

## Abstractification – A New Approach to the Evaluation of the History of Operations Research in the USA and Germany



Queuing in front of a toll bridge in Chicago 2008

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## Content

1	Introductory remarks.....	3
2	The Origin of Operations Research in the Cold War Context.....	5
3	The transmission of the linear programming to other mathematization approaches .....	8
4	The successful institutionalization of Operations Research 1950 - 1980 in the USA and West Germany .....	8
5	The reluctant application of Operations Research in industry .....	17
6	The rise of business informatics as a barrier to operations research .....	19
7	The initially problematic use of the large computer in mass data processing.....	21
8	Management Science and Operations Research .....	23
9	The Computer and Simulations in Operations Research .....	24
10	The artificial content of Cold War Operations Research .....	26
10.1	Dynamic Programming without application.....	26
10.2	The network flow model .....	27
10.3	The Quadratic Assignment problem as mathematical stalinism .....	27
10.4	Computed meals as mathematical entertainment.....	28
10.5	The transportation problem as an abstractification .....	29
10.6	The travelling salesman as an invention .....	32
11	The boom in transport optimization in the German Democratic Republic .....	32
12	Literature:.....	40

## Summary

The rise of Operations Research, which provides mathematical models for the management of commercial enterprises, in the political knowledge culture of Cold War Science is shown and then transferred to the institutionalization of Operations Research in Europe and in the Federal Republic of Germany. The predecessor organizations of the German Society for Operations Research are presented and the interaction of the annual conference of this society with the conferences on a European and worldwide level. It tells how numerous chairs for corporate research and operations research were founded at universities between 1960 and 1980. The connection between Operations Research and the macroeconomic field of econometrics in chairs, conferences and publications is explained and problematized. The great flood of publications on the subject of Operations Research between 1960 and 1980 is referred to, but the rise of the competing field of business informatics in the 1980s halted the success of Operations Research. Based on the historical study by Alexander Nützenadel, the difference between the field of econometrics, which is based on empirical data, and the field of operations research, which is more academically oriented, is worked out. The methodological approach of Operations Research is referred to as abstractification. An example for abstractification is the transport model of linear optimization, which simplifies (abstractifies) economic reality to such an extent that it can be transformed into manageable formulas. However, the transport model is

unsuitable for applications in the real economy and thus serves only as a self-referential project for the academic sector. This contribution shows that Operations Research lacks the level of empirical implementation of mathematical models known from econometrics and the social sciences. How transport optimization was taken up in the political knowledge cultures of the Eastern bloc (1945 - 1990) and in the German Democratic Republic is dealt with in a section.

## 1 Introductory remarks

This paper was written for the workshop Algorithmic Knowledge Cultures of the Deutsches Museum Munich in September 2017. It shows how the field of Operations Research (OR) has emerged in the political knowledge culture of the Cold War since 1945. First the rapid institutional rise in the social spaces of universities is illustrated, but then the low degree of empirical projects in the social spaces of commercial enterprises is described and reasons given. At the same time, the rapid proliferation of computers for corporate management has hindered the implementation of OR projects in companies. The decline of Operations Research in the social spaces of universities began in the 1990s, when more and more chairs were rededicated to business informatics and logistics.

As Alexander Nützenadel noted in 2005 in his historical scientific study "The Hour of Economists" on economics, econometrics and scientific policy advice in the Federal Republic of Germany (FRG) in the 1950s and 1960s,<sup>1</sup> the period 1950 – 1965, which was fundamental for the political and economic emergence and establishment of the FRG, had so far been little researched. In this paper I take up the approach of Nützenadel and extend its investigation from economics to the historization of mathematical planning procedures in economics and business administration in the Federal Republic of Germany. The section 10 of this paper has already been published in the journal Real World Economic Review, volume 88, July 2019.<sup>2</sup>

The Operations Research chairs are located in universities' business administration departments and deal with mathematical methods for the planning of material flow systems in factories, for the circulation planning of means of transport and for the creation of personnel deployment plans.<sup>3</sup> The research guiding ideas are the minimization of costs or the maximization of profits of an individual company. The cost and profit amounts are linked by definition via the turnover of a company as follows: Profit = Turnover - Costs. Costs or profits are modeled as a function of variables, and the minimum or maximum of this function is attempted to determine. In so-called linear programming, these functions are modeled as linear functions of the sets used and become the object of algorithms when they are minimized or maximized by complex structures of constraints, mostly expressed by linear inequalities, by compact sets in the n-dimensional number space. Often the algorithms have a loop structure of the form Repeat ... Improvement step ... until termination condition.

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<sup>1</sup> Nützenadel, economists, 2005.

<sup>2</sup> Vahrenkamp, Nominal Science, 2019.

<sup>3</sup> Operations Research is also abbreviated to OR and is also known in German as corporate research.

So far, the publications on the history of Operations Research have been rather uncritical success stories, such as the "Timeline" by Saul Gass and Arjang Assad from 2005 or the history of the OR by Stephen Johnson from 1997,<sup>4</sup> while the aim of this paper is to examine the field of Operations Research from the point of view of the history of science and to point out the social spaces in the Cold War science of the USA, but also in the Eastern Bloc, in which the algorithmic knowledge cultures of Operations Research emerged. For evaluation purposes, a new approach is used to characterize the OR as a mathematical discipline based on the development of new mathematical methods, but less interested in obtaining empirical data. If one compares Operations Research with the empirical sciences of econometrics, meteorology, astronomy and engineering, the OR's approach becomes clear. Atushi Akera and Brent Jesiek have already highlighted the leading role of mathematicians in the development of the electronic digital computer.<sup>5</sup> I would like to take up this kind of argumentation and show that Operations Research also provides a mathematician-driven view of the world that uses new mathematical methods to develop abstract models of the economic and social structures of society.

In the engineering sciences, econometrics, astronomy and meteorology, mathematical models are used to structure measured data in order to make better predictions. Computers are loaded with data to test models. The scholars work within the triangle data model computer and thus make this approach a data-driven one.<sup>6</sup> Numerous contributions in the literature show the emergence of mathematical models in meteorology, the collection of data in this field and their evaluation on computers in John von Neumann's group at the Institute for Advanced Study in Princeton from 1945 to 1955.<sup>7</sup> Gabriele Gramelsberger's contributions also demonstrate the empirical relevance of the branches of science biology and meteorology. The scientists mostly have personal experience with the material they are studying, as Nathan Ensmenger has shown using the example of laboratories in biological research.<sup>8</sup> Alexander Nützenadel demonstrated in his historical study the role of empirical economic data in the application of mathematical econometric models of the economy as a whole for forecasting economic development.<sup>9</sup>

However, the empirical reference to other scientific disciplines outlined here is missing in Operations Research. Heiner Müller-Merbach, Professor of Operations Research in Darmstadt, had already critically pointed this out in 1981, and this paper follows his approach.<sup>10</sup> Without an empirical research approach, the OR converts and abstractifies economic relations into mathematical models that provide material for academic practice and merely represent a value in itself, but do not serve to solve social and economic problems. Operations Research is therefore not data-driven, but driven by new mathematical methods and belongs to the field of applied mathematics. This reference to applied mathematics is also seen by professors for OR, such as the leading OR promoter Hans Künzi, who held a chair for OR at the University of Zurich. In his opening lecture at the annual conference of the German Society for Operations Research in 1971, he stated: "One does not go wrong if one regards the theory of the new branch of research as a subfield of applied mathematics".<sup>11</sup> Unlike in the data-driven

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<sup>4</sup> Gass/Assad, *Timeline*, 2005. Johnson, *Approaches*, 1997.

<sup>5</sup> Akera, *Calculating*, 2007. Jesiek, *Origins*, 2013. On the early history of the digital computer see also Rojas / Hashagen: *The First Computers*, 2000.

<sup>6</sup> Gramelsberger, *Science*, 2011.

<sup>7</sup> Thompson, *Weather 1957*. Aspray, Neumann, 1990.

<sup>8</sup> Ensmenger, *Construction*, 2012.

<sup>9</sup> Nützenadel, *economists*, 2005.

<sup>10</sup> Müller-Merbach, *Empirical Research*, 1981.

<sup>11</sup> Künzi: *Corporate Research*, 1971, p. 3.

sciences described above, the researchers had no personal experience with the material of their field. Empirical data was not the focus of OR, and therefore the triangle data model computer often remained unused. The paper shows that the OR lacks a level of empirical implementation of mathematical models, such as those known from econometrics and the social sciences, and that this level has not been the subject of textbooks or research efforts in the field of operations research.

It should be emphasised that the process of modelling simplifies social reality to the extent that mathematical formulae can be applied at all and any necessary data collection is also simplified, as shown below using the example of the Berlin Air Lift. However, all models, even in the above-mentioned disciplines of engineering, econometrics, astronomy and meteorology, simplify reality. In contrast to the OR, however, the results of the model calculations are again applied in the real world. However, the OR lacks this reference to reality, as this article shows using the example of the transport model.

## 2 The Origin of Operations Research in the Cold War Context

This section shows how Operations Research originated in the political knowledge culture of the Second World War and the subsequent Cold War. During the Second World War, Operations Research was developed in Britain and the USA to investigate methods for detecting enemy aircraft and submarines. Great Britain founded the group for Naval Operational Research and the USA the Antisubmarine Warfare Operations Research Group (ASWORG). After the Second World War, OR research did not break off, but the USA maintained special OR knowledge with the Navy Operations Evaluation Group, albeit with a reduced team. This group further developed the OR methods during the Cold War.<sup>12</sup>

In the social spaces of the mathematical departments in the U.S. armed forces, mathematicians strongly supported the development of the digital computer and related research in game theory and operations research. The Army's Ballistic Research Laboratory in Aberdeen, Md., was led by mathematicians and funded the development of the first electronic digital computer ENIAC at the Moore School of the University of Pennsylvania in Philadelphia. The Navy maintained a Naval Research office in Washington, D.C. with a mathematics department and supported numerous research and development projects.<sup>13</sup> The Air Force also operated the RAND Corporation (in Santa Monica near Los Angeles) with a Department of Applied Mathematics and the National Bureau of Standards (in Washington, D.C.) as agencies to finance and develop the digital computer, Operations Research and Game Theory. In the National Bureau of Standards, computer development was led by the Department of Applied Mathematics, which published a series of books on applied mathematics. The RAND Corporation was founded in 1948 in Santa Monica by the Air Force and was regarded as their think tank.<sup>14</sup> Research there focused not only on the future of air warfare and strategic bombing, but also on academic activities. RAND organized conferences and published books. As a newly formed branch of the military in 1947, the US Air Force (previously part of the US Army) sought to make a name for itself

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<sup>12</sup> Harris, Center, 1996, p. 62-64. Shrader, History, 2013, chapter one.

<sup>13</sup> Rees, Computing, 1982, pp. 102-120.

<sup>14</sup> Shrader, History, 2013, S. 60. For RAND Corporation see Edwards, World, 1996, S. 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).

by applying scientific methods to the programming and use of the digital computer - which was only expected in the future - for this task, as a Chief of Staff Circular of 13 October 1948 put it.<sup>15</sup>

The invention of linear programming was made independently by the Russian mathematician and later Nobel Prize winner Leonid Kantorovich in 1939 and the US mathematician George Dantzig in 1947 at RAND in the context of Cold War Science. Before Linear Programming was developed as a mathematical optimization method in the RAND Corporation, Kantorowitsch developed his Linear Programming Approaches in 1939, which had remained unknown in the USA until 1960.<sup>16</sup> In 1947, RAND started the SCOOP project, which was intended to produce planning documents and forecasts for the demand for spare parts and fuel for the various aircraft types on the worldwide Air Force bases. This project has already been described in various historical analyses of mathematization.<sup>17</sup> The aim of this project was to accelerate the planning steps for a military operation, the so-called programme. In expectation of the electronic digital computer, the use of mathematical planning methods should shorten the program steps. The RAND mathematician Georg Dantzig invented a mathematical planning approach in 1947 and called it Linear Programming. It provided calculation techniques to maximize a linear function over a convex and compact set in the n-dimensional number space spanned by linear inequalities. The RAND Corporation owned numerous CPC-IBM machines, and Dantzig programmed, but not until 1952, his SCOOP optimization problem with 45 variables on this machine to identify the minimum cost of worldwide spare parts supply for the Air Force. After 8 hours he got the result. In 1952, he also coded this problem on the Univac I high-speed digital computer.<sup>18</sup> Among Dantzig's numerous research memoranda, applications of his model in the SCOOP project, which was to coordinate the Air Force's repair capacity worldwide, remained unknown. Dantzig's work at RAND seemed to be academic and without applications. The head of the SCOOP project, Murray Geisler, estimated that the Air Force's requirements were too extensive to be treated as a linear programme of the time in terms of scale.<sup>19</sup> Independently of Dantzig's efforts, other scholars working on the SCOOP project have already been able to make decisions using methods other than linear programming to assemble air-transportable emergency crates of key spare parts, which are then distributed across all Air Force bases worldwide. It is remarkable from the point of view of scientific history that the development of linear programming was not marked by the expectation, otherwise expressed by economists, that economic science would be able to make similarly exact predictions to those in physics. These expectations motivated many mathematical economists in the 1940s, as Alexander Nützenadel pointed out in his investigation.<sup>20</sup>

As a showcase project for linear programming in the political knowledge culture of the US Air Force in the context of the Cold War, the SCOOP group also developed a model for the Berlin Airlift of 1948-

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<sup>15</sup> Paul Erickson et al., *How Reason Almost Lost Its Mind*, 60. On the history of RAND, see also the official presentation *50 Years Project Air Force*, 1996.

<sup>16</sup> The English translation can be found in Kantorowitsch, *Methods*, 1960.

<sup>17</sup> For the SCOOP Project see Ceruzzi, *Limits*, 1989, S. 41–43. Dantzig, *Impact*, 1985, S. 15. Dorfman, *Discovery*, 1984. Geisler, *History*, 1986, S. 3–17. Johnson, *Approaches*, 898. Erickson, *Mind*, 72. Klein, *Cold War*, 2007.

<sup>18</sup> Orchard-Hays, *History*, 1984, p. 300. For Dantzig's coding work, see also Dantzig, *Impact*, 1985, p. 26. For CPC machines, see Bashe et al., *IBM's*, 1986, p. 71.

<sup>19</sup> Geisler, *History*, 1986, p. 5. I am talking here about digital high-speed computers in order to distinguish the use of electronic analog computers, which were common in the US aviation industry for solving differential equations, see Vahrenkamp, *Computing Boom*, 2019. Professor Jürgen Heinhold of the University of Munich applied in 1962 for a DFG project on application possibilities of the electronic analog computer to problems of nonlinear optimization, see Brusberg, *Unternehmensforschung* 1965, p. 313.

<sup>20</sup> Nützenadel, *economists*, 2005, p. 91.

1949 (Operation Vittel) and made it public at various conferences. Based on the wide range of aircraft models used in the Berlin Airlift, the project abstractified the aircraft fleet and considered only C7 and C47 aircraft. It determined the most cost-effective schedule, taking into account fuel costs, crews and spare engines. The model was never used in daily planning, but served as a tutorial example to demonstrate the benefits of linear programming. It attracted academic attention, and some dissertations on this model were written. Murray Geisler, the head of SCOOP, suspected that the air force's requirements were too extensive and exceeded the scale that a linear programme could handle at the time. He assumed that 3600 variables and 3600 inequalities would be necessary.<sup>21</sup>

As Nutzenadel had established in his investigation, the economists of the 1940s had a widespread idea that mechanical analogies, such as hydraulic machines, were to be sought for processes in the national economy. This also included the statistical determination of material flows between economic sectors, which were then formalised into input-output tables that reflect all upstream supply relationships.<sup>22</sup> In the Bureau of Labour Statistics of the USA Wassily Leontief collected data for an Input-Output-Matrix of the USA and gained a high scientific reputation. But this matrix, let's say  $A$ , with 200 rows and 200 columns, could only be used with a high-speed digital computer that was not available until the mid-1950s. To use the table, the "Leontief Inverse" matrix  $(I-A)^{-1}$  had to be calculated, which was only possible with a computer.<sup>23</sup> Wassily Leontief's research also influenced SCOOP. In Project SCOOP, Dantzig expanded the matrix, known as inter industries relations, to 400 industrial sectors.<sup>24</sup> What is remarkable from the point of view of scientific history is how the SCOOP Group oscillated between local optimisation in a company or an organisation such as the Air Force and the macroeconomic level of the economy. Ideas on central economic planning ("market socialism") were discussed, which have asserted themselves in their enemy country – the Soviet Union. Under market socialism, the companies worked independently of each other, but the prices of the goods were calculated by a central computer ('super brain').<sup>25</sup> As a member of SCOOP, George Dantzig at the 1949 Activity Analysis Conference pointed out, like a Soviet planner, that Leontief's model could answer the central planning question of how much aluminum, steel, and electrical energy would be needed to meet the demands of increasing weapons production.<sup>26</sup> As Nutzenadel critically remarked, however, it remained open whether the input-output tables merely represent an impressive collection of statistics or whether they provide a useful basis for economic policy decisions.<sup>27</sup>

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<sup>21</sup> Murray Geisler, *A Personal History of Logistics*, 6. Marshall Woon and Murray Geisler, *Development of Dynamic Models for Program Planning*, 1951. For operation Vittel see Paul Erickson et al., *How Reason Almost Lost Its Mind*, 2013, p. 56s.

<sup>22</sup> Nutzenadel, *economists*, 2005, pp. 104–108.

<sup>23</sup> Frederick Moore, "A Survey of Current Interindustry Models", in *National Bureau of Economic Research*, 1955, 215-252. For the calculation time of matrix inversion on different machines see Gass, *Programming Shoppe*, 2002, 62.

<sup>24</sup> Dantzig, *Operations Research in the world*, 1967, p. 115.

<sup>25</sup> Dorfman, Robert, Paul Samuelson and Robert Solow, *Linear Programming and Economic Analysis*, New York, 1958, 395. This book appeared under copyright of the RAND Corporation. Philip Mirowski, *Machine Dreams*, 259.

<sup>26</sup> Marshall Woon and George Dantzig, "The Programming of independent Activities", in: *Koopmans 1951*, 15–18, here 18.

<sup>27</sup> Nutzenadel, *economists*, 2005, p. 108.

### 3 The transmission of the linear programming to other mathematization approaches

This section shows the rise of linear programming in the knowledge cultures of game theory and economics. When Dantzig presented his discovery of linear programming to John von Neumann in 1947, Neumann's mathematical genius was able to quickly make connections between linear optimization and two-person zero-sum play and also develop the duality theory of linear optimization.<sup>28</sup> Each linear program has a dual program with dual variables that uses the transposed coefficient matrix of the primal program. When solving the primal program, the dual program is implicitly solved at the same time. This primal-dual view considerably expanded the knowledge culture of linear programming. Whereas in the classical simplex algorithm the primary variables are always kept in the admissibility range, i.e. they are not negative and lie in the range of the admissible solutions of the polyhedron, in the dual program the dual variables are transferred step by step into their admissible range in parallel, so that at the end both the primary and the dual variables are admissible. Various algorithms are based on this primal-dual approach. The algorithm for the transport model examines how it can improve existing primary solutions by identifying attractive dual variables. The assignment problem as a specialization of the transport model proceeds differently. There, the dual variables are kept within the admissibility range at each step, while the primal variables are gradually transferred to the admissibility range.<sup>29</sup> The transport model radiates mathematical beauty, and intellectually and the “game” with primary and dual variables is very fascinating.

Economics has also taken up the primary and dual approaches. In the economic models, primal models are quantity-oriented, while dual models provide corresponding price information. In economics, linear programming could provide models that could be applied to production with linear production functions, to general equilibrium theory, to welfare economics, and to the theory of duopolies. In this respect, linear programming developed into an important component of the static equilibrium models of neoclassical theory. The famous economists Robert Dorfman, Robert Solow and Paul Samuelson were grateful to the RAND Corporation that Linear Programming was considered a fruitful analytical tool and in 1958 supported the publication of their book "Linear Programming and Economic Analysis", as they wrote in the preface. This publication in the RAND Books Series was very influential in that an international student edition also appeared.

### 4 The successful institutionalization of Operations Research 1950 - 1980 in the USA and West Germany

This section deals with the political knowledge cultures in which Operations Research emerged. This has already been researched by the group at the Max Planck Institute for the History of Science (MPI

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<sup>28</sup> Dantzig, *Impact*, 1985. Von Neumann/Morgenstern, *Theory*, 1944. Morgenstern, *Collaboration*, 1976. Henn/Moeschlin, *Mathematical*, 1977. Oskar Morgenstern took over a lectureship at the chair of Professor Rudolf Henn at the University of Karlsruhe in 1973.

<sup>29</sup> Mattfeld/Vahrenkamp, *Logistics Networks*, 2014, p. 173.



Group), which held a summer school on this topic in Berlin in 2010.<sup>30</sup> US Air Force projects have also driven the transition from military to civilian linear programming applications in administration and industry. RAND entered into agreements with the Universities of Chicago and Pittsburgh to apply the mathematical planning procedures summarized under the term "Operations Research" in the civil sector with the mathematical economist Tjalling Koopmans, with Abraham Charnes and with Herbert Simon.<sup>31</sup> In 1949 – just two years after Dantzig's discovery – RAND organized the later famous conference on Linear Programming at the University of Chicago, announced as "Activity Analysis of Production and Allocation", followed by the first symposium in Linear Programming in Washington, D.C., under the joint patronage of the RAND Corporation and the National Bureau of Standards in 1951. Both conferences took place without any experience with high-speed digital computers, which were only available at RAND in 1953. Together with Bob Mellon, head of an oil refinery, the University of Pittsburgh has carried out a linear programming project on behalf of the US Air Force to find the most cost-effective mixture of aviation gasoline.<sup>32</sup> The model contained 22 variables and was solved using electromechanical desktop calculators. The authors Charnes et al. did not mention the use of a digital IBM CPC machine or even a digital electronic computer. The motivation of the Air Force contract remains unclear. Was there a prevalent shortage of aviation gasoline? Or was the issue of aviation gasoline a sufficient justification for an Air Force contract? These questions shed light on the diffuse motivation of the Air Force in its R&D policy.

In the 1950s, the term Operations Research was used to describe heterogeneous mathematical methods such as game theory, dynamic programming, linear programming, warehousing, spare parts theory, queue theory, simulation and production control, which were used primarily in civilian industry. Scientific societies and journals on the subject of Operations Research were founded in the 1950s, such as the Operation Research Society of America (ORSA) in 1952 and the Institute for Management Science (TIMS) in 1953. In the 1960s, ORSA reached the amazing number of 8000 members.<sup>33</sup> Consulting companies also founded OR groups, as William Thomas emphasized in his study. In 1953, Abraham Charnes and William Cooper published the first textbook on linear programming.<sup>34</sup>

This section deals with the social spaces that are described as the institutionalization of the OR by mathematicians in economics departments of universities. The creation of ORSA and TIMS was not based on industry demand for OR applications, but turned out to be an autonomous expert movement of mathematicians supported by military research institutions. The Office of Naval Research has published Naval Research Logistics Quarterly since 1953, which published models of battlefields and became the world's leading international journal for Operations Research in the 1950s. The Office of Ordnance Research of the US Army held its first OR conference in January 1955.<sup>35</sup> In his 1960 book on the automation movement, Herbert Simon characterized Operations Research as a new science of management driven by mathematicians.<sup>36</sup> The autonomous OR movement of mathematicians was not unusual for the 20th century. One can also place Taylorism in the context of various expert movements

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<sup>30</sup> Erickson and others, *How Reason* 2013. Klein, *Cold War* 2015.

<sup>31</sup> Johnson, *Three Approaches to Big Technology*, 898. Paul Erickson et al., *How reason almost lost its mind*, 2013, 72. Klein, *The Cold War Hot*, 2007. Koopmans, *Activity Analysis*, 1951. Klein, *Cold War*, 2015.

<sup>32</sup> Charnes, *Programming Interdependent Activities*, 1952.

<sup>33</sup> Hanssmann, *Corporate Research*, 1971, p. 11.

<sup>34</sup> Thomas, *Operations Research* 2012. Charnes, *Linear Programming*, 1953.

<sup>35</sup> Churchman/Ackoff/Arnoff, *Introduction*, 1957, p. 429.

<sup>36</sup> Simon, *Science*, 1960, p. 15.

in the 20th century, as well as the rationalization debate in Europe in the 1920s and the automation debate in the USA and Europe around 1960.<sup>37</sup>

In the 1950s and 1960s, chairs of Operations Research were established in the faculties of university management in the USA and Great Britain. The first Chair of OR in Great Britain was established at the University of Lancaster in 1964. The Nato headquarters in Brussels set up a military OR group, which had an impact on the creation of an OR chair at the Catholic University of Leuven (Belgium), where Jacques Drèze founded CORE, the Center for Operations Research and Econometrics, in 1966.<sup>38</sup> In the 1960s, OR chairs were also established in Switzerland and the Federal Republic of Germany (BRD). As early as 1958, the habilitated mathematician Hans Künzi held an OR chair at the University of Zurich and from 1966 an additional parallel OR chair at the Swiss Federal Institute of Technology Zurich. Since 1962 he has been President of the Swiss Association for Operations Research (SVOR). In his opening lecture on "Operations Research in Science, Business and Politics" at the annual conference of the German Society for Operations Research in Bochum in 1971, Künzi reported on a project with the Swiss Ministry of Economics in which he modelled the cost-minimal allocation of arable land in Swiss agriculture using an optimisation model in order to ensure the supply of food to the Swiss population in the event of defence. To determine the optimal solution, the model ran for one hour on a high-speed digital computer. He also reported on a cost-minimized selection of a fighter aircraft for the Swiss military and the optimization of inner-city traffic light circuits.<sup>39</sup> However, these three examples lack industrial applications. From the title "Unternehmensforschung in Wissenschaft, Wirtschaft und Politik" ("Operations Research in Science, Business and Politics"), Künzi first refers to science and thus indicates the self-referential understanding of the social space of Operations Research.

Before the increased institutionalization of OR at universities in Germany began in the 1960s, the Working Group Operational Research (AKOR) was founded in Darmstadt in 1957 and the Deutsche Gesellschaft für Unternehmensforschung (DGU) in Munich in 1961, whose membership reached 259 in 1962. These associations published the journals "Ablauf- und Planungsforschung" (five times a year) and "Unternehmensforschung" (four times a year).<sup>40</sup> In 1971 AKOR and DGU merged to form the German Society for Operations Research (DGOR), which since then has held annual meetings and publishes its papers in annual proceedings. The number of personal DGOR members grew from 496 in 1972 to over 600 in 1978.<sup>41</sup>

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<sup>37</sup> Haber, *Efficiency*, 1964. Maier, *Taylorism*, 1970. Kline, *Cybernetics*, 2006.

<sup>38</sup> NATO Conference on the Role and Evaluation of Military Exercises in Operational Research, London, England, 25 August 1964. Kirby, M. and R. Capey, *The Origins and Diffusion of Operational Research in the UK*, 1998. Brusberg, *Unternehmensforschung* 1965, p. 52.

<sup>39</sup> Künzi, *Corporate Research*, 1971, p. 8.

<sup>40</sup> Brusberg, *Corporate Research*, 1965, p. 56f, p. 242-244. Albach, *Corporate Research*, 1967, p. 254.

<sup>41</sup> 40 Reinhold Sellien, Helmut Sellien (eds.), *Gablers Wirtschafts Lexikon*, 10th edition, Wiesbaden 1980, column 1003f. Bradtke, *Grundlagen*, 2003, p. 3. German Society for Operations Research (Hersg.), *Membership Directory*, 1978, Niddatal 1978. Brusberg, *Corporate Research*, 1965, p. 241.

In 1963, there were already three institutes for Operations Research at universities in Germany:<sup>42</sup>

- Institute for Industrial Enterprise Research at the University of Münster, headed by Ludwig Pack, Professor of Business Administration.
- Institute for Econometrics and Operations Research at the University of Bonn, headed by Martin Beckmann, Professor of Economics, after working with the mathematical economist Tjalling Koopmans (see below) in the Cowles Commission at the University of Chicago.<sup>43</sup>
- Institute for Operations Research at the University of Hamburg, headed by Herbert Jacob, Professor of Industrial Management and Organization.

The boom in Operations Research observed by Thomas Bradtke<sup>44</sup> in Germany between 1960 and 1970 was given a considerable boost by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) when it included the field of corporate research in its priority programme in 1961. In 1962 and 1963, she financed 16 and 30 small-scale projects on Operations Research, respectively, with one to two man-years each, at the chairs of West German universities, which were predominantly set up in model theory without empirical reference, as the thematic list of all projects revealed.<sup>45</sup> The DFG commissioned a report on the state of Operations Research, which was published as a 400-page book in 1965. The author, Diplomingenieur Helmut Brusberg, recommended an extension of the DFG priority programme and the inclusion of "at least one mathematician" in the local OR research groups.<sup>46</sup> There was no mention of female mathematicians in the report. The Faculty of Economic Sciences at the University of Bonn benefited from the close proximity of the DFG headquarters in Bad Godesberg. Not only was a literature reference for OR in Bonn financed by the DFG, which already comprised 836 volumes in 1963.<sup>47</sup> In 1962 and 1963, the faculty was also able to acquire two and three small projects respectively in the OR priority programme: Professor Horst Albach, who played a leading role in business administration, received the model theoretical projects:

- Operational issues of investment policy,
- Applications of Dynamic Programming in Investment Theory and
- Scheduling and production planning.

And Professor Wilhelm Krelle received two self-referential projects from the DFG: "Promotion of Operations Research."<sup>48</sup> Krelle graduated with a degree in physics and already played a decisive role in the OR network when the DGU was founded and as its chairman. On the macroeconomic level, he developed large econometric models of the German economy ("the Bonn Model") and became spokesperson of the DFG Collaborative Research Centre 21 "Economic Prognosis, Decision and Equilibrium Models" at the University of Bonn from 1970 to 1984. In subproject B1, he conducted research on mathematical econometric prognosis models of the economy as a whole.<sup>49</sup>

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<sup>42</sup> Brusberg, Corporate Research, 1965, p. 253.

<sup>43</sup> For the role of Tjalling Koopmans in the Cowles Commission see Mirowski, Machine, 2002.

<sup>44</sup> Bradtke, Basics, 2003, p. 2.

<sup>45</sup> Brusberg, Operations Research 1965, pp. 313-316.

<sup>46</sup> See also Albach, Unternehmensforschung, 1967.

<sup>47</sup> Catalogue of the Reference for Corporate Research, Institute for Econometrics and Corporate Research, University of Bonn 1963-1970, Institute for Econometrics and Corporate Research, Bonn, 1971.

<sup>48</sup> Brusberg, Operations Research 1965, p. 313s.

<sup>49</sup> On Wilhelm Krelle see Nützenadel, Ökonomen, 2005, pp. 118-119.

With an economic and mathematical education, Rudolf Henn occupied the Chair of Econometrics and Operations Research at the University of Karlsruhe in 1966 and became one of the leading OR promoters in Germany with his journal "Operations Research Verfahren" published since 1963. Volume 1, published in 1963, published the papers of the conference on OR procedures in industry held in Zurich on 9 and 10 December 1959. The conference was organized by the Research Center Operations Research and Econometrics of the University of Göttingen and the Institute of Business Administration of the University of St. Gallen.<sup>50</sup> Volume 2, published in 1965, contained the opening lecture by Henri Theil on "Econometrics and Operations Research ", which he gave at the joint meeting of TIMS and the Econometric Society in Zurich in September 1964, indicating the influence of TIMS in Europe and the link between the fields of OR and econometrics. With the publication of volume 3, the mathematician Burkhardt Rauhut, who holds a degree in mathematics, assumed the function of editor at the Henn Chair in the Institute for Economic and Social Sciences at the Technical University of Karlsruhe. In 1966, both Henn and Künzi jointly published the basic work "Einführung in die Unternehmensforschung" ("Introduction to Operations Research ") for university teaching in the Heidelberg pocket books of Springer Verlag in two volumes.<sup>51</sup>

Five newly created OR chairs in Germany indicate a successful institutionalisation of OR in the social spaces of universities in the period 1969 - 1981:

- Hans-Jürgen Zimmermann (Chair of Corporate Research) at the RWTH Aachen University in 1969. Zimmermann completed his studies in the mathematical models strongly influenced course of studies of the graduate engineer and received his doctorate in mathematical economics. Zimmermann introduced methods of fuzzy sets into the OR.
- Christoph Schneeweiss (Chair of Operations Research) at the FU Berlin 1971. Schneeweiss received his doctorate in physics, a field strongly influenced by mathematical models. Schneeweiss was president of EURO from 1999 to 2000 (see below).
- Heiner Müller-Merbach, 1972 Professor of Business Administration and Operations Research at the TH Darmstadt. From 1961 to 1967 he was an assistant at the Institute for Practical Mathematics of the TH Darmstadt.
- Dieter Pressmer (Chair of Corporate Research) at the University of Hamburg in 1974. He completed his studies in the mathematical models strongly influenced course of the graduate engineer. Pressmer was President of the 9th World Congress of IFORS 1984 (see below).
- Wolfgang Domschke (Chair of Operations Research) at the Bundeswehr University Hamburg 1975. Domschke obtained his academic degrees at the Faculty of Economics of the Technical University Karlsruhe, which is strongly influenced by mathematics.
- Richard Vahrenkamp (Chair of Operations Research) at the University of Kassel in 1981. Vahrenkamp completed his studies at the University of Heidelberg with a degree in mathematics.

The boom in Operations Research observed by Thomas Bradtke in the Federal Republic of Germany continued after this constellation in the years 1970 to 1980.<sup>52</sup> The tendency to fill OR chairs at economics faculties primarily with mathematically trained applicants can only be stated here. The

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<sup>50</sup> For the history of econometrics, see Nützenadel, Ökonomen, 2005, pp. 91s.

<sup>51</sup> Henn/Künzi, Introduction, 1966 with biographical data of Henn and Künzi.

<sup>52</sup> Bradtke, Basics, 2003, p. 2.

reason for the high reputation of this applicant category at the economic science faculties can only be explained by studying the archive holdings, where files of appointment procedures could provide information. One can generally assume a high reputation of the modern quantitative methods originating from the USA in Europe, which were also created and supported in the press by numerous picture reports about the arrival of large computers from the USA by air freight at airports in Germany and Switzerland.<sup>53</sup>

Hans Künzi and Martin Beckmann gained a dominant position in the German-speaking area of the OR research network (including Austria and Switzerland) when they published a softcover Lecture Notes series at Springer Verlag in 1968: The "Lecture Notes in Operations Research and Mathematical Economics", which were renamed "Lecture Notes in Operations Research and Mathematical Systems" from volume 15 onwards in 1969. It was renamed to "Lecture Notes in Economics and Mathematical Systems" in 1971 from volume number 60 onwards. Künzi also used volume 1 of the OR series on decisions in cases of uncertainty as training material for the SVOR.<sup>54</sup> With these series, Springer Verlag opened up a new publication format based on the duplication of typewriter manuscripts using the offset process, thus avoiding the costly lead typesetting and enabling rapid publication after manuscript submission. The rows grew explosively. The series "Lecture Notes in Economics and Mathematical Systems" reached the number of 170 titles in 1979, i.e. 16 titles per year since 1968, as the editors documented in a special volume.<sup>55</sup> The other series already reached the number of 50 titles in 1970, i.e. also 16 titles per year.<sup>56</sup> Before the success of the Lecture Notes series, Hans Künzi and Wilhelm Krelle laid the foundation for the hardcover book series "Ökonometrie und Unternehmensforschung" at Springer Verlag. Volume 1 was Künzi/Krelle/Oettli: Nichtlineare Programmierung, 1962, then four years later Volume 2 was published in 1966 with the German translation of Dantzig's book "Linear Programming and Extensions". Within 10 years, 20 more volumes followed.<sup>57</sup> The dictum "Hour of the Economists", coined by Alexander Nützenadel, seems to apply to the 1970s, considering the rapid expansion the Lecture Notes series and Künzi's and Krelle's hard-cover series.

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<sup>53</sup> See the great press echo of the arrival of a UNIVAC computer at Frankfurt's Rhein-Main airport in a PAN AM cargo plane on August 6, 1956. The computer was destined for the contract research company Battelle in Frankfurt a.M., see Die Lochkarte – Hausmitteilungen der Remington Rand GmbH Frankfurt a. M., No. 168, 1956, p. 1973.

<sup>54</sup> H. Bühlmann and others: Introduction to the Theory and Practice of Decision in Uncertainty, Berlin 1968, second edition 1969.

<sup>55</sup> Beckmann/Künzi 1979.

<sup>56</sup> Beckmann, Operations Research Today, 1971, Directory of Titles.

<sup>57</sup> A list of the published volumes is printed in Burkhard/Derigs: Assignment und Matching Probleme, 1980, backcover. Even before the Lecture Notes series, the Akademie Verlag in East Berlin published the protocols of the conference "Mathematics and Cybernetics in Economics" in a similar format to the Lecture Notes series already in 1965: Softcover, offset printing to enable rapid publication, as the foreword emphasized, and a colored, distinctive crossbar on the title (cf. figure 3). Apparently, this publication served as a model for the Lecture Notes serie.

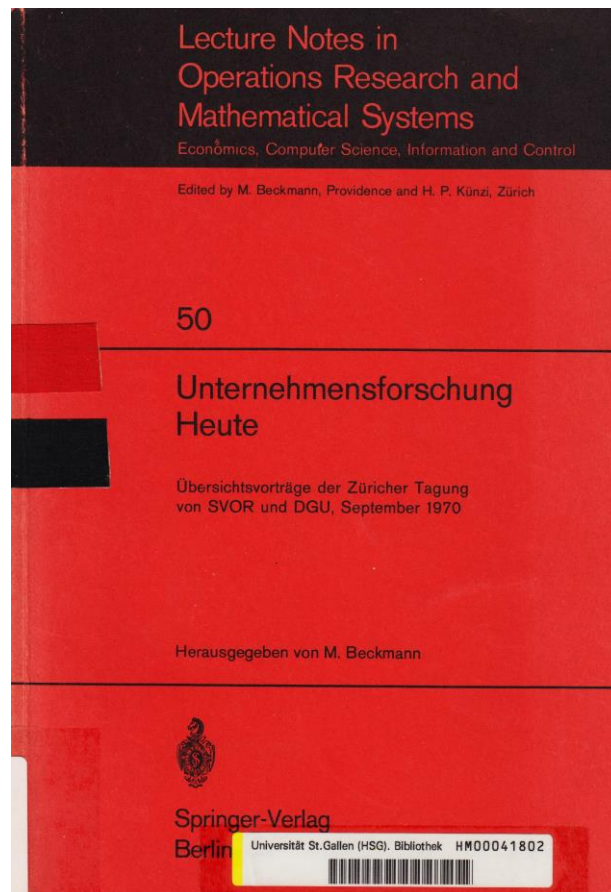


Figure 1: Lecture Notes, Volume 50, 1971

As the individual titles indicate, both Lecture Notes series united a colorful bouquet of diverse topics: e.g. OR procedures for operational applications, such as queue calculations. Then titles appeared on statistics, econometrics and economics. Together with Otto Opitz, Rudolf Henn published a textbook with a standard text on neoclassical consumption and production theory (OR series, vol. 25, 1970), which was used as accompanying material to the basic lectures at the TH Karlsruhe. But research reports were also published. Carl Christian von Weizsäcker, Professor of Economics at the University of Heidelberg, published a research report on Steady State Capital Theory (OR Series, Vol. 54, 1971). As volume 50 of the OR series, Martin Beckmann published the volume "Unternehmensforschung heute" in 1971, which contained six purely mathematical overview lectures at the joint conference of SVOR and DGU in Zurich in September 1970 (cf. figure 1):

- W. Dinkelbach: About a solution to the vector maximum problem,
- F. Fenschel: Recent developments in the field of queuing theory,
- D. Hochstädter: Recent developments in stochastic storage theory,
- P. Kall: Development trends in mathematical optimization,
- B. Korte: Integer programming,
- W. Uhlmann: Basic concepts of decision theory.

The fact that the editors of the Economics series combined the "Mathematical Systems" with "Economics" in the series title proved to be favourable for the marketing of mathematical OR methods and thus gave the "Mathematical Systems" a relevance in terms of content.

The international cooperation of national OR companies contributed to the formation of an international, self-referential system Operations Research and explains its explosive growth. Already in 1955, the US American, English and French national OR societies founded the International Federation of Operations Research Societies (IFORS). Seven members of AKOR participated in the first IFORS conference on 2-6 September 1957 in Oxford (England). The mathematician Hans Kregeloh, chairman of AKOR, gave a lecture on the dissemination of OR methods in Germany, Austria and Switzerland. AKOR sent 16 members to the second IFORS conference in Aix-en-Provence on 5–9 September 1960. At the third IFORS conference in Oslo on 1–5 July 1963, two members of AKOR reported on practical results.<sup>58</sup> For the young Federal Republic Germany, these international contacts were extremely important in order to gain a little reputation in post-war Europe. In 1975 the Aachen OR professor Hans-Jürgen Zimmermann united eleven national OR societies of Western Europe (i.e. excluding countries from the Eastern Bloc) under the umbrella "EURO".<sup>59</sup> While IFORS organised its international meetings every three years, EURO offered its international conferences in the remaining two-year gaps, which were attended by up to 2000 participants, as reported on the EURO website. EURO has been publishing the European Journal of Operational Research since 1976, whose explosive growth can be measured by the fact that the 96th volume was published in 1996. These international cooperations formed a self-referential system. An OR researcher at a university in Germany was able to attend the DGOR conferences every year, give lectures there and publish them as papers in the proceedings. These steps enhanced the scientific reputation. Without the quality of the papers increasing once again, researchers were able to present the nationally presented papers unchanged on an international level, thus doubling their reputation and combining it with a varied trip abroad.

As an analysis of the DGOR proceedings revealed, the vast majority of contributions were model theoretically without an empirical part that would have presented collected data. The self-referential system Operations Research thus offered a platform for extensive model theoretical activities that shielded scholars from the need to collect empirical data. At the annual conference of the DGOR 1981 in Göttingen, Heiner Müller-Merbach, since 1972 Professor of Business Administration and OR at the TH Darmstadt, had already taken a stand against the hypothetical and nominal nature of many OR papers, which, for example, invoked a fictitious industrial enterprise with the words "An industrial enterprise has three machines..." to then continue the model-theoretical approach. He called for a stronger empirical orientation. However, his appeal had no effect and the congress machines of DGOR, EURO and TIMS continued undisturbed to gain reputation. The annual conference of GOR 2017 in Berlin was still attended by 900 people.<sup>60</sup>

The image that AKOR, DGU and DGOR drew of Operations Research in the specialist public led to an exaggerated expectation of business leaders in Germany in the 1960s. The University Seminar of Economics of the University of Bonn, which saw itself as a education institute for business executives, criticized these expectations in a publication in 1971: "These ideas are taken to extremes when the mathematical procedures are seen in connection with the still mystical role of the computer... A member of the board of a large energy company, for example, had the expectation that one only had

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<sup>58</sup> Brusberg, Corporate Research, 1965, p. 242.

<sup>59</sup> Euro – The Association of the European Operational Research Societies, Newsletter 2, Brüssel 1975. Zimmermann, Founding 1995.

<sup>60</sup> GOR was the successor organisation to DGOR. <http://www.gor-ev.de/rueckblick-or-2017-in-berlin>. (accessed on 30 May 2018).

to collect some data and pull some machine programs off the shelf in order to receive the optimal investment plan at the other end of the computer....<sup>61</sup> In this respect, these expectations of business executives were exactly what the OR university researchers had pursued with their self-referential approach.

The history of the institutionalization of OR conveyed here shows the dual role of numerous chairs in the fields of OR and econometrics. These are the chairs of Drèze, Beckmann, Henn and Krelle. Also numerous conference organized panels both for econometrics and for OR. Beckmann and Künzi also offered a series of publications on both subject areas in their Lecture Notes. In 1979 Martin Beckmann together with Günter Menges and Reinhard Selten published the *Handbuch der mathematischen Wirtschaftswissenschaften* (Handbook of Mathematical Economics), which contained volumes on Operations Research and econometrics. In terms of scientific history, the dual role of OR and econometrics is remarkable because it is a coupling of two incompatible areas. Econometrics is macroeconomically oriented and uses empirical data on the national economy and its interdependencies, which it obtains from the Federal Statistical Office, as significant input for its mathematical models. Econometrics thus belongs to empirical economic research, which makes predictions and is therefore relevant for policy advice and in the economic departments of banks.<sup>62</sup> On the other hand, Operations Research is focused on operational processes and provides mathematical procedures independent of empirical data without making predictions.

The ideas of Operations Research were also disseminated in the socialist GDR. There the term "Unternehmensforschung" was not used, but "operational research". The *Grundlagenwerk* by Werner Dück and Manfred Blieferich appeared in 1971 in a three-volume work in East Berlin, which can be seen as a remake of the book by Henn and Künzi.<sup>63</sup> Also in volume 1 there are, as with Henn and Künzi, only mathematical basics in analysis and linear algebra. Volume 2 deals with game theory.

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<sup>61</sup> Hanssmann, 1971, p. 25.

<sup>62</sup> Nützenadel, economists, 2005, p. 92.

<sup>63</sup> Dück/Blieferich, Operations Research, 1971.



## 5 The reluctant application of Operations Research in industry

In a clear difference to the flood of publications on theory-based OR topics, however, the use of OR methods in the industry remained low. Martin Beckmann simply reversed this relationship between theoretical supply and user demand when, in 1979, he claimed the opposite: "Mathematical processes 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..."<sup>64</sup>

The low use of OR in the social spaces of industry was addressed by Merrill Flood, president of TIMS and head of the mathematical department of RAND, when he concised in his presidential address in 1955 that OR, while generally recognised as important, was merely "in the air".<sup>65</sup> As a promoter of linear optimization, Dantzig emphasized that the first application of this method in the industry was the design of aviation gasoline in a petroleum refinery in 1951.<sup>66</sup> As Dantzig noted in his 1963 book, the industry's acceptance of using Linear Optimization in production planning was restrained.<sup>67</sup> In other publications he reports on the successful application in the oil industry.<sup>68</sup> The low success of OR methods is also related to the fact that US companies had already increasingly used scientific methods in corporate management in the 1930s and 1940s and that the need for consulting was therefore not as pronounced as in Great Britain, where corporate management showed great deficits. There, OR was successfully applied in public utilities and in the basic industry. It was referred to as the "Golden Age of the OR" in the period from 1945 to 1970. OR was seen as a means to modernize the industry. OR research groups, such as the OR Research Group of the British Iron and Steel Research Association founded by Sir Charles Goodeve in 1950, have been set up primarily at the association level.<sup>69</sup>

In contrast to Great Britain, however, there were obstacles in the USA and West Germany to the broad application of Operations Research in the social spaces of companies, also to the extent that the models required empirical data in order to be able to calculate optimal solutions. However, the data were only to be collected in the enterprises. In OR publications, this data problem is mostly played down with formulaic statements. In his basic paper "Procedures of Operations Research and their Applications in Industry" in volume 1 of his journal "Operations Research Verfahren" Rudolf Henn writes: "In many operational processes it happens that one has a probability distribution in each time period for the variables." He doesn't say how to determine these probability distributions. Other professors could not answer these questions either. Rather, a division of labour between universities and "practitioners" in industrial companies developed. As the topics of the DFG small projects on OR by Professor Horst Albach shown above display, these are exclusively model theoretical without empirical

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<sup>64</sup> Beckmann, Operations Research 1979, foreword.

<sup>65</sup> Flood, Objectives, 1956.

<sup>66</sup> Charnes/Cooper/Mellon, Blending, 1952.

<sup>67</sup> Dantzig, Programming, 1963, p. 28. The book was published under the copyright of RAND.

<sup>68</sup> Dantzig, Operations Research in the World, 1965. See also Steinecke for applications, 1973.

<sup>69</sup> Kirby, Maurice and R. Capey: The Origins and Diffusion of Operational Research in the UK, in: The Journal of the Operational Research Society, Vol. 49, 1998, No. 4, 307–326, here 309. Kirby, Maurice: Operational Research in War and Peace: The British Experience from the 1930s to 1970, London 2003.

reference. Albach also led the University Business Seminar at the University of Bonn, which saw itself as a further education institute for business executives. For this seminar he had the management consultant Friedrich Hanssmann write a paper on Operations Research in which Hanssmann vividly described the difficulties of data collection in the company.<sup>70</sup> Albach wrote the foreword and thanked Hanssmann for his hard work. Albach, whose DFG projects and his 1967 paper can be regarded as a promoter of Operations Research,<sup>71</sup> had thus shifted the responsibility for empirical research to a practitioner. Albach also hinted at the reluctant application of OR methods in industry.<sup>72</sup> Nievergelt and others talk in their practical studies on Operations Research about the "high sacrifices" that their company had to make when introducing OR.<sup>73</sup>

In order to obtain data, the mathematically oriented OR researchers at the universities had to go into the social spaces of companies, for which, however, they did not have a social science education. From the perspective of a company's management, it is well known that collecting data about the individual operational processes within the company is both laborious and expensive. There is also resistance from the lower management to have their own decision-making area examined.<sup>74</sup> Management therefore balances the quality of the data against the cost of collection and tends towards simple rules. But OR consultants had to jump over the data collection barrier to gain high quality data that they could incorporate into their refined OR models. Because of these difficulties, the scale of Operations Research applications in the companies ultimately remained low. For example, Lewis Bodin wondered how low the level of vehicle route planning applications, such as milk collection from farms in the countryside or school bus planning in the suburbs, were in the 1990s, even though the scientific community had been researching route planning for 20 years.<sup>75</sup>

If one considers the promise of cost reduction through the use of operational research methods, the OR consultants were only able to reduce a small proportion of the costs with their models, since many industrial processes carry high fixed costs, so that a reduction of, for example, 5 percent of the variable costs did not seem particularly convincing. In addition, many processes showed cost curves that did not show a sharp minimum, so that deviations from the minimum costs were only of minor importance and rough estimation methods could be applied. In literature there is no known cost curve with a sharp cost minimum, such as a crack in a rock, which would justify an elaborate search for the cost minimum.

In their OR book of 1957, Churchman et al. showed in detail how data collection methods, such as cost curves in steel mills or queues at toll stations on the New York city highway, were carried out and spread warnings that OR researchers should not concentrate on methods but rather collect data in the company.<sup>76</sup> They should also become familiar with the social relations in the company from which they received the consultancy mandate.

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<sup>70</sup> Hanssmann, *Corporate Research*, 1971, p. 25.

<sup>71</sup> Albach, *Corporate Research*, 1967.

<sup>72</sup> *Ibidem*, p. 254.

<sup>73</sup> Nievergelt, E, O. Müller, F. Schlaepfer: *Practical studies on corporate research*, foreword.

<sup>74</sup> Kaplan/Cooper, *Cost* 1998.

<sup>75</sup> Bodin, *Years*, 1990.

<sup>76</sup> Churchman et al., *Introduction*, 1957, chapter 21.

However, the OR researchers did not turn to empirical projects in the social spaces of companies, but established themselves successfully in the social spaces of the economic science faculties of the universities. There they advanced the development of mathematical optimization methods and transformed their textbooks on Operations Research into pure method bibles. In volume 1, Henn and Künzi's two-volume work on Operations Research did not deal at all with Operations Research but only with mathematics: set theory, linear algebra, probability theory and statistics. Volume 2 also contained a chapter on game theory. Since Operations Research did not focus on economic relations within the company, empirically oriented research was largely lacking. The strong emphasis on mathematical methods has been rejected by business leaders since the 1950s. The OR specialists were accused of using incomprehensible "technical jargon", as Walter Trux, head of the mechanical engineering group Fichtel und Sachs, put it in his opening speech at the 1980 annual conference of the German Society for Operations Research in Essen.<sup>77</sup>

## 6 The rise of business informatics as a barrier to operations research

If the dissemination of OR is historicized, after a phase of successful institutionalization at the universities until 1970 there was stagnation and decline after 1980, which is due to the rise of the competing fields of business informatics and logistics.<sup>78</sup> Since the end of the 1980s, chairs for Operations Research have increasingly been converted into the fields of business informatics and logistics. As a specialist representative of OR professors at German universities within the Association of Business Economists, the Scientific Commission Operations Research increasingly lost members with the Denomination Operations Research. In 2019 only two of the 100 professors (chairs only within Germany, without Emiriti) of the Scientific Commission Operations Research possessed the denomination Operations Research, while the others possessed the denomination Business Informatics or Logistics.<sup>79</sup> A crisis of OR was also perceived in Great Britain.<sup>80</sup>

Apart from these academic upheavals, the use of Operations Research in corporate social spaces has also been hampered by the rise of database systems for production control. This business management control of enterprises by computers can be historicized as follows. The capacity of companies to modernise their own organisation was absorbed between 1960 and 2000 by the installation of ever newer and more powerful generations of computers for business management of production and could hardly pay attention to the advice of OR consultants. In the production industry the application of the relational database models preferred by business informatics for the control of the material flow in the production of the manufacturing industry stood in the center, while still in the 1960s IBM had favored hierarchical database models in vain. The relational database models became possible in the 1960s, when the transition from Turing-like linear storage on tape to random access to

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<sup>77</sup> Rider, *Operations*, 1992, p. 231. Trux, *Deployment*, 1981, p. 21.

<sup>78</sup> Bradtke, *Operations Research*, 2003, speaks of a crisis of the OR at the end of the 1970s, p. 3. Rudolf Henn stopped publishing his journal *Operations Research Verfahren* in 1979.

<sup>79</sup> Message from the Chairman of WK Operations Research, Professor Achim Koberstein, University Frankfurt/Oder.

<sup>80</sup> Fildes, R. and J. Ranyard: The foundation, development and current practice of OR: An editorial introduction and overview, in: *Journal of Operational Research*, vol. 49, 1998, 304–306.

magnetic disks took place and file systems became possible for the first time ever. The example of Fichtel & Sachs AG in Schweinfurt illustrates the growth in disk capacity. In this company, the disk capacity grew from 2.8 MB in 1975 to 15 MB in 1980.<sup>81</sup>

Dieter Pressmer, Professor of Operations Research at the University of Hamburg (see above), initiated a funding programme for the University's Information Systems department at the Federal Ministry of Education and Science in the 1980s and founded the Institute for Information Systems at the University of Hamburg in 1995.<sup>82</sup> The programs developed by Business Informatics for production control in the manufacturing industry (also known as PPS) date back to the simple bill of materials processors of the 1960s. As the first programs to efficiently utilize high-speed digital computers, Job Shop Scheduling programs were developed in the early 1950s that determined an optimal sequence of application programs (jobs) that were read into the computer as punch cards in batch to minimize the total waiting time of the valuable processor. These job scheduling programs were later integrated into PPS. PPS has been extended to include the management of additional operational functions such as sales, suppliers, finance, human resources and building planning, including various locations at home and abroad and referred to as Enterprise Resource Planning (ERP).<sup>83</sup> This meant that the entire company organization was mapped in this database program, but this did not always go smoothly. During the program installation in the companies conflicts arose between the rigidity of the intended software and the living organization of the companies.<sup>84</sup>

In the manufacturing industry, database models split the structures of machines, materials and bills of materials into thousands of tables in atomized normal forms, resulting in long runtimes on the computer to create production plans for the following day due to numerous hard disk accesses. The computers were running all night. This disadvantage could only be remedied when semiconductor-based main memories in the gigabyte range became technologically possible from the year 2000 onwards and thus the slow hard disk accesses to the atomized tables could be shifted to the fast main memory. The SAP software group sold this new ERP software under the HANA brand. In the 1990s, SAP added an optimization tool based on linear programming called "Advanced Planner and Optimizer" to its R3 production planning product.<sup>85</sup> There is no empirical knowledge about the use of this tool. Whether it was useful for production companies or just a marketing campaign by SAP cannot be decided.

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<sup>81</sup> Opening lecture at the ninth annual conference of the German Society for Operations Research in Essen in 1980 by Walter Trux. Trux, Mission, 1981, p. 22.

<sup>82</sup> The Pressmer obituary on the website [www.bwl.uni-hamburg.de/iwi/ueber-das-Institut/pressmer.html](http://www.bwl.uni-hamburg.de/iwi/ueber-das-Institut/pressmer.html), accessed on 15 March 2019.

<sup>83</sup> Crank, Enterprise, 2011. Fleischhack, World, 2016. She reports on applications of job shop scheduling programs in municipal data centers as late as the 1970s, p. 58.

<sup>84</sup> For an example of the SAP R/3 implementation conflicts at M.I.T. see Williams, Solid, 2000, p. 641-668.

<sup>85</sup> Bartsch, SAP APO, 2000.

## 7 The initially problematic use of the large computer in mass data processing

In this section, the problems of mass data processing with large computers in the social spaces of companies in the 1950s due to the small size of the main memory are to be pointed out, in order to then lead over to the topic of OR as management science.

I follow Timo Leimbach here, who in his study on the software industry distinguishes between two types of use of computers for administrative purposes in companies. On the one hand the computer as an automation of simple employee work and on the other hand as a tool that provides information to enable the manager to make decisions.<sup>86</sup> In the 1950s, the large computer was introduced into companies to automate administrative processes such as sales statistics, payroll accounting and warehouse management. Many of these areas had already been partially automated by the use of punch card machines, and the computer was able to continue these approaches of the punch card departments in the companies, especially since the input and output of data still took place via punch cards.<sup>87</sup> John von Neumann had given the digital large computer a special architecture. He combined a fast arithmetic unit with a fast main memory. This architecture made it possible to integrate differential equations, in particular, by moving millions of iteration steps of small amounts of data back and forth between the main memory and the arithmetic unit in a very short time. For computer manufacturers, the large digital computer in business administration was not a particularly large sales market in the 1950s. The number of installations remained low. In fact, a different architecture prevailed which von Neumann had not taken into account. A fast arithmetic unit was combined with a slow main memory realized by a magnetic drum. Among the up to 70 types of digital computers with magnetic drums that appeared on the market in the USA in the 1950s,<sup>88</sup> the IBM 650 became the successful model of this architecture.

A large computer such as the IBM 701 or the Univac 1103 may have been successful in scientific calculations such as the integration of differential equations, but its application in administrative data processing looked less favorable. This application was accompanied by a great rationalization rhetoric of efficiency, speed and cost savings. However, as Thomas Haigh pointed out in his study on the introduction of digital computers for administrative data processing in the 1950s, this path was extremely laborious because large computers only had tiny main memories and the processing of mass data had to be split into numerous separate runs. The speed advantage of the large computer was thus lost.<sup>89</sup> However, the classic tabulating machines did not have this main memory restriction.

In administrative data processing, sorted data stocks were particularly important. Sales data, personnel data, customer data, material data and supplier data were given numbering systems with which certain data records could be quickly found in a sorted inventory; the magnetic tape only had to be prewound

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<sup>86</sup> Leimbach, History, 2010.

<sup>87</sup> Vahrenkamp, Informationsexplosion, 2017, pp. 209-242. Extended version at [http://www.vahrenkamp.org/files/Punch\\_Cards\\_Vahrenkamp\\_WP1\\_2017](http://www.vahrenkamp.org/files/Punch_Cards_Vahrenkamp_WP1_2017).

<sup>88</sup> Weik, Survey, 1955.

<sup>89</sup> Haigh, Tabulator, 2001.

until the data record number appeared. However, the data always had to be re-sorted as soon as changes occurred. Unlike punched cards, however, the linear magnetic tapes became cages for the mass data. Sorting mass data stored in magnetic tapes on large computer systems proved to be a major bottleneck, as the tapes with mass data had to be split into numerous separate runs due to the small main memory, while sorting on punch card machines was possible without any problems. Paul Ceruzzi estimated that large computer systems spent 25% of their time sorting. In an advertisement, the Electronic Data Division of RCA even speaks of 40% for sorting.<sup>90</sup> The slow main memory of the IBM 650 and the slow mass memory with magnetic disks (600 milliseconds average access time) of the IBM 1401 did not play a role in the cumbersome sorting processes.<sup>91</sup> In computer science, sorting algorithms became an important field of research; Donald Knuth of Stanford University published a sorting bible in 1973 that was overflowing with over 700 pages.<sup>92</sup>

While the medium-sized IBM machine 650 did not yet have its own printing unit, but had to be connected to a tabulating machine, the machine 1401 together with the high-speed printer 1403 in 1959 brought IBM a breakthrough in administrative data processing with computers. The 1000 lines per minute high-speed printer was able to print an image of the company's data on huge piles of paper that were transported to the offices on small trolleys.<sup>93</sup>

The success of the 1401 was due in part to the fact that many programs from the old IBM tabulating machines could be transferred to this machine with translation programs – as was already the case with the IBM 650. IBM further developed the tabulating machine-oriented approaches in administrative data processing when it introduced the S/360 large computer in the 1960s. In this machine there was a status that emulated the successful machine 1401. This allowed the old programs of the 1401 to continue to be used and convinced customers to switch to the 360 machine. The great success of IBM's punch-card oriented software product "Report Program Generator" (RPG), which lasted until the 1980s, with the sum<sup>94</sup> of a turnover list or similar lists being drawn over various criteria and printed out as reports on paper, on the IBM S/360 demonstrates this policy of continuing the old tabulating machine approaches of administrative data processing, which certainly also explains IBM's market success in part.<sup>95</sup> In a way, it seems absurd today if the old tabulating machine programs ran in the slow 1401 mode on the high-performance S/360 machine, but this indicates the great importance of report lists for company management.<sup>96</sup> As long as mass data was stored on tapes as the primary storage medium and not yet on random access disk drives, the high speed of the S/360 machine could not really be exploited anyway, so the slow 1401 mode did not carry much weight.

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<sup>90</sup> The advertisement of RCA Electronic Division can be found in *Datamation*, Vol. 6, 1960, p. 7. Ceruzzi, *History*, 2000, p. 89. Vahrenkamp, *Informationsexplosion*, 2017, shows the importance of sorting processes when punch cards are used.

<sup>91</sup> Baer, *1400 Series*, 1976, p. 629s.

<sup>92</sup> Knuth, *Computer Programming*, 1973.

<sup>93</sup> Haigh, *Tabulator*, 2001, p. 86. Ceruzzi, *History*, 2000 p. 73s.

<sup>94</sup> Other statistical functions could also be programmed, such as mean, minimum and maximum of the values in question. The function maximum was important for utilities. In industry electric power was rated according to the daily maximum use.

<sup>95</sup> Campbell-Kelly/Aspray, *Computers*, 1996, p. 133. On RPG see Rottmann, *IBM/360*, 1966. Heger, *100 years*, 1990, p. 140-144. On the use of hard disk drives for seat reservation for 1000 flights per day of the US airline United Airlines on the IBM machine RAMAC already in 1959 see Thompson, *RAMAC*, 1959. I owe this source to Dr. Daniela Zetti of ETH Zurich.

<sup>96</sup> Ceruzzi, *History*, pp. 149-151.

## 8 Management Science and Operations Research

In the automation debate of the 1950s, the second aspect of the use of computers was also strongly emphasized: to provide management with data to support them in decision-making situations, as the report lists already did. The explanations went so far as to formulate also the goal of automating or at least partially automating decisions of the management with the digital computer.<sup>97</sup> A recourse to the methods of Operations Research gave this field the aura to provide the necessary methods for the automation of management decisions. As early as 1955 – when hardly any large digital computers were installed in administrative data processing – Herbert Simon and Russel Ackhoff held a conference at Harvard to support management decisions using computers and OR methods.<sup>98</sup> In 1960, Simon published the book "The New Science of Management Decision", which was influential in the automation debate. In this book Simon enumerates the two possibilities of computer use, the automation of simple employee work and the support of management. Typical of the uncritical approach in the automation debate, he saw Frederick Taylor and Taylorism as precursors of Operations Research.<sup>99</sup> Simon could not provide concrete approaches to how management decisions should be supported, but he only presented keywords by enumerating the various methods of operations research, such as game theory, dynamic programming, linear optimization and simulation.<sup>100</sup> Looking at the stony path outlined above that computer applications had to take to automate simple employee work in the 1950s, Simon's remarks seem fabulous. At that time it was not possible to simply use the computer as a working tool, for example by approaching a computer and entering a query about turnover, stock or financial resources on the screen using the keyboard. Rather, the computers had only input consoles with switches and light bulbs, but without a screen. After all, punch cards for programs and data had to be produced, compiled and read into the computer.<sup>101</sup> How sophisticated programs for the analysis of large amounts of data should be executed in the tiny main memory, and thus even managers could be supported, remains a matter of fantasy. To use Operations Research, of all things, to support management was of little use, since the promoters had not taken into account the merely low empirical orientation of Operations Research. Thus, Operations Research could not provide the empirical methods to support management. The representatives of Operations Research were also the wrong addressees of Simon's automation thesis in so far as they had kept their field of expertise largely free of computer applications. In the textbooks on Operations Research, no reference is made to the computer. In the basic work by Henn and Künzi from 1966, the "electronic calculator" is mentioned only once in old-fashioned terminology.<sup>102</sup> As in the textbooks, the same picture can be seen in research. In the proceedings of the annual conferences of the German Society for Operations Research and Operations Research, lectures on computer applications only occur occasionally: At the 1971 meeting not at all, at the 1972 meeting only two papers among 30 papers.<sup>103</sup> As one of the few

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<sup>97</sup> Simon, *Management*, 1960, p. 14. The automation of management decisions was also discussed in the Soviet Union, see Gerovitch, *Cybernetics*, 2002, p. 266.

<sup>98</sup> Ackhoff/Simon, *Proceedings*, 1955, where Ackhoff recommended the use of Operations Research for management.

<sup>99</sup> For the automation debate see Vahrenkamp, *Botschaften*, 1988. For the Taylorism debate see Vahrenkamp, 1977, updated as Working Paper at: [http://www.vahrenkamp.org/files/WP20\\_2018.pdf](http://www.vahrenkamp.org/files/WP20_2018.pdf).

<sup>100</sup> Simon, *Management*, 1960, pp. 14-16.

<sup>101</sup> For the process of compiling with the Fortran language on the IBM 650, see the Columbia University field report at <http://www.columbia.edu/cu/computinghistory/650.html>. (Retrieved on 30 May 2018).

<sup>102</sup> Henn/Künzi, *Corporate Research*, 1966, Volume 2, p. 171.

<sup>103</sup> Physica Verlag Würzburg 1972 and 1973, respectively.

OR scientists, the graduate mathematician Ulrich Derigs, employed at the "Seminar for Industry" of the University of Cologne, published software for solving OR algorithms in 1980 together with Rainer Burkhard, Professor of Mathematics at the Mathematical Institute of the University of Cologne.<sup>104</sup>

When computers became more powerful in the 1960s and screen terminals, timeshare systems, file systems on hard disk drives and database systems based on them could be set up, the idea arose to give upper management easy access to the information that was already available in the databases of the operative mass data processing systems. This led to a debate on management information systems (MIS) with a rapidly growing number of publications, with the focus on information provision, but Operations Research only playing a secondary role.<sup>105</sup> In MIS, the manager was designed as a user who could start terminal queries in the database. Setting up an MIS was considered expensive and its usefulness more difficult to prove than in mass data processing. It remained controversial whether the MIS promoters had promised too much. Some authors even saw a failure in MIS.<sup>106</sup>

## 9 The Computer and Simulations in Operations Research

In the literature, the topic of simulation covers a wide area. This section is limited to discrete Monte Carlo simulations, without going into simulations that solve systems of differential equations with computer programs, as in meteorology, astrophysics and industrial dynamics by Jay Forrester.<sup>107</sup>

In Operations Research, the discrete simulation of production systems or traffic systems was also a topic. They were used as software programs on digital computers when no closed solutions with mathematical formulas could be derived and parts of the system depended on random variables with certain distribution functions. They were also used when experiments with real systems were too expensive or too dangerous, such as chain reactions in a critical mass of uranium atoms.

The debate on Monte Carlo simulation takes up the complex of questions 7 on political knowledge cultures of the workshop Algorithmic Knowledge Cultures and places them in the context of Cold War Science in Los Alamos. John von Neumann was the first scientist ever to use simulation supported by random numbers. He wanted to get a heuristic impression of the scattering of neutrons during chain reactions in atomic bombs and "optimize" these bombs according to certain goals. His wife, Clara von Neumann, and Nicholas Metropolis programmed the ENIAC computer and together calculated neutron scattering in 1948.<sup>108</sup> Both were equipped with numerous punched cards containing random numbers. Klara von Neumann and John von Neumann both came from upper middle-class homes in Budapest

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<sup>104</sup> Burkard/Derigs, Assignment, 1980.

<sup>105</sup> Alavi/Carlson, Review, 1992, pp. 45-62.

<sup>106</sup> Teichroew, Management, 1976, pp. 845-847.

<sup>107</sup> For simulation in meteorology, see Gramelsberger, Computerexperimente, 2010, p. 209. Forrester, Industrial, 1961. This book later provided the methodological model for the world model of the Club of Rome.

<sup>108</sup> On the ENIAC computer and the programming of Metropolis and Clara von Neumann, see Haigh/Priestley/Rope, ENIAC, 2016.



and had personal experiences of visiting the gambling casino in Monte Carlo, Monaco. Based on an idea by Stan Ulam, both Stan Ulam and John von Neumann had invented the use of randomised methods in 1946 in Los Alamos and gave the method the name "Monte Carlo method". This term fascinated mathematicians and scientists immediately, because Monte Carlo was probably associated worldwide with gambling. The RAND Corporation of the US Air Force jumped on this trend. Although she did not have a digital computer in 1949 and had no experience with simulation, she organized the first scientific conference on the Monte Carlo method in Los Angeles at UCLA University, which was later followed by others.<sup>109</sup>

Operations Research also adopted the Monte Carlo method and gave itself a mysterious coat of paint. However, in chapter four the authors Henn and Künzi brought almost exclusively trivial applications to the Monte Carlo method of their book (volume 1), such as the erratic "way of a drunken man" (random walk), the needle experiment of Buffon from 1733 and the turnover of a newspaper salesman. With these examples, they were unable to convince business leaders of the benefits of operations research, demonstrating that they had no intention of doing so, but were merely targeting the academic arena to present material for OR courses. With the success of Monte Carlo methods, the need for random numbers increased greatly to allow simulations to be repeated with a different set of random numbers, thus ensuring the replicability of simulation experiments. Textbooks published tables with equally distributed random numbers. A RAND Corporation publication with random numbers became a bestseller in the RAND book program.<sup>110</sup> In theoretical computer science, a separate branch of research grew up to develop software for the generation of equally distributed random numbers.<sup>111</sup> From the 1960s, Hans Künzi reported on applications of simulations at his Zurich Chair of Operations Research in cooperation with the Swiss Military. Air battles were simulated on the computer in order to determine a cost-minimal procurement of a fighter plane of different types. He also reported on simulations of inner-city individual traffic in order to optimize traffic light circuits.<sup>112</sup> OR experts in the GDR also used the term Monte Carlo, but without referring to the casino.<sup>113</sup>

The historization of simulation can also take up question complexes 4 for the visualization of the workshop Algorithmic Knowledge Cultures. While in the 1980s the simulation languages SIMAN and ARENA, mainly used by mechanical engineers for the simulation of production systems in batch mode, were still in use, software packages with graphical user interfaces came onto the market in the 1990s. Like a construction kit, it was possible to put together working machines, waiting rooms and material handling systems, visualise them on screens and identify bottlenecks in the material flow. The individual elements were provided with randomised arrival and departure times whose distribution could be chosen (equal distribution, normal distribution and Poisson distribution). Critical to the application of this software was to obtain empirical data on the behavior of individual elements.

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<sup>109</sup> Dyson, Turing's, 2012, describes in Chapter 12 the calculations of Klara von Neumann and Nicholas Metropolis. Dyson's book is based on research in the Princeton University archives. Haigh/Priestley/Rope, ENIAC, 2016, Chapters 8 and 9 provide a detailed description of ENIAC programming. It is not known whether von Neumann achieved his goal of "optimizing" the atomic bomb with the Monte Carlo simulation. Monte Carlo Method, 1951. Galison, Computer, 2011, p. 125.

<sup>110</sup> 50 Years Project Air Force, 1996, p. 50.

<sup>111</sup> Galison, Computer, 2011 Churchman et al., Operations Research, 1957, give on page 173 a table of random numbers they obtained from RAND Corporation. Henn and Künzi, Unternehmensforschung, 1966, give a table of random numbers on page 129s of volume 1.

<sup>112</sup> Künzi, Corporate Research, 1972, p. 9s.

<sup>113</sup> Dück et al., Operational Research, 1971, Volume 2, pp. 383-387. Schubert, Efficiency, 1965.

Characteristic data of the working machines of the mechanical engineering manufacturers and the experiences of production engineers were used.<sup>114</sup> While practical applications of simulation software for the layout of production systems have no known failures in the literature, it should be noted in theoretical terms that the results of layout simulations only provide mean values, but that large deviations can occur in the realization of random variables.

As the computing power of computers rose sharply, randomized procedures from Operations Research were able to test millions of alternatives in a very short time. Huge search areas could be scanned with realizations of random variables for favorable solutions.<sup>115</sup> In the 1990s, for example, numerous deterministic OR procedures were converted into randomised procedures. The use of evenly distributed random variables, which almost every programming language had implemented with a random generator, was now taken for granted, without even bombastically speaking of Monte Carlo. As a new research branch of Operations Research, genetic algorithms and simulated annealing were investigated.<sup>116</sup> The latter simulates the cooling behaviour of crystals in order to jump out of local minima and obtain better solutions. The former imitates evolution in nature. Values of variables were modeled as binary 1-0 strings. With the mutation, individual positions in the string were changed randomly. With recombination, parts of two strings were randomly exchanged. The selection process selected the most promising randomized solutions. Genetic algorithms and simulated annealing were ideal fields for OR, as they gave new impetus to the method orientation of OR and finally connected the OR with the computer.

## 10 The artificial content of Cold War Operations Research

The following section discusses the Transport Model, the Travelling Salesman Problem, and the Diet Problem and highlights their artificial content from Cold War Operations Research. But also other OR questions have this artificial content and were not used in business, so they remained academic. The literature reveals a lack of critical accounts on these OR-problems.

### 10.1 Dynamic Programming without application

**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.<sup>117</sup> 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 contrainuitive 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

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<sup>114</sup> Eley, Simulation, 2012. Wenzel et al., Simulation, 2008. Herbert Simon pointed out as early as 1960 that simulation studies have a need for empirical data that is difficult to satisfy, see New Science, p. 19.

<sup>115</sup> For the one-dimensional cutting problem see Vahrenkamp, Random, 1996.

<sup>116</sup> Michalewicz, Algorithms, 1996, pp. 250-252.

<sup>117</sup> See for example Martin Beckmann, *Dynamic Programming*, Berlin 1968.

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.<sup>118</sup> 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.<sup>119</sup>

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.<sup>120</sup>

## 10.2 The network flow model

**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 abstractifies 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 abstractified context, the mathematicians Lester Ford and Delbert Fulkerson were able to formulate the famous duality theorem "Max-Flow-Min-Cut" in 1956.<sup>121</sup> 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.

## 10.3 The Quadratic Assignment problem as mathematical stalinism

**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.<sup>122</sup> Beckmann and Koopmans worked together at the Cowles Commission in Chicago.<sup>123</sup> Their article deals with a 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 (sum of 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

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<sup>118</sup> Schneeweiss, Christoph: Dynamische Programmierung, in: Beckmann, Martin, Günter Menges und Reinhard Selten (Hrsg.): *Handwörterbuch der Mathematischen Wirtschaftswissenschaften, Teilband Unternehmensforschung*, Wiesbaden 1979, p. 32.

<sup>119</sup> Klein, Cold War, 2007, cf. note 7.

<sup>120</sup> Klein, *ibidem*.

<sup>121</sup> Lester Ford Jr., D.R Fulkerson: "Maximal flow through a network." *Canadian J. Mathematics*, 8, 1956, S. pp. 399-404.

<sup>122</sup> Tjalling Koopmans and Martin Beckmann: "Assignment Problems and the Location of Economic Activities." *Econometrica*, Vol. 25, No. 1 (Jan., 1957), pp. 53-76.

<sup>123</sup> Mirowski, *Machine Dreams*, (cf. note 6), p. 252.

plant with regard to the exchange of intermediate products.<sup>124</sup> 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,<sup>125</sup> 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.<sup>126</sup> 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.<sup>127</sup> However, this was only proven in 2000 and could therefore not have played a role in the construction.

## 10.4 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.<sup>128</sup> 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

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<sup>124</sup> Waescher, Gerhard: *Innerbetriebliche Standortplanung bei einfacher und mehrfacher Zielsetzung*, Wiesbaden, 1982.

<sup>125</sup> "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 and Reinhard Selten (eds.): *Handwörterbuch der Mathematischen Wirtschaftswissenschaften, Teilband Unternehmensforschung*, Wiesbaden 1979, preface.

<sup>126</sup> 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. Burkard supplies a bibliography: Burkard, Rainer: "Quadratic Assignment Problems." In: *Handbook of Combinatorial Optimization*, pp. 2741-2814, ibidem.

<sup>127</sup> Nyberg, Axel: "Applications of the Quadratic Assignment Problem", see: [http://web.abo.fi/fak/taf/at/ose/doc/Pres\\_15112013/Axel%20Nyberg.pdf](http://web.abo.fi/fak/taf/at/ose/doc/Pres_15112013/Axel%20Nyberg.pdf).

<sup>128</sup> George Stigler, "The Cost of Subsistence." *Journal of Farm Economics*, vol. 27, 1945, no. 2, pp. 303-314.

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.<sup>129</sup> 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.<sup>130</sup>

## 10.5 The transportation problem as an abstractification

The transport model discussed in the following shows the paradox that its discoverer was awarded the Nobel Prize in 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 and destinations in order to minimize the total costs of transport.<sup>131</sup> 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).<sup>132</sup> 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

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<sup>129</sup> George Dantzig, *Linear Programming*, (cf. note 58), pp. 551-553. Georg Dantzig, "The Diet Problem." *Interfaces*, vol. 20, 1990, no. 4, 43-47.

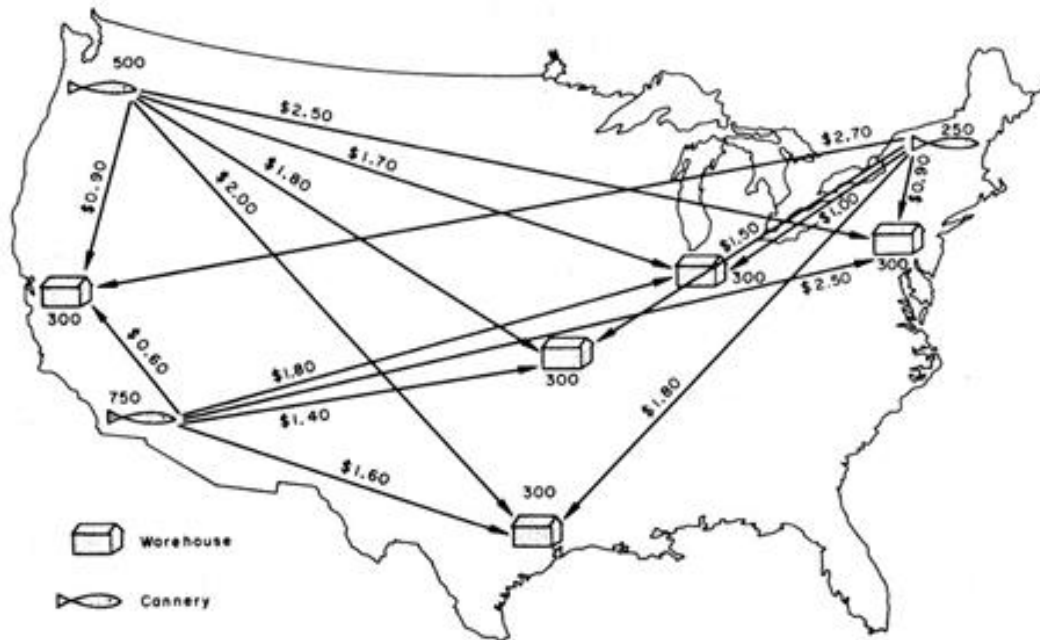
<sup>130</sup> Paul Erickson et al., *How Reason Almost Lost Its Mind*, (cf. note 7), p. 65.

<sup>131</sup> George Dantzig, "Linear Programming", (cf. note 58), chapter 14. Dorfman et al., *Linear Programming*, (cf. note 56), chapter 5.

<sup>132</sup> 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.

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 2.

**Figure 2** The Transportation Problem in Dantzig's book 1963. Transportation inside the US between canneries and warehouses with transport rates.<sup>133</sup> (Source: George Dantzig: *Lineare Programmierung und Erweiterungen*, (German edition) Springer Verlag, Berlin, 1966, p. 3)<sup>134</sup>



As a nominal approach, Dantzig produced this map 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.

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.<sup>135</sup>

<sup>133</sup> 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.

<sup>134</sup> That Dantzig chose canneries as example reminds to John Steinbeck's book *Cannery Row* playing in Monterey. Steinbeck received the Nobel Prize in 1962 – one year before Dantzig's book appeared.

<sup>135</sup> Michael Gorman, "Empty Railcar Distribution." In Bruce W. Patty (ed.), *Handbook of Operations Research Applications at Railroads*, New York 2015, pp. 177 – 190.

## 10.6 The travelling salesman as invention

In the United States of the 1940s, the profession of the traveling salesman 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. Dantzig'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 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.<sup>136</sup> 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.<sup>137</sup> 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 Drexler, 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. Merrill Flood reported in his paper that he had heard of applications.<sup>138</sup>

## 11 The boom in transport optimization in the German Democratic Republic

The application of OR methods in the Eastern Bloc was characterized by political knowledge cultures. While in the Soviet Union the use of mathematical planning methods – also known as cybernetics – in the national economy was initially rejected as “Western” in the early 1950s, Nikita Khrushchev's criticism of Stalin at the 20th Party Congress of the CPSU in 1956 and with a conference on economic mathematics in Moscow in 1959 changed the attitude.<sup>139</sup> In 1967, George Dantzig, then professor of OR at Stanford University, estimated that in the Soviet Union several times as many mathematicians,

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<sup>136</sup> G. Dantzig, R. Fulkerson and S. Johnson, “Solution of a Large-Scale Traveling-Salesman Problem.” RAND Research Memorandum, P 510, April 1954.

<sup>137</sup> Gass and Assad, *Timeline*, 2005 (cf. note 12), p. 48.

<sup>138</sup> 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.

<sup>139</sup> On the debate on cybernetics in the 1950s see Seising, *Cybernetics*, 2010. On cybernetics in the USSR see Gerovitch, *Cybernetics*, 2002, here p. 155. Brusbeck, *Unternehmensforschung*, 1965, p. 46.



OR researchers and computer science researchers were working in relation to the USA in order to catch up in the production of goods.<sup>140</sup>

In the German Democratic Republic (GDR), communist party (SED) leader Walter Ulbricht was sceptical about cybernetics and data processing at the beginning of the 1950s, but at the end of the 1950s he became the promoter of cybernetics and data processing. Cybernetics as a systems science has now been widely discussed. In 1964 the international conference "Mathematics and Cybernetics in Economics" took place in East Berlin.<sup>141</sup> The computer was seen as an ideal tool of the planned economy.<sup>142</sup> In 1963, the GDR Council of Ministers called for the establishment of a computer-assisted accounting system for the national economy in the guideline for the New Economic System of Planning and Management of the National Economy.<sup>143</sup> Even the Swiss OR promoter Hans Künzig was able to publish a paper on mathematical optimization with FORTRAN and Algol programs in the GDR in 1966 at the Leipzig publishing house Teubner Verlag.<sup>144</sup>

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<sup>140</sup> Dantzig, *Operations Research in the World*, 1967, p. 117.

<sup>141</sup> Dittmann/Seising, *Cybernetics 2007. Mathematics and Cybernetics in Economics*, International Conference in Berlin in October 1964, Proceedings, Akademie-Verlag Berlin 1965.

<sup>142</sup> Donig, *DDR-Computertechnik*, 2006, p. 252. Potthoff, *linear programming*, 1961. Nützenadel, *economists*, 2005, p. 201.

<sup>143</sup> The directive peculiarly spoke of "highly mechanized computing systems". In the "Prague Spring" of 1968, Rudi Dutschke, the leader of the rebellious West Berlin students who grew up in the GDR, told the astonished students of the University of Prague who, after 20 years of communism, were actually striving for a market economy control of the economy that the planned economy was the superior system thanks to the IBM computer S/360, see Stepan Benda's memories of his meeting with Rudi Dutschke in Prague at <https://www.tschechien-online.org/blog/meine-begegnung-rudi-dutschke-im-april-1968-prag-01082016-17424>. (accessed on 30 May 2018).

<sup>144</sup> Hans P. Künzi, Hans G Tzschach, Carl A Zehnder: *Numerical Methods of Mathematical Optimization: with ALGOL and FORTRAN Programs*, Leipzig: Teubner, 1966.

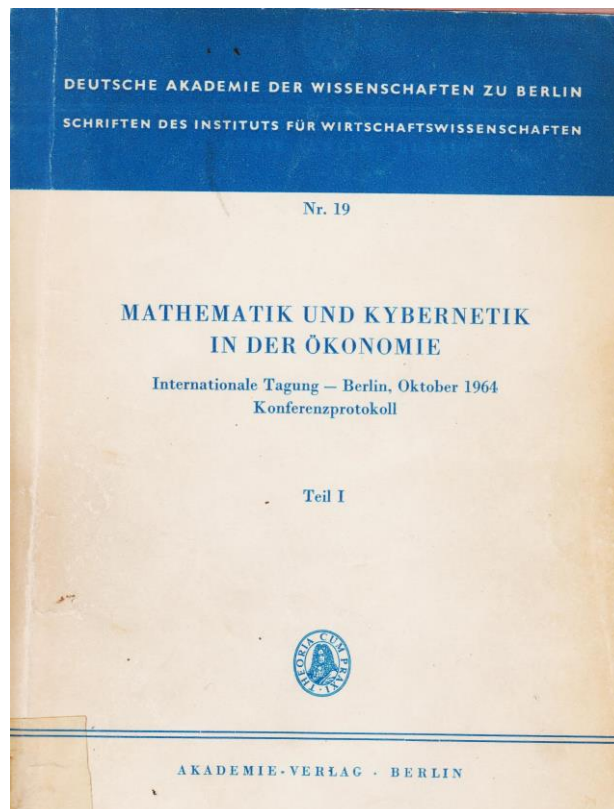


Figure 3: Volume Mathematik und Kybernetik, 1965

Among the multitude of cybernetics methods, I will pick out the computer-aided transport optimization here. The entire Eastern Bloc experienced a boom in transport optimisation at the beginning of the 1960s. In contrast to the capitalist world, methods of computer-aided transport optimisation, such as route planning and the transport model, were eagerly adopted in the Eastern Bloc, as they seemed to correspond to the simplifying approaches of the planned economy. As emphasized by the chairs of Economic Policy at universities in Western-Germany, the planning approaches of central administrative economies can be characterized by simplification. The broad variety of goods that characterizes Western markets is reduced to only a few types of goods.<sup>145</sup>

In the following, the social spaces of transport optimisation are dealt with. Since 1959, at party conferences of the SED and in recommendations of the highest management bodies of the GDR, reference was repeatedly made to existing "unnecessary, contrary and uneconomical transports" in the national economy, which had to be identified and eliminated using modern methods in order to achieve a high economic benefit.<sup>146</sup> In numerous research institutions, such as the Central Institute for Automation in Dresden and the Dresden University of Transport, Building and Urban Affairs, these political guidelines were gladly accepted.<sup>147</sup> Karl Hofmann studied the supply relationships in the basic

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<sup>145</sup> Eucken, *Economic Policy*, 1990, p. 78.

<sup>146</sup> Hofmann/Schreiter/Vogel, *Optimierung*, 1964, p. 6. These authors as well as Potthoff (*Linearprogrammierung*, 1961) give extensive bibliographies with sources from Poland, Hungary, USSR and Czechoslovakia.

<sup>147</sup> Further research institutions took part in transport optimisation: The Test and Development Centre for Motor Traffic in Dresden, the Institute for Transport Research in Berlin, the University of Architecture and Civil Engineering in Weimar, the Institute for Economics of the German Building Academy in Leipzig, the State Planning Commission and the National Economic Council, see Hofmann et al., *ibid.*, p. 7. See also K. Kohlmay's

industry at the University of Transport and Communications and established optimised supply relationships for wood, coal, sulphuric acid and building materials based on railway transport using the transport model. He awarded numerous diploma theses and dissertations. However, the extent to which the optimisations remained merely academic and were not implemented remained open.

In the coal industry, the abstractification in the model did not succeed smoothly, as many coal types had to be distinguished. Furthermore, the data set for the distribution of lignite briquettes was too large for the approximately 50 thousand bit drum memory of the digital computer ZRA1, manufactured by Carl Zeiss in Jena, which was common in the GDR at that time. The number of coal suppliers had to be reduced from 50 to 21, as did the number of customers from 3000 to 74.<sup>148</sup> The optimisation programme also achieved unsatisfactory solutions for the supply of pine wood. Small wood-processing companies were assigned to distant wood sources, which resulted in high transport costs for the companies and caused resistance to optimisation.<sup>149</sup> Figure 2 below shows the coordination of lime deliveries in the GDR.

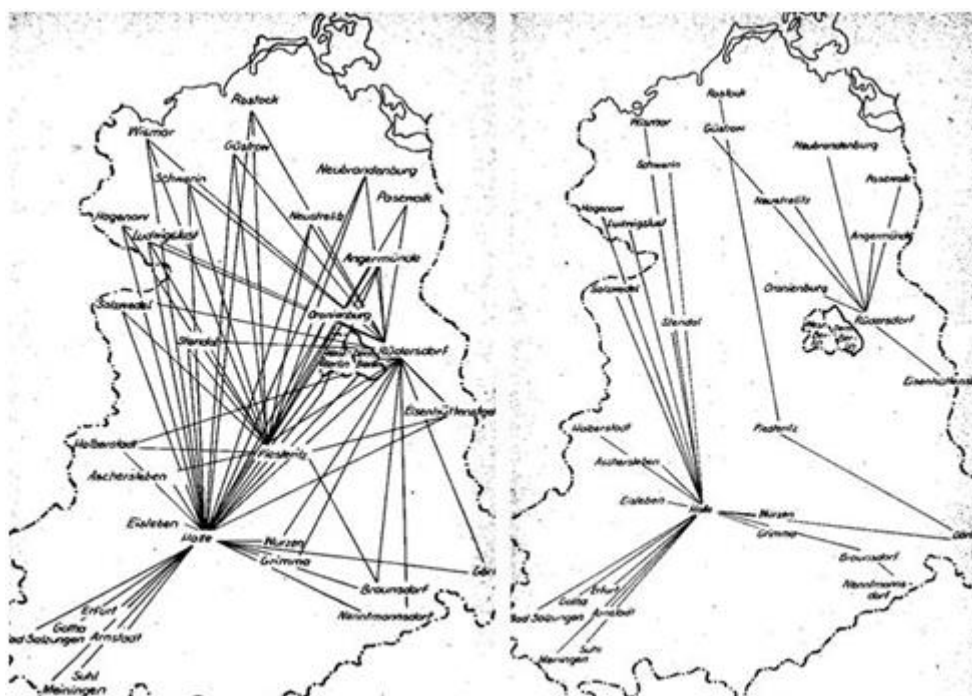


Figure 4: Centralization of transport relations for lime in the GDR

At the end of their publication, the authors Hofmann et al. also report on obstacles that stand in the way of abstractification in the transport model: The customers were to be convinced of the changed supply relationships and any necessary organisational or technical changes were to be discussed with them. In contrast to the optimizers' desire for stable supply relationships, changes in quantities and quality requirements are constantly occurring in lively economics. Long-term supply relationships in the state distribution offices, sales offices and associations of state-owned enterprises were changed

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opening lecture on the congress "Mathematics and Cybernetics in Economics", in: Deutsche Akademie, *Mathematik und Kybernetik*, 1965, pp. 4-11.

<sup>148</sup> Hofmann et al., *ibid.*, p. 72.

<sup>149</sup> *ibid.*, p. 90.

without these enterprises benefiting from the advantages of optimisation.<sup>150</sup> In the research reports of the Test and Development Centre for Motor Traffic at the Dresden University of Transport and in the journal "Der Verkehrspraktiker", it was also acknowledged that so far there have been few applications of the transport model, but examples of the supply of flour to bakeries in Dresden and the supply of bricks to construction sites have been mentioned.<sup>151</sup>

The volume "Methodik für die Optimierung der Transporte mit Kraftfahrzeugen" published in 1964 by the Dresdener Versuchs- und Entwicklungsstelle focused on the transport of goods by truck. In addition to the transport model, the round trip problem ("Travelling Salesman Problem") and the route planning problem based on it are presented there. The route planning problem starts from a central depot and compiles the total number of daily grocery stores in a city into a series of separate delivery routes for delivery vehicles. The following figure visualizes this problem for 10 grocery stores and three tours.

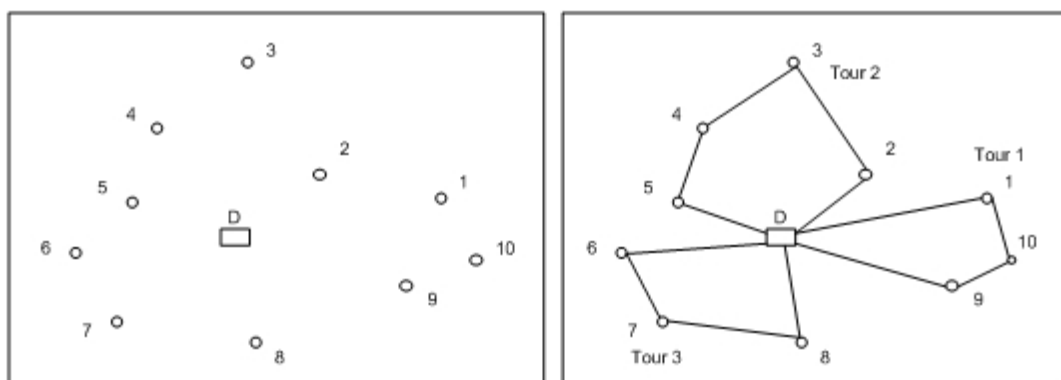


Figure 5: Delivery of 10 grocery stores in a city from a depot D, left without linking tours, right with three tours. (Source: drawn up by the author)

The tour planning problem asks how the stores are to be assigned to individual supply tours and how the shortest sequence of stores to be visited is to be determined in the individual tours - the latter a Travelling Salesman problem (see above).<sup>152</sup> The aim of the planning is to determine a breakdown into daily routes and their sequence in such a way that the total number of kilometres driven by the delivery vehicles is minimised. The individual journeys of the delivery vans starting from the depot were optimized with heuristic procedures for the round trip problem to shortest routes. The application of Dantzig's optimization methods to the roundtrip problem with a computer was rejected, pointing out that this approach would test too many alternatives. Instead, simple heuristics were

<sup>150</sup> *ibid.*, p. 101.

<sup>151</sup> Experimental and Development Centre for Motor Traffic, Methodology, 1964. On pages 25f, the computers accessible for research in the GDR are compiled as a table. Annual reports of the Experimental and Development Centre 1962 and 1963, files of the Ministry of Transport, Federal Archives Berlin, file DM 1/7152. Verkehrspraktiker, 1964, pp. 6-7.

<sup>152</sup> Hoffman and Padberg, Travelling Salesman, 1996.

mentioned which were well suited for "manual calculations".<sup>153</sup> Manual calculations carried out with the table calculator were unproblematic insofar as the problems were manageable and the individual supply tours seldom included more than 10 retail outlets.

In the Western OR literature, however, it was pointed out that the route planning problem described here was too much simplified as a "basic model" and therefore only suitable for academic teaching and that numerous additional conditions had to be taken into account in real-life applications, such as the return of empties or certain time restrictions on delivery. But precisely these additional conditions, which vary depending on the application, prevented the creation of a generic basic model to which the additional conditions could simply be "stuck". For this reason, the model had to be redefined from scratch for each application.<sup>154</sup>

The authors of the Experimental and Development Centre named the locations of institutions throughout the GDR that provided computers - mostly the ZRA1 - for calculations. These computer locations took over the programming and the actual calculation due to the delivered data, for which 160 German Marks were charged per computer hour and 12 German Marks for a mathematician hour for programming. Users should therefore weigh a "manual calculation" against the computer calculation.<sup>155</sup> The authors also addressed data collection problems. The road network was to be created from map material, with applications for the purchase of maps being submitted to the State Geodesy Control if the maps were not commercially available. The goods to be shipped should be recorded by type and weight. Milk deliveries to retail stores in various cities such as Dresden, Berlin and Rostock are mentioned as an application of the route planning problem. In Dresden there was a shortening of the daily delivery routes from 730 km to 580 km. During the optimisation in Dresden it turned out that the former supply runs overlapped, so that the elimination of the overlaps made it possible to shorten the route without optimisation.<sup>156</sup>

In order to apply the round trip problem to the route planning problems, it was necessary to determine in advance the individual delivery areas in which the individual route was to be optimized. There was no mathematical procedure for this decomposition, as the authors complained in the 1964 volume "Methodik für die Optimierung der Transporte mit Kraftfahrzeugen" on page 19. The British researchers G. Clark and J. Wright did not publish their tour planning data until the same year, 1964, when they were able to determine the delivery areas using the Savings method.<sup>157</sup> Clark and Wright's approach is interesting in that it starts from an unusual starting solution, the one that is the worst of all: Each shop is served by a truck in a shuttle tour from the depot, without involving the service of other shops. In an iteration process, shuttle tours are combined step by step, which promise the greatest savings in travel distance back to the depot. The authors Hofmann et al. also mention factors that stand in the way of abstractification. This is how the daily fluctuating needs of the grocery stores are called, so that one had to work with rough average values. Separate delivery schedules were

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<sup>153</sup> Experimental and Development Centre, Methodology, 1964, p. 20.

<sup>154</sup> Mattfeld and Vahrenkamp, logistics networks, 2012.

<sup>155</sup> Experimental and Development Centre, Methodology, 1964, p. 20, p. 25f. Hofman et al., Optimization, 1964, p. 29.

<sup>156</sup> Experimental and Development Centre, Methodology, 1964, p. 19.

<sup>157</sup> Clarke/Wright, Scheduling, 1964.

recommended for the peak demand on Saturday. The plans for Sunday delivery, however, meant that many stores remained closed, so that new plans had to be drawn up for Sunday.<sup>158</sup>

In the following, we will show how transport optimization was embedded in the political knowledge cultures of the GDR and met with resistance there. Mathematicians in the GDR were sceptical about the use of OR methods. The head of the testing and development centre for motor traffic at the Dresden University of Transport, the mathematician Werner Haering, complained at the 1964 meeting of heads of the motor traffic administrations (BDK) in Magdeburg that the shipping departments of industry was hardly interested in optimising the use of trucks.<sup>159</sup> The negative attitude of the shipping departments resulted not least from the centralisation of truck traffic, which the SED had undertaken since 1959. The industry was deprived of its own truck fleets, which it had used in so-called factory transport, and centralised as state-owned transport companies, which now offered transport services to the shipping departments.<sup>160</sup> The Motor Transport Department of the Ministry of Transport wanted to take action against this hesitant attitude of the loading industry and launch a broad training campaign. Already in March 1963 in Weimar and in June 1964 in Zabeltitz, training programmes for transport optimisation for the shipping departments took place.<sup>161</sup> The mathematical transport optimization met the politicized field of the centralized truck policy of the SED.

In the application of tour planning, the GDR was about 20 years ahead of Western-Germany (FRG). It was not until the 1980s that the main memory of the computers available in companies in FRG, at around 300 kilobytes, was large enough to use route planning software such as the TRAFFIC package from Siemens. This software was used above all in the sales organisations of the financially strong companies in the beverage industry and milk processing. As already known from the centralised transport policy in the GDR, problems with the abstractification of route planning also arose in the FRG. The shops supplied by the delivery vehicles always wanted to be served by the same driver in the recurring routes - a wish that the route planning software did not take into account. There were also problems to include shops with different delivery rhythms in a common tour.<sup>162</sup> In the route planning packages, the actual route planning was considerably extended to a truck fleet management system, which included accounting for routes, vehicle costs and personnel deployment. However, high licensing costs for software manufacturers hampered widespread use until the 1990s.<sup>163</sup>

The boom in transport optimisation in the GDR came to an end at the end of the 1960s. Researchers referred to the alleged relevance of the transport problem. The authors Dück et al. justified it tautologically in 1971 as follows: "In the economy the transport problem is given great importance ...because of its great economic significance."<sup>164</sup> By "economy" the authors mean the national economy. However, the researchers could not point to any convincing applications.

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<sup>158</sup> Experimental and Development Centre, Methodology, 1964, p. 19.

<sup>159</sup> Traffic Practitioner, Lack of Interest, 1964, p. 6f.

<sup>160</sup> Vahrenkamp, Dream, 2015.

<sup>161</sup> Verkehrspraktiker, Lacking Interest, 1964, p. 7. Versuchs- und Entwicklungsstelle, 1964, Preface.

<sup>162</sup> For the use of route planning in the beverage industry and in milk processing, see Lück, Logistik, 1984, p. 437-473. For the problem of the same driver, see *ibid.*, p. 458 and Vahrenkamp, Dream, 2015, p. 15.

<sup>163</sup> Vahrenkamp, market study, 2006.

<sup>164</sup> Dück et al., Operation Research, 1971, vol. 2, p. 186.



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