 1960. All these movements were already subjects of critical studies exploring their goals and the limited extent to which they achieved them. Furthermore, the studies explored the actors, the influence of government policy and views in public debates, scientists, employers and trade unions.[11]

As primary sources, this paper relies upon material provided by the 60th anniversary edition of Morgenstern's and Von Neumann's book "Game Theory and Economic Behaviour", published by Princeton University Press in 2004. It also refers to original papers on Game Theory and Linear Programming which the RAND Corporation offers on its web site and on contemporary

France, 21-23 June 2007. Paul Erickson: *The World the Game Theorists made*, University of Chicago Press, 2015.

[8] Atsushi Akera, *Calculating a Natural World – Scientists, Engineers, and Computing during the Rise of U.S. Cold War Research*, MIT Press 2007. Brent Jesiek, "The Origins and early History of Computer Engineering in the United States." *Annals of the History of Computing*, vol. 35, 2013, October, pp. 6-18.

[9] Gabriele Gramelsberger, *From science to computational sciences: studies in the history of computing and its influence on today's sciences*, Zurich, Diaphanes, 2011.

[10] Nathan Ensmenger, "The Digital Construction of Technology: Rethinking the History of Computers in Society." *Technology and Culture*, Volume 53, Number 4, October 2012, pp. 753-776.

[11] Samuel Haber, *Efficiency and Uplift*, Chicago 1964. Charles Maier, "Between Taylorism and Technocracy: European ideologies and the vision of industrial productivity in the 1920s." *Journal of Contemporary History*, 5 (1970), issue 2, pp. 27–61. Ronald Kline, "Cybernetics, Management Science, and Technology Policy: The Emergence of 'Information Technology' as a Keyword, 1948–1985." *Technology and Culture*, 47 (2006), issue 3, pp. 513–535.

conference proceedings. For the history of Operations Research, this paper refers to Dantzig's book on Linear Programming (1963) and to the contemporary journals which *The Society of Operations Research* and *The Institute for Management Science* have issued. The book "An Annotated Timeline of Operations Research" (2005), edited by Saul Gass and Arjange Assad, serves as a collection of references to original papers.[12]

**Morgenstern's and Von Neumann's push for Game Theory**

Similar to digital computers, Game Theory developed as a view of the world as perceived by mathematicians and was pushed by the same institutions as the Institute for Advanced Study (IAS) in Princeton and the RAND Corporation. This body of theory splits into two strands: mathematical and experimental. The latter conducts experiments in groups of test persons, and studies how they behave when following certain rules. Kurt Lewin founded "Group Studies" in the 1920s as part of the experimental psychology of the University of Berlin, and was later head of the research unit for group dynamics at MIT.[13] In the 1950s, behavioural psychologists and economists introduced experiments in groups to study the behaviour of test subjects in market exchange and game playing. In the 1980s, Reinhard Selten, who received the Nobel Prize in economics for Mathematical Game Theory (together with John Nash) in 1994, turned his attention to experimental Game Theory, together with his pupil Axel Ockenfels.[14] Both branches of Game Theory developed, to a large extent, independently. But mathematicians at the RAND Corporation conducted some experiments in the early 1950s.[15] The mathematical branch of Game Theory did not pick up on results from the experimental one but based on mathematical axioms.[16] In the following, the history of Mathematical Game Theory will be focussed on, in which the term Game Theory is understood to refer to Mathematical Game Theory.

Against the background of Cold War R&D, John Von Neumann was one of America's leading mathematicians and scientists. He was not only engaged in designing digital computers and atomic bombs, but also shaped Princeton and RAND into centres of Game Theory. From 1941, he gave lectures on Game Theory at the University of Princeton, where he met Oskar Morgenstern – an Austrian immigrant (and refugee) and economist.[17] Together they wrote the book *Theory of Games and Economic Behavior* that was published in 1944 by Princeton University Press, and contained more than 600 pages.[18] The book laid the ground for a new field of applied mathematics that abstractified social relations in society to develop simple

[12] Saul Gass and Arjange Assad, *An Annotated Timeline of Operations Research*, New York 2005.
[13] Anna Perlina, *Shaping the Field: Kurt Lewin and experimental psychology in the interwar period*, Berlin 2016. Philipp Ullrich, *Der Beitrag von Kurt Lewin zur Grundlegung des modernen Managements*, Kassel 2005.
[14] For the experimental Game Theory see Vernon Smith, "Game Theory and Experimental Economics: Beginnings and Early Influences", in Roy Weintraub (ed.), *Toward a History of Game Theory*, London, 1992, pp. 241-281. Anatol Rapoport and Albert Chammah, *Prisoner's Dilemma*, Univ. of Michigan Press, 1970.
[15] Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), pp. 135-142
[16] The turn from mathematical Game Theory to experimental Game Theory in the 1980s can be studied in the journal *Game Theory and Economic Behavior*. The first volume, in 1989, was devoted to mathematical Game Theory, whereas the tenth volume, in 1995, had experimental contributions.
[17] Urs Rellstab, "New Insights into the Collaboration between John von Neumann and Oskar Morgenstern." In Roy Weintraub (ed.), *Toward a History of Game Theory*, (London, 1992), pp. 77-94. Oskar Morgenstern, "Collaboration between Oskar Morgenstern and John von Neumann on Theory of Games." *Journal of Economic Literature*, vol. 14, 1976, no. 3, pp. 805-816.
[18] *Theory of Games and Economic Behavior*, Princeton UP, 1944. John von Neumann published already in 1928 in German language "Zur Theorie der Gesellschaftsspiele", *Mathematische Annalen*, vol. 100, pp. 295-320.

models of competition between firms and social conflicts between two or more antagonistic “players” who pursue “strategies”. Morgenstern and Von Neumann coined the term “Game Theory”, unheard of until then. The authors did not derive their models from social life, as known from social sciences or experimental Game Theory, but their approach was based purely on axiomatic mathematics. They observed phenomena in society in order to derive axiomatic mathematical models that seemed to be of value for society only in a nominal sense. But they did not provide techniques on how to apply their models. Game Theory remained a field of academic mathematics that existed purely for its own sake.

The approach of Morgenstern and Von Neumann was as following. To make a model of competition between two players (named A and B) they assumed that players get payoffs or profits depending on the (fictive) strategies they chose. Not derived from empirical research, the authors introduced a payoff table with numeric values for each player, which they invented at their office desk. The tables have the dimensions 2x2, in which each player could choose from two strategies, then the dimensions 3x3, in which each player could choose from three strategies, etc. The payoff tables are assigned to the strategies of A and B: the lines to the strategies of A, the columns to the strategies of B. The tables therefore show all the possible combinations of payoffs for A and B, depending on the choices made by the players. The following tables show two 3x3 payoff tables, called A’s Profits and B’s Profits, in a piece of 1946 coverage on Game Theory by the New York Times.[19]

**Table 1** A’s Profit. Example of a payoff table as published by the New York Times on 10 March 1946.

| | A’s Profits | | |
|---|---|---|---|
| | $B_1$ | $B_2$ | $B_3$ |
| $A_1$ | 2 | 8 | 1 |
| $A_2$ | 4 | 3 | 9 |
| $A_3$ | 5 | 6 | 7 |

**Table 2** B’s Profit. Example of a payoff table as published by the New York Times on 10 March 1946.

| | B’s Profits | | |
|---|---|---|---|
| | $B_1$ | $B_2$ | $B_3$ |
| $A_1$ | 11 | 2 | 20 |
| $A_2$ | 9 | 15 | 3 |
| $A_3$ | 8 | 7 | 6 |

When, in the example of tables 1 and 2, player A chooses strategy $A_1$ and player B strategy $B_2$, then A receives amount 8 as payoff ( in cell 1,2 ) and player B amount 2 ( in cell 1,2 ). The

[19] On March 10, 1946.

exact meaning of the payoff is left open: it could be measured in Dollars or in subjective utility values. Positive values could be seen as gains, negative values as losses.[20] The tables show the result of abstractification: they were stripped of all social and political context and reduced the decision situation to calculate the optimal solution inside the tables. The complexity of the world was reduced to few entries of a matrix, as Paul Erickson critically observed.[21]

The payoff tables display the payoffs for when the game is played just once. The player's choice of strategies is called 'pure strategy'. This situation changes when the players take in a long sequence of repeated games, where the strategies are randomly mixed with certain but constant probabilities. Then the average payoff, evaluated by using the probability values, is considered for each player (expected payoff). The turn from pure strategies to mixed strategies has important implications. For mathematicians, it appears as a standard method of generalization, linking probabilities to strategies and leading Game Theory into the abstract space of numbers. But in the real world, players do not have such a large amount of time and money to play such a long sequence of repeated games. In politics, time can be a very scarce resource. So, the concept of mixed strategies cannot be applied in the real world. In his popular account of Game Theory, the RAND author John Williams tried, on two pages, to convince the reader that the turn from pure to mixed strategies was justified. But he did not understand that mixed strategies were a mathematical fiction that could not be applied to the real world.[22] The MPI-group indicated that the repetition of a game induced effects of learning and therefore deviations from the first results. In their empirical study on Prisoner's Dilemma games, Rapoport and Chammah saw in the concept of mixed strategies a "natural" extension of repeated board games.[23] But this assumption is misleading, as economics and politics are not board games, and repeated runnings are not possible.

The author Arthur Copeland, in the Bulletin of the American Mathematical Society in 1945, saw the book *Theory of Games and Economic Behavior* as one of the major scientific achievements of the first half of the 20th century.[24] The book, however, did not sell very well. Von Neumann saw the book as a "dead duck". But then something surprising happened, presumably because of John Von Neumann's overwhelming influence on science policy at the East Coast. On March 10, 1946, the New York Times put a sensational headline on the front page of its Sunday edition: "A new approach to economic analysis that seeks to solve hitherto insoluble problems of business strategy by developing and applying to them a new mathematical theory of games of strategy like poker, chess and solitaire has caused a sensation among professional economists". The economist Leonid Hurwicz published another article in the same issue of the New York Times, with two 3x3 payoff tables (as shown in tables 1 and 2 above), as an example of how to apply Game Theory to the duopolistic competition of two enterprises.[25] To build his payoff tables, Hurwicz did not use empirical field studies in duopol cases but invented the tables on his office desk. The New York Times coverage led to a breakthrough in Game Theory. The first edition of the book quickly sold out, and in 1947 a second edition appeared in which the authors inserted a new third chapter on

[20] Behavior psychologists measure utility values on interval scales so that by adding a constant to the values in the tables one can turn all values into the positive domain, see Rapoport and Chammah, *Prisoner's Dilemma*, (cf. note 14), p. 39.
[21] Paul Erickson: *The World the Game Theorists made*, University of Chicago Press, 2015.
[22] John Williams, *The Compleate Strategyst*, New York 1966, second edition, 206s.
[23] Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), p. 145. Rapoport and Chammah, *Prisoner's Dilemma*, (cf. note 14), p. 23.
[24] *Bulletin of the American Mathematical Society* 51, 1945, p. 498. For further reviews see the 60th anniversary edition of *Theory of Games and Economic Behavior*, Princeton UP, 2004.
[25] For the duopoly cases in Game Theory see Guerrien (cf. note 1).

utility theory. Again, this strand of theory was purely mathematical and not derived from investigations in social contexts.[26] It is not easily accessible, and for the author of this paper, completely unintelligible. The third edition appeared in 1953. The new field of Game Theory mushroomed. The breakthrough in Game Theory represented by the *New York Times* coverage suggested that Game Theory was a media event and led to great esteem in public and academic fields. Since the 1950s, universities have published a steady stream of books on Game Theory, as an investigation in the library catalogue of the Technical University of Berlin revealed:

**Table 3** Number of published books on Game Theory according to decades.
(Source: Library catalogue Technical University of Berlin)

| | |
|---|---|
| before 1964 | 40 books |
| 1964 till 1975 | 124 books |
| 1976 till 1987 | 158 books |
| 1988 till 2000 | 225 books |
| after 2000 | 199 books |

The output of books reached its height in the 1990s, when John Nash won the Noble Prize 1994. The Noble committee awarded its Prize in economics for research in Game Theory also in the years 2005, 2007 and 2012.

Surprisingly, the New York Times coverage refers to poker, chess and solitaire, but not to a genuine example of duopolistic competition such as, for example, Shell versus British Petroleum in the petroleum industry. Game Theory, then, had an image of being for entertainment, and only promised applications "to social, political and economic phenomenon(s)", as Rudolf Henn and Otto Moeschlin proposed in their retrospective in honour of Oskar Morgenstern's 75th birthday in1977. Game Theory achieved an extraordinary level of success, with more than 6000 publications by 1977.[27] Mathematicians exported the field of Game Theory, together with Operations Research, into economics departments in universities.[28] The proposition that mathematicians in the field of Game Theory had filled positions in economic faculties can be substantiated by the careers of prominent Game Theory scholars such as Robert Aumann, Reinhard Selten and Joachim Rosenmüller. All three obtained a doctorate in mathematics before becoming game theoreticians. Robert Aumann founded the Center for Game Theory in Economics at Stony Brook University on Long Island, New York, in 1989. He was awarded the Nobel Prize in Economics in 2005. Reinhard Selten became full professor at the Faculty of Economics of Freie Universität Berlin in 1969 and joined the newly founded Center for Mathematical Economics at Bielefeld University (Germany) in 1972. The Center became part of the newly founded Faculty of Economics at Bielefeld University in 1974. Selten received the Nobel Prize in Economics in 1994. Joachim Rosenmüller became full professor at the Faculty of Economics of the University of Karlsruhe (Germany) in 1972 and joined the Center for Mathematical Economics at the University of Bielefeld in 1978.

[26] Also the chapters on utility theory in microeconomics do not pick up results from social sciences, see Hal Varian, *Microeconomic Theory*, New York, 1978.
[27] Rudolf Henn and Otto Moeschlin, *Mathematical Economics and Game Theory – Essays in Honor of Oskar Morgenstern on his 75th birthday*, Berlin 1977, p. 4. The book contains a short bio of Morgenstern, pp. 1-10, and a bibliography of his publications, pp. 695-709.
[28] Philip Mirowski: *Machine Dreams*, (cf. note 6), p. 488.

Morgenstern and Von Neumann proposed, in the foreword of their book, that the solution to social problems could be reached with the aid of Game Theory, but they did not present any such solution. Until now, not a single example for the application of Game Theory to social problems, with an empirically derived payoff table, has been published as Bernard Guerrien proved at the four volume set *Handbook of Game Theory with Economic Applications* (edited by Robert Aumann and Sergiu Hart 2002).[29] Despite of this eminent lack of application, Game Theory held a position of high esteem in the minds of the public. On the life of John Nash, a popular book appeared in 1998 and a movie 2001 *A Beautiful Mind*, supporting the view of Game Theory as a media event.[30]

### Zero sum games and lack of applications

As many surveys on Game Theory have pointed out, there was no unifying concept for the "solution" to a game. Morgenstern and Von Neumann proposed, for their two persons zero sum games, the intuitively appealing minimax solution. In the two persons zero sum games setting, only one table exists, displaying the gains of player A as positive numbers that are, at the same time, the losses of player B. This game type could represent the market shares of two competing firms. The gains in the market shares of one firm are the losses of the other one. Player A tries to maximize his gains and player B to minimize his losses. Player A choses a strategy (a row in the table) that maximizes the least gain of whatever player B does. Player B choses a strategy (a column in the table) that minimizes the greatest loss of whatever player A does. A saddle point in pure strategies exists if the least gain maximized by player A is equal the minimum of the greatest loss of player B. This saddle point is seen as a solution to the game. The strategies chosen to obtain the saddle point are called pure strategies.

But in the case that a saddle point in the payoff table does not exist in pure strategies, the authors applied a standard method from mathematics: the generalisation. They assigned probabilities to the strategies of the players and showed that, in this case, an equilibrium point exists for certain probabilities p and q, where the expected gains of player A equals the expected losses of player B. To obtain this kind of solution the players had to play a long sequence of plays and to mix their strategies randomly with probability p and (p–1) for player A and q and (1–q) for player B. This kind of procedure was called mixed strategies. For students in a university course, it is a nice exercise to compute the probabilities p and q by two equations with unknowns p and q in a 2x2 table, but this exercise disguises the lack of application. The generalization of a saddle point as mixed strategies applies very well in mathematics. But how should it be applied in politics? In the context of Game Theory, the Vietnam War was an important issue.[31] The RAND Corporation could have made a proposal in the Vietnam War: throw an atomic bomb onto Hanoi with a probability of 0.30 and make an invasion with ground forces with a probability of 0.70. These applications of mixed strategies with certain probabilities are only possible if one repeats the application and randomly mixes it many times: 30 times the atomic bomb and 70 times the invasion. But history is unique, and not subject to repeated trials. So, it is impossible to apply zero-sum two person games in politics.[32]

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[29] See Guerrien and also Syll (cf. note 1).
[30] Sylvia Nasar, *A Beautiful Mind*, New York 1998.
[31] Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), p. 133.
[32] Also Haywoods confessed difficulties to apply mixed strategies, see O. G. Haywood, "Military Decision and Game Theory." *Journal of the Operations Research Society of America*, vol. 2, no. 4 (Nov. 1954), pp. 365-385. Also J. McDonald, *Strategy in Poker, Business and War*, New York, 1950.

Already by the beginning of the 1950s, the lack of applications of Game Theory had become evident at RAND. It was seen as a nice intellectual spirit.[33] Objections arose to the model of zero-sum two person games. The payoff matrix was stripped of its social and political context and was viewed as too simple to display complicated situations in competition between firms or in political conflicts. The RAND Corporation could apply zero-sum two person games to make a re-interpretation of historic battlefield situations in terms of Game Theory, but could not gain new insights.[34] In 1959, criticism arose from Albert Tucker and Duncan Luce that the solution of matrix games did not prescribe rational behaviour nor "predict behaviour with sufficient precision to be of empirical value."[35] The lack of applications observed also Guerrien and Syll in their critical accounts.[36]

### The Nash equilibrium and prisoner's dilemma

Albert W. Tucker was a mathematician at Princeton University who, since 1948, had held a contract with the Office of Naval Research for basic research into logistics.[37] This contract shows that the label "logistics" was sufficient to support mathematical research. By editing volumes on Game Theory, the Princeton mathematician Albert W. Tucker, together with Harold W. Kuhn from Stanford University, turned Princeton into an important centre of Game Theory. In 1950, the famous volume *Contribution to the Theory of Games* appeared, published by Princeton University Press. Although supported as a logistics project by the Office of Naval Research, the editors underlined frankly in the foreword that no applications were intended. Instead the papers in the volume would address pure mathematics. The same editors published a second volume in 1953 as part of the Logistics Project of the Office of Naval Research, which would shed some light on the application of Game Theory.[38] Other than in the first volume, which focussed on non-cooperative Game Theory that models situations of competition, the second volume had a section on cooperative n-person games, modelling cooperation in cooperative project work or "coalitions" in voting assemblies.

The later-to-be-famous John Nash was doctoral student of Albert W. Tucker. In addition to the minimax solution in Von Neumann's and Morgenstern's antagonistic two person games, he introduced an element of cooperation between the players. In his 1950 dissertation, through the application of the Kakutani fixed point theorem, he discovered the existence of an equilibrium point for mixed strategies in non-cooperative games but provided no algorithm to compute this equilibrium in mixed strategies. In the equilibrium point, the players could not improve the payoff in their chosen situations. If one player altered their strategy, both players would lose some of their payoff. Therefore, they were dependent on each other. In 1994, Nash received the Nobel Prize in economics for his discovery (together with Reinhard

[33] Philip Mirowski, *Machine Dreams*, (cf. note 6), pp. 327-329.
[34] Robin Rider, "Operations Research and Game Theory: Early connections", in Roy Weintraub (ed.), *Toward a History of Game Theory*, (London, 1992), pp. 225-237, here p. 229, p. 236. William Riker, "The Entry of Game Theory into Political Science", in Roy Weintraub (ed.), *Toward a History of Game Theory*, (London, 1992), pp. 207-224, here p. 216.
[35] Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), p. 140.
[36] (cf. note 1).
[37] Mina Rees, "The Computing Program of the Office of Naval Research, 1946-1953", (cf. note 3), p. 110. Paul Erickson, *The World the Game Theorists Made*, University of Chicago Press 2015, p. 101.
[38] Harold Kuhn and Albert Tucker (eds.), *Contributions to the Theory of Games*, Princeton UP, 1950, foreword of Kuhn and Tucker.

Selten).[39] Between 1950 and 1954, Nash published some minor papers on Game Theory at the RAND Corporation. Afterwards, he turned to pure mathematics, as in the famous Hilbert problems. John Von Neumann and the Game Theory group at RAND rejected the approach of Nash's equilibrium.[40]

To demystify the concept of the Nash equilibrium I give a simple example in pure strategies in tables 4 and 5 which display simple domination points – the concept of dominant strategies was already known from two persons games. Examples of this kind entered the books on microeconomics in the 1980s. The example consists of modified values of the tables 1 and 2. This example shows further, how the concept of a Nash-equilibrium implies some kind of cooperation. They contain the large values 10 and 25 in row 3 and column 2. These dominant values appear in cell (3,2) in both payoff tables. In this case, player A cannot improve his situation when he chose line 3. Player B makes the best choice in selecting column 2 when player A had already chosen line 3.

**Table 4** A's Profit. Example of a payoff table with a domination point.

| | A's Profits | | |
|---|---|---|---|
| | $B_1$ | $B_2$ | $B_3$ |
| $A_1$ | 2 | 8 | 1 |
| $A_2$ | 4 | 3 | 9 |
| $A_3$ | 5 | **10** | 7 |

**Table 5** B's Profit. Example of a payoff table with a domination point.

| | B's Profits | | |
|---|---|---|---|
| | $B_1$ | $B_2$ | $B_3$ |
| $A_1$ | 11 | 2 | 20 |
| $A_2$ | 9 | 15 | 3 |
| $A_3$ | 8 | **25** | 6 |

The Nash-equilibrium appears to be a simple domination concept in pure strategies. But if the Nash-equilibrium does not exist in pure strategies, one could find it with the aid of mixed strategies, as Nash showed. But these strategies remained unknown because they could not be computed.[41] The MPI-group recognized Nash's new concept of cooperation, in contrast to Von Neumann's two person games.[42] Because Nash did not deliver an algorithm to determine the mixed strategies, Von Neumann criticised the Nash equilibrium as a pure existence assertion – nothing else as a fixed point theorem.

[39] John Nash, "Non-Cooperative Games." *The Annals of Mathematics*, vol. 54, 1951, (2), pp. 286-295. Already in 1937, von Neumann discovered an equilibrium point by application of Brouwer's fixed point theorem.
[40] Philip Mirowsky, *Machine Dreams*, (cf. note 6), p. 334.
[41] Hal Varian, *Intermediate Microeconomics*, New York 2014, p. 542.
[42] Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), p. 141.

In the 1980s, Game Theory entered microeconomics courses at universities through a rediscovery of the Nash equilibrium, but only in pure strategies.[43] The lack of application induced the lecturers of microeconomics to present invented textbook examples of Game Theory that are not derived from empirical research. The Chicken Game describes the behaviour of teenagers in suburbs. The students in the classroom may have rolled their eyes and asked why this example was important for economics. Some economists argued that Game Theory had been important in resolving the Cuban Crisis of 1961 – a claim that was rejected by the MPI–group.[44] Other than applied economics, Game Theory lacks an intermediate layer between theoretical concepts and application in society. In macroeconomics one can derive, from the concept of Production Theory, for example, the Cobb-Douglas production function from empirical data, and answer the following question: How much does the gross domestic product increase if the supply of labour force increases by 100.000 people? Game Theory cannot answer questions of this kind. Also, Social Sciences provide many techniques, in terms of converting theoretical concepts into empirical measurement, that were not picked up by Game Theory.

The famous Prisoner's Dilemma game is not an abstractification of social relations in prisons, but an invention of the RAND mathematician Merill Flood. He used this game theoretic setting to derive arguments against Nash's equilibrium concept.[45] There are many accounts of Prisoner's Dilemma. I will draw on the most methodologically careful study on Prisoner's Dilemma, which was completed by Anatol Rapoport and Albert Chammah. They showed that this type of game is an abstractification of the behaviour of two competing firms to prevent their markets from excess capacity by joint quotas. Not playing the game only one time, Rapoport and Chammah showed incentives to leave a common cooperative position and end at a defect.[46] This abstractification provides a suitable frame for interpretation in a duopolistic case of firms' competition but gains no new insights beyond the existing literature on duopolistic behaviour.[47] For the Cold War intellectuals at RAND, the Prisoner's Dilemma game was central to describing a rational choice in the conflict between the USA and Soviet Union, as the MPI group pointed out.[48]

### Game theory at RAND

Besides what was happening at Princeton, the RAND Corporation also developed as a centre of Game Theory. John Von Neumann played an important role in establishing the research program at RAND and a strong group for Game Theory.[49] RAND had already edited a bibliography on Game Theory, with more than 200 entries, in 1952.[50] The RAND Corporation was an ideal environment for Game Theory. It was assumed that in the Cold War, the

[43] See for example Hal Varian, *Intermediate Microeconomics*, (cf. note 41). Philip Mirowski, *Machine Dreams*, (cf. note 6), p. 348.
[44] Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), p. 141.
[45] Philip Mirowski, *Machine Dreams,* (cf. note 6), pp. 334, 354.
[46] Rapoport and Chammah, *Prisoner's Dilemma*, (cf. note 14), p. 26.
[47] See Guerrien (cf. note 1) for cases of duopolistic behaviour.
[48] Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), p. 320.
[49] Philip Mirowski, *Machine Dreams*, (cf. note 6), 212s.
[50] RAND Publication RM-950, Santa Monica 1952. See also Angela O'Rand, "Mathematising of the Social Science in the 1950s: Early Development and Diffusion of Game Theory." In Roy Weintraub (ed.), *Toward a History of Game Theory*, London, 1992, pp. 177-189. Robin Rider points out to compile bibliographies provided high reputation for the new field of Game Theory, see her paper "Operations Research and Game Theory: Early connections." In: Roy Weintraub (ed.), *Toward a History of Game Theory*, London, 1992, p. 226.

application of Game Theory would be a useful aid for politicians. John Williams, head of the mathematical department at RAND, wrote a popular book on Game Theory for the intelligent layman. In the 1950s, Game Theory was seen as an esoteric and mysterious subject, familiar only to specialized researchers, particularly those in the military. The book *The Compleat Strategyst – Being a Primer on the Theory of Games* was published in RAND's book series in 1954. It aimed to bridge the gap between Game Theory and the public, and was very successful, being pressed ten times and translated into various languages.[51] It even entered the Eastern Bloc, with Russian, Polish and Czech translations. Many universities used this book for their courses in Game Theory. It is remarkable that the book did not rely on complex calculations where a digital computer would be needed but carried out only simple calculations that could be done on a calculator. This conclusion does not support the commonly held view of a close interrelation between digital computers and Game Theory. In the second revised edition of 1966, the book had a sixth chapter added, in which it showed how to compute a saddle point in mixed strategies with the aid of Linear Programming, indicating a close connection between these two strands of theory.

The later-to-be-famous Lloyd Shapley also worked at RAND and issued a long list of RAND-papers on cooperative n-person games. He understood the players as numbers 1,2,…,n and considered subsets of the player set {1,2…,n}. He assigned to each subset ("coalition") a value v, that could be understood as a yield in a working cooperative (coalition), or as a voting power of the coalition in an assembly.[52] Shapley measured the marginal contribution of an individual i to a coalition C as the difference of the coalition's value, once with i as member of C, and once without i. The Shapley value of the individual i became famous as the average marginal contribution over all possible coalitions. The value v was derived from mathematical axioms but not from results of experimental Game Theory. So, the construction of the theory followed, only on a nominal level, the phenomena of social, economic or political life to mediate an intuitive understanding of the reader, but not to investigate empirical phenomena. Shapley made this nominal view explicit as he, in a paper on voting in a stockholder's meeting, underlined that this paper would only be nominal to help the reader, but should not be applied to joint stock companies.[53] In another RAND-paper he judged his examples for games as "artificial".[54] From the years 1950 to 1954 John Nash also held, during the summer months, short term contracts at RAND, where he published small RAND-papers on cooperative two person games in which he reduced to the non-cooperative case and an analysis of the board game "Hex", which was popular in Denmark.[55]

## Operations Research

This section provides an overview of the institutionalization of Operations Research (OR), shows reasons for the barriers of application of OR, and describes OR as a research field for mathematicians. Operations Research is the application of mathematical models for planning

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[51] John Williams, *The compleat Strategyst*, New York 1954, (cf. note 22), foreword. Williams died in 1964, see the obituary in the *New York Times* on November 22, 1964.
[52] Lloyd Shapley, "A Value for n-Person Games." In Albert Tucker and Harold Kuhn (eds.), *Contribution to the Theory of Games*, vol. 2, Princeton University Press, 1953, pp. 307-318.
[53] Lloyd Shapley, "Values of Large Games III, A Corporation with two large Stockholders." Research Memorandum RM 2650, RAND Corp., 1961, p. 1.
[54] Lloyd Shapley, "Values of Large Games IV", Research Memorandum RM 2650, RAND Corp., 1961, p.1.
[55] John Nash, "Two Person Cooperative Games", RAND Paper P-175, 1950. John Nash, "Some Games and Machines for Playing Them", RAND paper D-1164, 1952.

in administration, in manufacturing enterprises or in transport enterprises and comprises heterogeneous mathematical theories such as Game Theory, production planning, storage policy, networks and queuing theory, with Linear Optimization as a centre. After gathering data, the mathematicians look within their models for the optimal solution in order to minimize costs or maximize profits in a company.

During WW2, OR was founded in Great Britain and the US, developing methods to detect aircraft and submarines. In the UK, the group for Naval Operational Research was founded, and in the US, the Antisubmarine Warfare Operations Research Group (ASWORG). After WW2, the US Navy Operations Evaluation Group (OEG) maintained special OR knowledge, with a reduced staff and further development of OR methods during peace time.[56]

As a newly established branch of the military in 1947, the US Air Force was eager to get a reputation for the application of scientific methods in planning and using the digital computer – expected in the future – for this task as a circular letter from the Chief of Staff on 13 October 1948 indicated.[57] The Air Force developed the optimizing technique Linear Programming as the core of Operations Research during the project SCOOP at the RAND Corporation, 1947 – 1953. This project has already been described in various accounts.[58] The aim of this project was to accelerate the planning steps for a military operation, called a program. In expectation of the digital computer, the application of mathematical planning methods was to shorten the programming steps. The RAND mathematician Georg Dantzig invented a mathematical planning approach in 1947, calling it Linear Programming. It provided computational techniques to maximize a linear function over a convex and compact set in the n–dimensional number space that was spanned by linear inequalities.

As a showcase for Linear Programming application by the Air Force in the Cold War context, the SCOOP group also developed a model for the Berlin Airlift of 1948-1949 (Operation Vittel) and promoted it at various conferences. Abstractifying from the broad variety of aircraft models that were employed in the Berlin Air Lift, the model considered only C7 and C47 airplanes and determined the least costly schedule, taking fuel costs, crews and spare engines into account. The model was never used in day-to-day planning but served as a tutorial example to demonstrate the usefulness of Linear Programming. It attracted academic attention, and some dissertations on this model were written.[59] Murray Geisler, the head of SCOOP, guessed that the requirements of the Air Force were too extensive and surpassed the magnitude that a Linear Program could handle at that time. He guessed that 3600 variables and 3600 inequalities would be necessary.[60]

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[56] Carl Harris, "Center for Naval Analysis." In Saul Gass and Carl Harris (eds.): *Encyclopedia of Operations Research and Management Science*, Boston, Kluver 1996, pp. 62-64.
[57] Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), p. 60.
[58] On the project SCOOP Paul Erickson et al., *How Reason Almost Lost Its Mind,* (cf. note 7), made a careful study. See also Paul Erickson, *The World the Game Theorists Made*, (cf. note 7), p. 96. Paul Ceruzzi, *Beyond the Limits. Flight enters the Computer Age*, MIT Press 1989, pp. 41-43. George Dantzig 1963, *Linear Programming and Extensions*, Princeton University Press, 1963, p. 15. This book appeared under copyright of the RAND Corporation. For the early history of Linear Programming and the forerunner Leonid Kantorovich, see Robert Dorfman, "The Discovery of Linear Programming." In *Annals in the History of Computing*, issue 3, July-September (1984 vol. 6), pp. 283-295. Murray Geisler, *A Personal History of Logistics*, Bethesda 1986, pp. 3-17.
[59] Murray Geisler, *A Personal History of Logistics*, (cf. note 58), p. 6. Marshall Woon and Murray Geisler, "Development of Dynamic Models for Program Planning", (cf. note 55). For the Operation Vittel see Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), 56s.
[60] Murray Geisler, *A Personal History of Logistics*, (cf. note 58), p. 14. Marshall Woon and Murray Geisler, "Development of Dynamic Models for Program Planning." In Tjalling Koopmans (ed.), *Activity Analysis of Production and Allocation*, New York, 1951, pp. 189–215, p. 206.

For an observer, the way the SCOOP group fluctuated between local optimization in a firm or an organisation like the Air Force and the macroeconomic level of the economy appears curious. Ideas about central planning of the economy ("market socialism") were discussed, which prevailed in their enemy country – the Soviet Union. In market socialism, the firms operated independently but the prices of the goods were calculated by a central computer (the "superbrain").[61] Wassily Leontief's research also influenced SCOOP. In the Bureau of Labour Statistics, Leontief gathered data for a national Input–Output–Matrix and earned a high reputation. But this matrix, say A, with 200 rows and columns could only be used by means of a high speed digital computer, only available in the mid 1950s, since the "Leontief–Invers" matrix $(I–A)^{-1}$ had to be computed.[62] As a member of SCOOP, George Dantzig pointed out in a soviet manner at the conference on activity analysis 1949, Leontief's model could answer the central planning question of how much aluminium, steel and electrical power would be needed to meet the demands of a rise in weapon production.[63] As the historian of economic thought, Alexander Nutzenadel, critically noted, it remained open, however, whether the input-output tables merely represent an impressive collection of statistics, or whether they provide a benefit for economic policy decisions.[64]

Projects by the Air Force also pushed the jump from military to civil applications of Linear Programming in administration and industry. Contracts were made with the universities of Chicago and Pittsburgh, where they were generalized to "Operations Research" by Tjalling Koopmans, Abraham Charnes and Herbert Simon.[65] In 1949 – only two years after Dantzig's discovery – RAND organized the famous conference on Linear Programming at the University of Chicago, announced as the "Activity Analysis of Production and Allocation", followed by the First Symposium in Linear Programming in Washington D.C., under the joint auspices of the RAND Corporation and the National Bureau of Standard, in 1951.[66] Both conferences were held without any experience in the high speed digital computers, which were only available at RAND in 1953. Together with the oil refinery manager Bob Mellon, the University of Pittsburgh made a Linear Programming project for the lowest cost blending of aviation gasoline under contract of the Air Force. The model contained 22 variables and was solved by means of office calculators. The authors Charnes et al. did not mention the digital IBM CPC machine or even a digital computer. The motivation of the Air Force contract remains unclear. Was there a prevailing shortage of aviation gasoline? Or was the issue "aviation gasoline" a sufficient justification for an Air Force contract? These questions shed light on the diffuse motivation of

[61] Dorfman, Robert, Paul Samuelson and Robert Solow, *Linear Programming and Economic Analysis*, New York, 1958, p. 395. This book appeared under copyright of the RAND Corporation. Philip Mirowski, *Machine Dreams,* (cf. note 6), p. 259.
[62] Frederick Moore, "A Survey of Current Interindustry Models." *National Bureau of Economic Research*, 1955, pp. 215–252. For the computing time of matrix inversion on various machines see Saul Gass, "The First Linear-Programming Shoppe." *Operations Research*, 50 (2002), issue 1, pp. 61-68, here p. 62.
[63] Marshall Woon and George Dantzig, "The Programming of independent Activities." In Tjalling Koopmans, *Activity Analysis of Production and Allocation*, New York 1951 (cf. note 60), pp. 15-18, here p. 18. Marshall Woon and Murray Geisler, "Development of Dynamic Models for Program Planning" (cf. note 60).
[64] Nützenadel, Alexander: *Stunde der Ökonomen: Wissenschaft, Politik und Expertenkultur in der Bundesrepublik, 1949-1974*, Göttingen 2005, p. 108.
65 Stephen Johnson, "Three Approaches to Big Technology", (cf. note 6), p. 898. Paul Erickson et al., *How reason almost lost its mind*, (cf. note 7), p. 72. Judy Klein, "The Cold War Hot House for Modeling Strategies at the Carnegie Institute of Technology", lecture at First Annual Conference on the History of Recent Economics (HISRECO), University of Paris X -Nanterre, France, 21-23 June 2007. Tjalling Koopmans, *Activity Analysis of Production and Allocation*, New York 1951.
[66] Tjalling Koopmans, *Activity Analysis of Production and Allocation* (cf. note 60). George Dantzig, *Linear Programming*, (cf. note 58), p. 25.

the Air Force in its R&D policy.[67] The consulting firms also established OR-groups, as William Thomas pointed out in his study.[68] In 1953, Abraham Charnes and William Cooper published the first textbook on Linear Programming.[69] Scientific societies and journals were founded in the 1950s, such as the Operation Research Society of America (ORSA) in 1952 and the Institute for Management Sciences (TIMS) in 1953. In the 1960s, ORSA reached the amazing number of 8000 members.

The founding of ORSA and TIMS were not responses to requests from the industry for OR applications but were rather an autonomous movement of expert mathematicians supported by military agencies. In his book on the automation movement, Herbert Simon characterized Operation Research as a new science of management that was pushed by mathematicians.[70] In a conference on computer and management in 1955, Simon saw in Operations Research a possibility to automate management decisions. OR–models should be applied on the new high speed digital computers, available since 1953.[71] But his hope was not fulfilled. OR–experts were mathematicians not acquainted with empirical data and applications to computers. OR–textbooks contained purely mathematical models without implementation on digital computers.

In the 1950s, Operations Research established chairs in departments of management at universities in the US and Great Britain, and in the 1960s OR chairs opened in Belgium, Switzerland and West Germany. In Zurich, the mathematician Hans Kunzi, who held a doctorate in mathematics, occupied even two parallel OR chairs and became president of the Swiss OR Society.[72] In 1975 the German OR professor Hans-Juergen Zimmermann (Technical University of Aachen since 1969) merged eleven national OR societies in Western Europe (excluding the Eastern bloc) under the umbrella “EURO”.[73] The mathematical economist Martin Beckmann achieved a leading position in the European OR network when he held an OR professorship at the University of Bonn (Germany) in 1963. Together with OR professor Hans Kunzi, he edited even two series: the “Lecture Notes in Economics and Mathematical Systems” and the “Lecture Notes in Operations Research and Mathematical Economics” at Springer publisher, from 1968. Both series grew explosively, each with 16 titles per year.

Despite its successful institutionalization, OR’s application in industry remained minimal. The president of TIMS, the RAND mathematician Merill Flood, admitted in his presidential address

[67] Charnes, A., W. Cooper and B. Mellon, “Blending Aviation Gasoline. A Study in Programming Interdependent Activities in an Integrated Oil Company.” *Econometrica*, vol. 20, 1952, no. 2, pp. 135-159.
[68] Thomas, William, “Operations Research vis-à-vis Management at Arthur D. Little and the Massachusetts Institute of Technology in the 1950s.” *Business History Review* 86 (2012), pp. 99-122.
[69] Abraham Charnes and William Cooper, *An Introduction to Linear Programming*, New York 1953.
[70] Herbert Simon, *The New Science of Management Decision*, New York 1960, 14s.
[71] Russel Ackhoff and Herbert Simon, *Proceedings of the Automatic Data Processing Conference*, Graduate School of Business Administration, Harvard University, Boston, 1955. For this conference see also Thomas Haigh, “The Chromium–Plated Tabulator: Institutionalizing an Electronic Revolution, 1954–1958”, *Annales in the History of Computing*, 23 (2001), issue 4, 75–104, here 77.
[72] Charles West Churchman, Russell Lincoln Ackoff and Leonard Arnoff, *Introduction to Operations Research*, New York 1957. Philip Morse, “Report on the First Summer Program in Operations Research at M.I.T.”, in Journal of the American Operations Research Society, 1, 1953, 303-305. Rudolf Henn and Hans P. Kuenzi, *Einführung in die Unternehmensforschung*, two volumes, Berlin 1968. Philip Mirowski, *Machine Dreams*, (cf. note 6), p. 490.
[73] Bulletin 1 of the European Association for Operational Research, 1975.

of 1955 that OR laid only "in the air".[74] OR researchers had to notice that data collection in an enterprise involved "organized human behaviour" which the mathematicians did not expect.[75] From the management of enterprises, it is known that to gather data inside an enterprise is both tedious and expensive and raises tensions. Management had to balance quality of data and the costs of gathering it and was inclined to use rules of thumb.[76] Because the OR-consultants had to jump over the barrier of high quality data to apply refined methods of Operations Research, the extent of its application in enterprises was low. Lewis Bodin, for example, wondered – when facing 20 years of research – about the low degree of application in the field of vehicle routing for milk collections on farms in the countryside, or the routing of school busses in the suburbs in 1990.[77] When one takes into regard the promises of cost savings, OR consultants could only handle this to a small degree, because many industrial processes carried a high burden of overhead costs, so that a reduction of, say, 5% of variable costs seemed rather unconvincing. In addition to this, many processes exhibited a cost curve that had only a flat minimum at the optimal solution, so that deviations from that point did not carry weight and rules of thumb seemed justified. In the literature, no cost curve is seen that manifests a sharp minimum such as a cleft in a rock and would justify a costly search for the optimal solution.

Although Churchman et al. gave, in their OR book of 1957, some warnings that scholars should not concentrate on methods but had to gather data and become acquainted with social relations inside the enterprise from which they were commissioned, mathematicians ignored these warnings, did not gather data and successfully captured the scientific staff in economics departments of universities.[78] Other than the books by Churchman et al., in which methods of data collection in steelworks and at turn-pike stations in New York are shown in detail, the mathematicians turned their books on Operations Research to pure method bibles.[79] The triangle data-model-computer remained blank. Oriented to mathematical methods, the mathematicians had no experience in social sciences with which to gather in enterprise data for their models. The scholars had no data – so they needed no computer. Remarkably, OR textbooks do not refer to computing, although personal computers had been widely available since the 1980s and spreadsheet software could easily template network models.[80] The scholars compensated for the lack of data by inventing data at their office desks. Every example in university lectures on Game Theory were invented payoff tables. Dantzig (1963), for his book on Linear Programming, invented examples of the transportation problem, the traveling salesman problem and the diet problem, as shown in the following sections.

[74] Merrill M. Flood, "The Objectives of TIMS" *Management Science*, Vol. 2, No. 2 (Jan., 1956), pp. 178-184.
[75] Russel Ackhoff, "The Development of Operations Research as a Science" *Operations Research*, vol. 4, no. 3, 1956, pp. 268-275, here p. 268.
[76] Robert Kaplan, *Cost & effect: using integrated cost systems to drive profitability and performance*, Harvard UP 1998. Churchman et al., *Operations Research*, (cf. note 66), p. 16.
77 Lewis Bodin, "Twenty Years of Routing and Scheduling" *Operations Research*, vol. 38, no. 4, 1990, pp. 571-579.
[78] Churchman et al., *Introduction to Operations Research*, (cf. note 72), chapter 21.
[79] The first volume of the two volume book of Henn and Kunzi, *Einführung in die Unternehmens-forschung, Berlin 1968,* contained no OR at all, but a basic course in mathematics (linear algebra and calculus). OR invaded successfully also the Eastern Bloc. As a remake of the book of Henn and Kunzi in 1971 appeared a three volume book on OR in Eastern-Berlin. Werner Dueck and Manfred Diefenbach (eds.), *Operationsforschung*, also in volume 1 pure mathematics.
[80] Martin Campbell-Kelly, "Number Crunching without Programming: The Evolution of Spreadsheet Usability", in *Annals of the History of Computing*, Volume 29, Issue: 3, July-Sept. 2007, pp. 6-19.

**The artificial content of Cold War Operations Research**

The following sections discuss the Transport Model, the Travelling Salesman Problem, and the Diet Problem and highlights their artificial content derived from Cold War Operations Research. But, also other OR questions focus on this artificial content and have not been applied in business, so they remained academic, as is explained here. The literature reveals a lack of critical accounts on these OR–problems.

**Dynamic Programming** designs models of optimal decisions over time and assumes a fixed future time horizon. As a RAND researcher, the mathematician Richard Bellman first published on this subject in 1957 and found many imitators.[81] It was assumed that Bellman could repeat Dantzig's success with a new approach 10 years after his Linear Programming. This approach explicitly included the time dimension of economic action and divided the future course of time into different periods in which different policy options could be chosen. In a sensational because contraintuitive approach, Bellman first determined the optimal policy in the end period and gradually worked his way back from there to the present time (backward recursion). Dynamic programming was ideal for OR models, since there is no empirical data on future developments, i.e. researchers do not have to work empirically. Like Linear Programming, Dynamic Programming was only able to find optimal solutions with the help of computers because of the complex calculations involved. In 1979, Christoph Schneeweiss pointed out the high main memory requirements of reverse recursion, which could only be met for very small models using the then state of the art computer technology.[82] Thus Dynamic Programming was not in a position to provide calculation programs for the worldwide spare parts supply of the Air Force, as Judith Klein assumed in her study on Cold War Dynamic Programming.[83]

The question why Dynamic Programming was superior to simple decision rules based on uncertain assumptions about future developments, such as investment decisions, remained unanswered. With abstractification, Dynamic Programming transformed uncertain data about the future into seemingly secure, accurate data and does not reflect the curiosity of applying an elaborate, accurate algorithm to uncertain data. Judy Klein's critique of Dynamic Programming as Cold War Science also fails to recognize this weakness of Dynamic Programming.[84]

**The network flow model** simplifies the partial differential equations known as Navier-Stokes equations about flowing liquids in tubes developed by engineers and physicists in the 19th century. The network flow model abstracts the complex Navier-Stokes equations to such an extent that no friction occurs during the transport of liquids in tubes, i.e. the transport is lossless and vortex-free. In this simplified context, the mathematicians Lester Ford and Delbert Fulkerson were able to formulate the famous duality theorem “Max-Flow-Min-Cut” in 1956.[85] But applications of network flow models remained unknown. The network models of Operations Research were not included in the debate about the network expansion of important infrastructures, such as the electricity grid or the gas pipeline network.

[81] See for example Martin Beckmann, *Dynamic Programming*, Berlin 1968.
[82] Schneeweis, Christoph: Dynamische Programmierung, in: Beckmann, Martin, Günter Menges und Reinhard Selten (Hersg.): *Handwörterbuch der Mathematischen Wirtschaftswissenschaften*, *Teilband Unternehmensforschung*, Wiesbaden 1979, p. 32.
[83] Klein, Cold War, 2007, cf. note 7.
[84] Klein, ibidem.
[85] Lester Ford Jr., D.R Fulkerson: “Maximal flow through a network.” *Canadian J. Mathematics*, 8, 1956, S. pp. 399-404.

**The Quadratic Assignment problem** was first formulated by the mathematical economists Martin Beckmann and Tjalling Koopmans in a joint article in Econometrica in 1957, which became famous and was cited about 1500 times.[86] Beckmann and Koopmans worked together at the Cowles Commission in Chicago.[87] Their article deals with an question that only appears at first glance as an economic problem, namely the spatial arrangement of different production plants on given settlement areas. Hypothetical – empirical data were not available – supply relationships are assumed among the enterprises that are included in the model being measured in tons. The spatial distances in kilometres between the factories are known. The question is how the factories should be optimally arranged on the land so as to minimise the transport performance (tonnes*km) when goods are exchanged between the factories. There were also publications at the company level dealing with the arrangement of machinery in an industrial plant with regard to the exchange of intermediate products.[88] The abstractification underlying the Quadratic Assignment problem becomes clear in the one-dimensional goal of minimizing the transport performance. In contrast to Beckmann's assertion that Operations Research can be applied in complicated decision-making situations,[89] the authors Koopmans and Beckmann reduced the complexity of the decision-making situation of the Quadratic Assignment problem to one dimension of transport performance. In a democratic society, the Quadratic Assignment problem is hung in a vacuum. Only soviet planners in Stalinism could gather so much power to take such a one-dimensional approach to the settlement of factories. In democratic societies, however, a large number of criteria are incorporated into location policy. The configuration of factories with machines also has a similarly complex goal bundle, as Gerhard Waescher has demonstrated in his standard book.

In computer science and combinatorial mathematics, the Quadratic Assignment triggered a flood of publications, for example in the Handbook of Combinatorial Optimization, which was last published in five volumes in 2013 and already had predecessor editions.[90] This problem could only be solved exactly up to a problem size of n = 30 by 2013. However, applications with empirical data remain unknown. Axel Nyberg claimed in his lecture on November 15, 2013 at the Abo University in Turku (Finland) that the hospital in Regensburg in Germany, built in 1972, had an optimal layout according to the Quadratic Assignment problem.[91] However, this was only proven in 2000 and could therefore not have played a role in the construction.

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[86] Tjalling Koopmans and Martin Beckmann: “Assignment Problems and the Location of Economic Activities.” *Econometrica*, Vol. 25, No. 1 (Jan., 1957), pp. 53-76.
[87] Mirowski, Machine Dreams, (cf. note 6), p. 252.
[88] Waescher, Gerhard: *Innerbetriebliche Standortplanung bei einfacher und mehrfacher Zielsetzung*, Wiesbaden, 1982.
[89] “Mathematical methods are finding ever more applications in the economic and social spheres, especially where decision-making in complicated situations is at stake. Operations Research in particular, which involves the application of mathematical models for economic decisions, has developed rapidly due to this need...”, (translated from German by R.V.) in: Beckmann, Martin, Gunter Menges und Reinhard Selten (eds.): *Handworterbuch der Mathematischen Wirtschaftswissenschaften, Teilband Unternehmensforschung*, Wiesbaden 1979, preface.
[90] Burkard, Rainer: “Quadratic Assignment Problems.” In: *Handbook of Combinatorial Optimization*, pp. 2741-2814, edited by Panos M. Pardalos, Ding-Zhu Du and Ronald L. Graham, Springer Verlag, 2013. The mathematician Burkhard supplies a bibliography: Burkard, Rainer: “Quadratic Assignment Problems.” In: *Handbook of Combinatorial Optimization*, pp. 2741-2814, ibidem.
[91] Nyberg, Axel: “Applications of the Quadratic Assignment Problem”, see: http://web.abo.fi/fak/tkf/at/ose/doc/Pres_15112013/Axel%20Nyberg.pdf.

**Computed meals as mathematical entertainment**

To attach a semblance of application, Dantzig invented new OR–problems to be solved with the aid of Linear Programming: the diet problem and the traveling salesman problem. Here I will focus on the diet problem. This problem was invented by the later Nobel Prize winner and economist George Stigler in 1945. It is a strange problem: How to nourish a person sufficiently for the lowest cost? Stigler contrasted the content of nutrients in various foods (such as vegetables, fruit and meat) with the cost of its procurement and asked how to serve a meal for a person with sufficient nutrients at the lowest cost.[92] Stigler's paper exists in a vacuum and is not linked to the economic situation of the US in 1945. Many consumption goods were rationed due to the war. The municipal and state run programs on social welfare focussed on poor people. Did Stigler want to reduce the cost of these programs? Why did Stigler search for the lowest cost, not for the second lowest or even the maximum cost? The strange diet problem survived for many decades in Operations Research textbooks, without any explanation as to why it might be useful.

In 1947, Jack Laderman of the Mathematical Tables Project in the National Bureau of Standards solved the diet problem with the new technique of Linear Programming. His approach consisted of 9 equations and 77 variables, and he solved it with the aid of office calculators, as an academic exercise without application. Dantzig devoted even a chapter in his 1963 book to this problem. Even on IBM's high speed digital computer 701, he coded the problem at the RAND Corporation, but his computed meals were never served to the pilots of Dantzig's employer, the Air Force. Dantzig did not recognize the double curiosity of applying advanced computational techniques to an invented problem based on only weak data – a problem that was neither posed by industry, councils nor the Armed Forces. As empirical data, he displayed in his book a table with nutrients, where the content of ascorbic acid varied by more than 100 percent between various types of apples.[93] So Dantzig could not answer the question of whether a pilot should eat one or two apples each day. Whereas the MPI–group regarded the diet problem as a serious scientific problem, one can criticise by stating that Dantzig's procedure lowered the cutting edge technology of high speed digital computers to the level of a toy, made purely for mathematical entertainment.[94]

**The transportation problem as an abstractification**

The transport model discussed in the following shows the paradox that its discoverer was awarded the Nobel Prize for Economics, but that his model was never applied in economic reality. The reasons for this failure will be explained. One can generalise this case to the effect that the transport model stands for many other models of the OR whose relevance is always only claimed.

The Transportation Problem is always an important chapter in every textbook on Operations Research and describes how to distribute the transport of goods between various sources

[92] George Stigler, "The Cost of Subsistence." *Journal of Farm Economics*, vol. 27, 1945, no. 2, pp. 303-314.
[93] George Dantzig, *Linear Programming*, (cf. note 58), pp. 551-553. Georg Dantzig, "The Diet Problem." *Interfaces*, vol. 20, 1990, no. 4, 43-47.
[94] Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), p. 65.

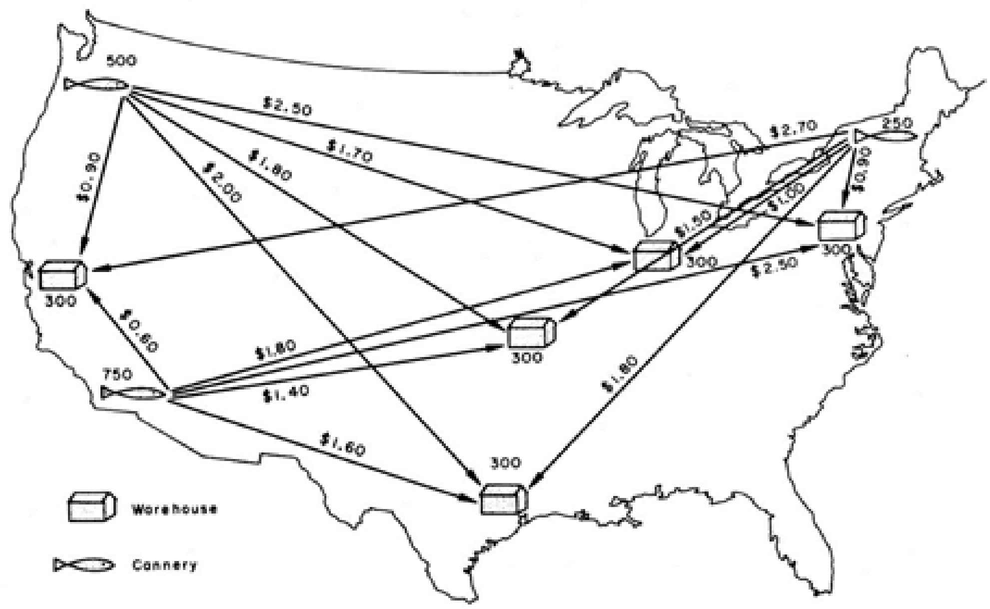
and destinations in order to minimize the total costs of transport.[95] Regarding the Transportation Problem, one can reveal the nominal nature of this problem. The economic world is used to identifying and abstractifying transportation problems and converting them into simple mathematical models for the academic world, without the intention of solving a problem in the real world. During WW2, the mathematical economist Tjalling Koopmans – who earned a doctoral degree in mathematical physics in the 1930s – formulated the so-called Transportation Problem. He observed, as a member of the Combined Shipping Board, bottlenecks in the transport chain and received the Nobel Prize in economics in 1975 for his discovery of the Transportation Problem (together with the Russian scientist Leonid Kantorovich for his discovery of Linear Programming).[96] The Transportation Problem can serve as an important example for the procedure of abstractification. Koopmans envisioned suppliers and receivers of goods, but he narrowed the focus to only one kind of goods, so that it remained indifferent for a receiver from which supplier they get the goods. As a consequence, the model cannot handle different types of goods. A motor truck or a ship could not load different types of goods as it is common in the real world. Furthermore, Koopmans excluded the economies of scale – commonly prevailing in the economy – in transportation costs, so that the transportation of one ton had to pay the same rate as a transportation of 1000 tons. Finally, he did not consider fluctuations in transportation rates during the lapse of time, which are also common in the real world. In this stripped version of the transport problem, the reader can gain impressive insights into primal and dual variables and their economic interpretation. Very appealingly, this problem can be graphically sketched with a view of the fishing industry's locations, for example, by a map of the United States which displays where canneries and warehouses are located and connected by transportation relations. George Dantzig did this in his book already in the introduction on page 3 to underline the importance of his book, cf. figure 1.

As a nominal approach, Dantzig produced the map in figure 1 as an invention on his office desk, but not from empirical data of a contract with a cannery firm. While the map calls upon the authority of an important economic problem, this impression is misleading. Like Game Theory, until now, no application of the Transportation Problem has been published. Koopmans abstractified this problem so much that it remains in the world of numbers and could not gain traction in the real world. No enterprise in the transportation trade (ship, aircraft, railway, motor truck) called for a project to optimize routes by the transportation problem. Remarkably, many OR textbooks did not apply a spreadsheet software to present and compute the transportation problem but preserved old-fashioned methods for finding an optimal solution. The north-west rule and the stepping stone method were outdated in the age of spreadsheet software, where one can apply Excel's Visual Basic to determine dual variables.

[95] George Dantzig, "Linear Programming", (cf. note 58), chapter 14. Dorfman et al., *Linear Programming*, (cf. note 56), chapter 5.

[96] Tjalling Koopmans, "Optimum Utilization of the Transportation System." In *Proceedings in the International Statistical Conferences*, Vol. 5, Washington DC, 1947. (Reprint in *Econometrica*, vol. 17, 1949, Supplement). George Dantzig, *Linear Programming*, (cf. note 58), 300. For the discovery of Linear Programming by Leonid Kantorovich see Dorfman, "The Discovery of Linear Programming" (cf. note 53). Dorfman et al., *Linear Programming*, (cf. note 58), p. 284. The Transportation problem was also discovered in 1941 by Frank Hitchcock, "The Distribution of a Product from Several Sources to Numerous Location." *Journal of Mathematics and Physics*, vol. 20, 1941, pp. 224-230. For the research of Koopmans at the Cowles Commission at University of Chicago and the cooperation with RAND see Philip Mirowski, *Machine Dreams*, (cf. note 6), pp. 263–272.

**Figure 1** The Transportation Problem in Dantzig's book 1963. Transportation inside the US between canneries and warehouses with transport rates.[97] (Source: George Dantzig: *Lineare Programmierung und Erweiterungen*, (German edition) Springer Verlag, Berlin, 1966, p. 3)




In the academic field of Operations Research, scholars were interested in their models but not in application, and so the question did not attract their attention in the 70 years since its discovery of 'why' the Transportation Problem is insufficient to be applied to problems in the world of economy. At first sight, the coordination of empty railcars in a railway company to be sent back to the sources of material seemed to be an appropriate application for the Transportation Problem. However German Railways did not coordinate their trains loaded with coal but rather used shuttle trains between the sources of coal and consumption destinations. Empirical research into railway systems revealed the time structure of transportation. The railway company needed forecasts for the demand of empty railcars that the Transportation Problem could not provide.[98]

### The travelling salesman as invention

In the United States of the 1940s, the profession of the traveling salesmen was held in high esteem by the public. Dantzig took this up when he invented the so–called traveling salesman problem. Also, this famous problem arose in the academic environment of the RAND corporation as an invention of the mathematician Dantzig to shed some light of application on Linear Programming, but not as a contract with a firm that wanted to improve its sales organisation. At RAND, the Travelling Salesman problem was seen as an additional intellectual challenge to Game Theory. Dantzig abstractified a problem of the daily life of a traveling salesman to visit customers and proposed with a small semantic shift that a traveling salesman has to visit not a number of customers but a number of cities. Danzig's question was how to organise the travel visiting these cities with the least sum of distances to be travelled. The RAND researchers, the mathematicians George Dantzig, Delbert Fulkerson

[97] Also in their joint paper "A Model of Transportation" Koopmans and Reiter showed maps of shipping routes of the world, 245s, in Koopmans, *Activity Analysis*, (cf. note 60), pp. 222-259.
[98] Michael Gorman, "Empty Railcar Distribution." In Bruce W. Patty (ed.), *Handbook of Operations Research Applications at Railroads*, New York 2015, pp. 177 – 190.

and Selmer Johnson, proposed on their office desk a route through the 48 states of the United States where they picked for each state one city. The route contained even the thinly populated state of Montana with less than half a million inhabitants where a salesman could hardly sell products in contrast to heavily populated states as California or Pennsylvania. In addition, the district Washington D.C. was merged into the route – a route that a traveling salesman in the physical world never would travel. The road distances between the cities were derived as "desktop research" from a road atlas.[99] The proposed route through the 48 states of the United States did not serve a sales organisation to guide its salesmen but was a good marketing story of Dantzig as he – supported by a map of the United States – appealed to the national proud of US citizens in every state. He showed that Linear Programming is a unifying tie connecting the single states. Gass and Assad made the humorous remark in their timeline: "See the USA in a Chevrolet", underlining the not very serious approach of the Travelling Salesman problem.[100] In the last 60 years the traveling salesman problem, with its semblance of application, fascinated mathematicians with a steady growing number of cities to be visited – parallel to the rising computing power of digital computers – until by the year 2017 they considered a route through 1.9 million cities of the world. Empirical surveys on the need for solution methods for the Travelling Salesman problem in industry remained unknown. The leading OR scholar in Germany, Andreas Drexl, who was the leading researcher at the University of Kiel (Germany) according to the press release of his University of Kiel, reported in a press interview that he was impressed by the beauty of the Travelling Salesman problem. Merill Flood reported in his paper that he had heard of applications.[101]

## Conclusion

This paper explores the influence that mathematicians took in the development of Game Theory and Operations Research at the RAND Corporation and in the academic world of mathematical and economic departments. It shows how mathematicians abstractified problems from social life to derive simple models as material for academic purposes and raises some doubts on the widely held view of important applications of Game Theory and Operations Research. The paper shows that important theorems in Operations Research were based on simple models and inventions and reveals the lack of empirical research. Examples, such as mixed strategies and the Transportation Problem, show how abstractification leads into the space of numbers where no applications in the real world were possible. The method of abstractification generates formal models that could not be supplemented by empirical data and lacks a layer of empirical research to generate data and apply their methods to economics and society. Therefore, their models were only nominal mathematics, without application.

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[99] G. Dantzig, R. Fulkerson and S. Johnson, "Solution of a Large-Scale Traveling-Salesman Problem." RAND Research Memorandum, P 510, April 1954.
[100] Gass and Assad, *Timeline*, 2005 (cf. note 12), p. 48.
[101] Press release University Kiel on 28 November 2005. Handelsblatt on 12 December 2005. "Flood, Merrill: The Traveling-Salesman Problem." *Operations Research*, Vol. 4, No. 1 (Feb., 1956), pp. 61-75., here p. 65.