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Mathematical Management – Operations Research in the United States and Western Europe, 1945 – 1990**

Abstract

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.

Keywords: transport model, verhicle routing, linear programming, abstractification, TIMS, IFORS, Euro conferences, Lecture Notes in Operations Research, pen and paper, Dantzig, air lift
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Introduction

With its drive to optimise the world, the field of operations research reached the height of its influence in academic circles in the 1970s. This paper outlines the rise and fall of this important field of management. It begins by describing how the field of operations research (OR) emerged in the political and intellectual culture of the Cold War since 1945. It then illustrates the rapid institutional rise of operations research in the social spaces of Western European universities, flanked by NATO, as an export of U.S. approaches, before highlighting and explaining the small number of empirical projects in the social spaces of business enterprises. This paper provides evidence that the mathematical models of operations research were not management support for leading businesses but that operations research was an autonomous movement of mathematicians. According to John Krige, the export of American operations research was American soft power intended to strengthen Western Europe as a bulwark against communism (Krige, 2006, Chapter 8). This paper focuses on Western Europe and the Federal Republic of Germany and highlights differences in OR implementation in East Germany (GDR). It is based on a wealth of published sources. Extended versions of this paper the reader can load from the author's website as working papers on the history of computing.[1]

As a field of study, operations research is part of business administration and deals with mathematical models for planning material flows in factories, traffic planning, and for personnel allocation planning to support management decisions. Operations Research focuses on minimising costs and maximising the profits of individual companies. The variables of costs and profit are linked by definition by the turnover of a company as follows: profit = turnover – costs. Costs or profit are modelled as a function of variables, and the minimum or maximum of this function must be determined as an "optimal solution" and as a guideline for management. In what is known as Linear Programming, these functions are modelled as linear functions of the quantities used and become the object of algorithms when they are minimised or maximised under complex structures of constraints, mostly expressed by linear inequalities and representing compact sets in the n-dimensional number space. At the optimal solution, the variables exhibit certain numerical values, and the management can implement the solution in the enterprise when it changes the tasks on the production floor according to the values of the variables.

Publications on the history of operations research have thus far mostly been uncritical success stories such as "Timeline" (2005) by Saul Gass and Arjang Assad, the history of operations research (2015) by William Thomas, or the history of operations research (1997) by Stephen Johnson (Gass & Assad, 2005; Johnson, 1997; Thomas, 2015). This paper will critically reappraise the field of operations research as a part of management theory and will do so from the perspective of the

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history of science. Criticisms will include the lack of an empirical orientation and the disregard for computers, which are completely ignored in the success stories.

As early as 1981, Heiner Müller-Merbach, the Darmstadt university professor of operations research, was critical of the lack of empirical data in OR, and this paper follows his approach (Müller-Merbach, 1981). It argues that, without an empirical orientation, OR converts on the office desk economic relations into simple mathematical models and simplifies in a process of abstractification the social context. This procedure contributes only to the academic world and merely represents a value in itself but does not solve any social or economic problem. Operations research, therefore, is not driven by empirical projects and empirical data but rather is driven by new mathematical methods and belongs to the field of applied mathematics. This connection to applied mathematics has also been recognised by OR professors such as the leading OR promoter Hans Künzi, who will be discussed below. In his opening remarks at the annual meeting of the German Society for Operations Research, he stated: "You are not mistaken if you consider the theory of the new branch of research to be part of applied mathematics" (Künzi, 1972, p. 3).

It must be emphasised that any modelling process simplifies social reality so that mathematical formulas can be applied, and any data collection that may be required is simplified as well. All models, including those from the disciplines of engineering, econometrics[2], astronomy, and meteorology, simplify reality. Unlike OR, however, the results of modelling in these fields are applied to the real world. In physics, for example, researchers simplified matter to a collection of vibrating atoms, as Max Planck did for his radiation formula and Albert Einstein for his theory of specific heat. However, these drastic simplifications were offset by important results. Planck was able to deduce his radiation formula from this approach, and Einstein, too, was able to explain the behaviour of specific heat at low temperatures using this model (Fölsing, 1993, p. 142, 175). However, this reference to reality is missing in OR, as this paper will demonstrate using the example of the Transport Model.

The Emergence of Operations Research in the Context of the Cold War

Many studies have shown how operations research emerged in the political and intellectual culture of the United States and Britain during World War II and the subsequent Cold War era (Erickson et al., 2013; Klein, 2015; Thomas, 2015; Mirowski, 2002). This aspect will, therefore, not be dealt with in detail here; the significance of Linear Programming for the Berlin Airlift in 1948 will be described below. Other influences from the United States on the development of operations research in Western Europe will be outlined here. For example, influential OR textbooks from the United States were published in German and French (but not

2 On the history of econometrics, see Alexander Nützenadel (2005).

in Italian), such as "Linear Programming" (1963) by George Danzig and "Introduction to Operations Research" (1957) by West Churchman et al. From the latter, a Spanish edition appeared in 1973 in Madrid.

In 1947, the SCOOP project group in the mathematical department of the RAND Corporation (Santa Monica, California) – a think tank of the U.S. Air Force – developed the mathematical algorithm of Linear Programming, which was to become the core element of operations research.[3] The conflict surrounding the Berlin Blockade of 1948 was the first important confrontation between the Soviet Union and the United States in the Cold War and is part of the founding myth of the Federal Republic of Germany, which was founded in 1949 as a western German state and a bulwark against communism. The airlift supplied West Berlin, which had been cut off by the Soviet Union, with essential goods. These were carried by cargo planes from West German airports. The soldiers of the occupying Western Allies thus became friends with West Germans.[4] As a showcase project for Linear Programming in the political and intellectual culture of the U.S. Air Force and in the context of the Cold War, the SCOOP group developed a model for the Berlin Airlift of 1948–1949 (Operation Vittel) and published it at various conferences. This Linear Programming model for the airlift can serve as a prime example of my thesis on abstractification. The model of the airlift was made only for the academic arena. It served neither to prepare nor to manage the airlift. In 1948, the United States possessed only two digital mainframe computers. The tiny central memories of these computers would hardly have been able to calculate a model with 3,600 variables.

The Institutionalisation of Operations Research

This section will examine social spaces, i.e. the institutions of operations research created by mathematicians at university departments of economics. In the 1950s, the term operations research was used in the United States to describe a heterogeneous set of mathematical methods such as game theory, Dynamic Programming, Linear Programming, warehousing, spare parts theory, queuing theory, simulation and production control, which were intended to be primarily used in civilian industry. Supported by the military, scientific societies and journals that focused on operations research were established in the 1950s, for example, the Operations Research Society of America (ORSA) in 1952 and the Institute for Management Science (TIMS) in 1953. Philip Morse, the head of the Pentagon's Weapons Systems Evaluation Group, became the first president of ORSA and encouraged companies of the military-industrial complex to join it; ORSA soon had more than

3 This project has been described in various historical analyses of mathematisation (Ceruzzi 1989, p. 41–43; Dorfman 1984; Geisler 1986).

4 Die Berliner Luftbrücke: Ereignis und Erinnerung, edited by Helmut Trotnow und Bernd von Kostka (2010).

500 members (Krige, 2006). In the 1960s, ORSA had an astonishing 8,000 members (Hanssmann, 1971, p. 11).

ORSA and TIMS were established not in response to a demand by industry for OR applications but rather by an autonomous movement of mathematicians who were supported by the military research institutes of the three branches of the American armed services, i.e. the Navy, the Air Force and the Army. The Office of Naval Research began issuing the Naval Research Logistics Quarterly in 1953. This journal published models of battlefields, among other things, and became the world's leading international journal for operations research between 1953 and 1980. The Office of Ordnance Research of the U.S. Army held its first OR conference in January 1955 (Churchman et al., 1957, p. 429). In 1949, RAND organised what would become the famous Linear Programming Conference at the University of Chicago, which was announced as "Activity Analysis of Production and Allocation". This was followed by the first symposium on Linear Programming in Washington, D.C., which was held under the joint auspices of the RAND Corporation and the National Bureau of Standards in 1951. In his book on automation, published in 1960, Herbert Simon characterised operations research as a new science of management promoted by mathematicians (Simon, 1960, p. 15). The United States provided travel funds for three international conferences (IFORS, see below) on operations research in the NATO member states Britain, France and Norway between 1957 and 1963. The participants of these conferences mainly came from NATO countries. The autonomous OR movement among mathematicians was not unusual in the 20th century. Taylorism can also be seen in the context of various expert movements in the 20th century, as can the rationalisation debate in Europe in the 1920s and the automation debate in the United States and Europe around 1960 (Haber, 1964; Maier, 1970; Kline, 2006; Vahrenkamp, 2013).

In the 1950s and 1960s, the faculties of economics at universities in the United States and Britain (Lancaster in 1964) established chairs of operations research. As early as 1956, the West German Ministry of Defence supported three smaller projects on "OR methodology" – i.e. mathematical models – to the universities of Kiel, Münster and Munich in order to increase awareness of OR throughout FRG (Benecke, 1958, p. 23).[5] NATO took important steps to propagate OR in Western Europe. In the 1950s, the NATO headquarters SHAPE hosted four conferences on OR – with 120 participants in 1956 – and thus brought OR to mainland Europe (Davies & Verhulst, 1958, p. 1). Within NATO, OR was also referred to as "Scientific Advisory" (S.A.) and included in the Advisory Group of Aeronautical Research and Development (AGARD) (van der Bliek, 1988). In April 1957, the two NATO organisations, SHAPE and AGARD, hosted an OR conference at the Palais de Chaillot, one of the most prestigious conference venues in Paris (Davies & Verhulst,

5 Archival research should bring to light further information on such OR projects.

1958). In retrospect, the papers presented at the NATO conferences appear rather superficial. Conference participants mostly assured one another of the importance of OR. The actual objectives of NATO OR, however, went unmentioned. Was the objective to improve radar or the accuracy of antiaircraft guns? How could the supply of spare parts be accelerated? After France left NATO, SHAPE was relocated from France to Belgium in 1966. This had repercussions on OR institutionalisation in Belgium, where in the same year, Jacques Drèze founded CORE, the Center for Operations Research and Econometrics, at the Catholic University of Leuven (Belgium) (Brusberg, 1965, p. 52; Mirowski, 2002, p. 490).

In the 1960s OR chairs, also referred to as chairs of business research, were established at universities in Switzerland and FRG. As early as 1958, Hans Künzi, a professor of mathematics, held an OR chair at the University of Zurich and – in what was likely unique in the academic world – from 1966 onward, he held an additional OR chair at the Federal Institute of Technology in the same city. He became the President of the Swiss Association of Operations Research in 1962. Künzi's dual professorship illustrates the excessive public expectations placed on the problem-solving capacity of operations research. In 1966, Rudolf Henn, who had training in both economics and mathematics, took over the chair of econometrics and operations research at Karlsruhe University. He became one of the leading OR promoters in FRG by publishing the journal "Operations Research Verfahren" from 1963 onwards. In 1966, Henn and Künzi jointly wrote the standard university textbook "Einführung in die Unternehmensforschung "(Introduction to Operations Research), which was published by Springer in two volumes (Henn & Künzi, 1966). Volume 1, however, did not address operations research but instead focussed on mathematics: Set theory, linear algebra, probability theory and statistics. This is a good example of the pronounced mathematical orientation of OR.

The growing influence of operations research in FRG between 1960 and 1970 (Bradtke, 2003, p. 2) gained considerable momentum when the German Research Foundation included operations research in its priority programme in 1961. It financed 16 small projects on operations research in 1962 and 30 in 1963 with one to two man-years at economic faculties of West German universities. These projects focussed on mathematics and model theory and did not have an empirical basis, as is shown by the list of project subjects (Brusberg, 1965, p. 313–316). The fact that six new OR chairs were established in FRG suggests that OR was successfully institutionalised in the social spaces of universities between 1969 and 1981. The chairs were invariably held by mathematicians. There was a clear trend in economics departments to appoint mathematically qualified applicants to OR chairs. The reason for the excellent reputation of this group of applicants in economics departments can only be found by examining archival material on appointments. In general, we can assume that the modern quantitative methods from the United States had a high standing in Europe.

Hans Künzi and Martin Beckmann – who had studied mathematics and physics at the University of Göttingen in the 1950s, had been Professor of Econometrics and Operations Research at the University of Bonn since 1963, and had been engaged in joint research with Tjalling Koopmans in the Cowles Commission in the USA (Mirowski, 2002, p. 289) – gained a dominant position in the European OR research network when they edited the English-language softcover series "Lecture Notes in Operations Research and Mathematical Economics" under various titles with the Springer publishing company. By 1979, the series "Lecture Notes in Economics and Mathematical Systems" comprised a total of 170 issues, i.e. 16 issues per year since 1968. This was documented by the editors in a special volume (Beckmann & Künzi, 1979). As the titles show, the Lecture Notes series covered a wide range of different subjects but did not include computer applications. Disregarding computers became a characteristic feature of the mathematical OR movement. The height of the movement was likely reached in the 1970s when Tjalling Koopmans was awarded the Nobel Prize in Economics for his work on the Transport Model. After operations research had ignored computers for decades, its decline in the social spaces of universities began in the 1980s, when more chairs of business informatics and logistics were established instead.

International cooperation contributed to the formation of an international, self-referential operations research system and explained the explosive growth of national OR societies. This arena was established by three international conferences on OR in Oxford (England) in 1957, Aix–on–Provence in 1960 and Oslo in 1963. As early as 1959, the American, British and French OR societies founded the International Federation of Operational Research Societies (IFORS) (Rand, 2000). A conference prior to the founding of IFORS was held in Oxford (England) from 2 to 6 September 1957 and was organised by TIMS, ORSA and the British OR Society. It had as many as 250 participants, mainly from NATO member states and the British Commonwealth, as well as two Polish participants, who were the only representatives of the communist bloc (Davies, 1957, p. 523).[6] By 1960, IFORS already had ten members, all of whom – except for India and Australia – were NATO member states: the Federal Republic of Germany, the Netherlands, Norway, France, Belgium, Canada, the United States, and the United Kingdom. In 1975, OR professor Hans-Jürgen Zimmermann from Aachen University brought together eleven national OR societies from Western Europe (and excluded Eastern Bloc countries) in what was known as "EURO" (The Association of European Operational Research Societies, 1975; Zimmermann, 1995, p. 404–407). While IFORS held international conferences every three years, EURO hosted international conferences in the other two years. The OR researchers were eager to attend these conferences. The EURO website reports on 2000 scholars. EURO began publishing the European Journal of Operational Research in 1976. The rapid growth of

6 The Polish participants were Professor Jan Oderfeld and Professor Rajski, both from the Institute of Mathematics at the University of Warsaw.

this journal is reflected by the fact that the 96th volume was already published in 1996.

Reluctant Application of Operations Research by Industry

The strong emphasis on mathematical methods had met with disapproval from company directors since the 1950s. OR specialists were accused of using incomprehensible jargon, as Walter Trux, the director of the mechanical engineering company Fichtel und Sachs, put it in his opening remarks at the 1980 annual conference of the German Society for Operations Research in Essen (Rider, 1992, p. 231; Trux, 1981, p. 21).[7] In a marked contrast to the flood of publications on theory-oriented, mathematical OR topics without computer applications, OR methods were rarely used by industry. As Dantzig noted in his book "Linear Programming", which was published under RAND copyright in 1963, the industry was reluctant to use Linear Programming for production planning purposes (Dantzig, 1963, p. 28). In other publications, he reported that the oil industry had successfully used operations research methods (Dantzig, 1965, p. 113–118). There were also indications that OR methods were used in the West German steel and chemical industries, as was revealed by an empirical survey conducted by Volker Steinecke in 1973.[8] In 1957, the RAND Corporation criticised the Linear Programming approach in the oil industry for its excessive simplification. It argued that the maximum profit of refineries depended on many additional factors that were not included in the model (Goldstein, 1958, p. 56). Such arguments refer to the validity of Linear Programming approaches. Validity is a modelling quality criterion cultivated by applied statistics which was ignored in OR literature. Compared to the OR, climate science has a higher methodological level. There, the problem of closure is discussed when a model captures all relevant variables (Müller et al. 2013). The 1959 approach taken by Herbert Simon, who was an economist and behavioural scientist, accepted limits on rational decision-making. This approach takes into account the costs of information acquisition as a limitation for model refinement. Simon's behavioural approach is the antithesis of the mathematical paradigm of operations research (Simon, 1959).[9]

7 Rudolf Henn provided an example of jargon in his essay “Notes on the Simplex Method” (Bemerkungen zur SimplexMethode), where he explained the method in terms of ordered fields rather than the n-dimensional number space (Operations Research Verfahren, Vol. 2, 1965, pp. 91–107). In Volume 4 of Operations Research Verfahren of 1967, Bernd Goldstein published an absurd paper of more than 300 pages of mathematical formulas for Markov chains without a single line of text.

8 Die Lineare Zuschnittoptimierung in der Stahlindustrie beschreibt Volkmar Kussl (1964, p. 257).

9 Simon wavered, however, between behavioral science and mathematical OR papers, see Erickson et al., How Reason, p 207.

The limited success of OR methods is also due to the fact that American companies had increasingly used scientific methods in corporate management as early as the 1930s and 1940s and therefore had little need for consulting. The consulting services provided by the field offices of IBM and Powers for the introduction and improvement of punched card technology should, however, be mentioned (Akera, 2007). In Germany, science played a large role in production processes in the Nazi war economy. As a result, there was little need for OR consultants in FRG (Flachowsky, 2015; Kirby & Capey, 1998, p. 309). The situation was different in Britain, where corporate management had major deficits. Here, OR was successfully applied in public utilities and the primary sector of the economy. The period from 1945 to 1970 was referred to as the "Golden Age of OR". OR was seen as a means to modernise the industry. OR research groups were established mainly at the association level, for example, the OR Research Group of the British Iron and Steel Research Association, which was founded by Sir Charles Goodeve in 1950 (Kirby & Capey, 1998; Kirby, 2003).

The widespread use of operations research in the social spaces of companies also met with difficulties because empirical data were required for the models in order to calculate optimum solutions. Such data, however, had yet to be collected in the companies. Collecting data on individual operational processes within a company is both tedious and costly. This is well-known from a management perspective and plausible according to Simon's theory of bounded rationality. Furthermore, people in lower management tend to dislike the idea of having their own area of responsibility studied (Kaplan, 1998). Management thus seeks a balance between data quality and collection costs and tends to follow simple rules. In his empirical study on the use of OR in West German companies, which was based on surveys conducted in 1970 and 1971, Rolf Gössler admitted that even "experienced companies" did not have accounting and information systems commensurate with the data requirements of OR studies (Gössler, 1974, p. 228). In addition, many industrial processes exhibit flat cost curves that do not show a sharp minimum, so deviations from the minimum costs were only of minor importance, and rough estimation methods could be applied. In the 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.

Operations Research and Management Science

In his influential book "The New Science of Management Decisions" (1960), future Nobel laureate Herbert Simon examined two possibilities for computers: the automation of simple employee work and support for management. In a move that reflects the uncritical approach in the automation debate at that time, he regarded

Frederick Taylor and Taylorism as a predecessor of operations research.[10] Simon, however, was unable to provide concrete ways of supporting management decisions with OR methods and computer applications. Instead, he only cited buzzwords such as the different methods of operations research, which included game theory, Dynamic Programming, Linear Programming and simulation (Simon, 1960, pp. 14–16). In the book "Cybernetics and Management", which was published in 1959 and proved influential in the cybernetics debate, Stafford Beer, who was an OR consultant with the British steel company United Steel, also ascribed operations research a decisive role in the conceptual design of industrial control processes. But Beer also used operations research as a mere buzzword without explaining what it was (Beer, 1967, p. 90).[11]

Simon's proposal of using computer implementations of methods of operations research to support management was of limited use since Simon did not consider the minimal empirical orientation of OR. Operations research was unable to provide the empirical methods needed to support management. Proponents of OR were also the wrong target audience for Simon's hypothesis since they had kept their speciality largely free of computer applications. Textbooks on OR and OR curricula at universities made no reference to computers at all. In Henn and Künzi's groundbreaking work published in 1966, there is only one mention of what they called an "electronic calculator" (Henn & Künzi, 1966, p. 171). In the 1971 second edition of his book "Operations Research", Heiner Müller-Merbach highlighted the importance of computers for OR (although only in the foreword) but did not make any mention of the software used. In 1993, when personal computers were widely used and powerful enough to deal with things such as Transport Model, the authors Klaus Neumann and Martin Morlock published a textbook called "Operations Research", in which they made no mention of computers at all. In 1998, Theodor Ellinger ignored computers in the even revised fourth edition of his textbook "Operations Research" (written together with Günter Beuermann and Rainer Leisten).

The OR Lecture Notes series edited by Künzi and Beckmann also avoided the subject of computers. Although the term "computer science" appeared on the covers, the 50 titles that were published up to 1971 were almost exclusively mathematical. This pattern in textbooks and in the Springer series can also be seen in research. The proceedings of the annual meetings of the German Society for Operations Research contain only isolated mentions of presentations on computer applications:

10 For more information on the Taylorism and automation debates, refer to Richard Vahrenkamp: Von Taylor zu Toyota. Rationalisierungsdebatten im 20. Jahrhundert, Cologne 2013.

11 Beer became famous when, in 1972, he equipped Salvador Allende's socialist government in Chile with a decentralised computer network to control the public sector, as described in Eden Medina: Cybernetic Revolution – Technology and Politics in Allende's Chile, MIT Press 2011.

none at the 1971 annual meeting and two papers out of 30 at the 1972 annual meeting.[12] Few authors of OR textbooks touch on the subject of software. One of the few scientists to do so was the mathematician Ulrich Derigs, who was employed at the "industry seminar" (with its promise of empiricism) of the University of Cologne and who published software for solving OR algorithms in 1980, together with Rainer Burkhard, a professor of mathematics at the Institute of Mathematics of the University of Cologne (Burkhard & Derigs, 1980). In their 1983 book "Operations Research", Walter Dürr and Klaus Kleibohm also gave an overview of the most important software packages for the Linear Programming of mainframe computers produced by the large computer manufacturers CDC, Univac and IBM. In the same way, the authors Paul Schmitz and Alfred Schönlein gave insights into OR software packages in their 1978 book "Linear and Linearised Optimisation Models and their DP-based Solution".

Transport Model in the Academic Arena

The Transport Model is a drastically simplified model that describes how the transport of a homogenous good between different sources and destinations with set constant transport costs per tonne should be organised to keep transport costs to a minimum. An example is shown in Figure 1. But the seemingly harmless Transport Model reveals a paradox. On the one hand, those who discovered it received a Nobel Prize in Economic Sciences in 1975. The Transport Model was always an important chapter in every textbook on operations research and in the curricula of management schools. So it belongs to the core of operations research. On the other hand, this theory had no realistic economic applications in business and remained in the academic arena. This section will attempt to explain the reasons for this lack of application. In general, the Transport Model is representative of the many other OR models whose relevance has always been claimed but never proven.

The Transport Model is economically justified as follows in the literature. Churchman et al. unexpectedly introduce the Transport Model in their textbook by citing the example of how railway companies coordinate empty wagons but provide no empirical foundation for this example. They use the reference to railways only to add a semblance of empiricism to their work (Churchmann et al., 1957, p. 283). In their textbook "Linear Programming", which was published by RAND in 1958, Dorfman et al. claim that there are numerous applications of the Transport Model in economics and in the business world without providing any proof. They describe one of their examples as "purely fictitious" (Dorfman et al., 1958, p. 106–117, example on page 117).[13] Henn and Künzi refrain from providing any economic interpretation of the Transport Model and only mention the mathematical model in their textbook "Einführung in die Unternehmensforschung" (Introduction to

12 Both Physica Verlag Würzburg 1972 and 1973.

13 This book was influential because it was also published as an international students' edition.

Operations Research). They are thus unable to explain what the Transport Model has to do with operations research. Dantzig also fails to elaborate on the economic benefits of the Transport Model in his textbook on Linear Programming, which was published in German and French. Instead, he only talks about an optimal transport plan (Dantzig, 1963, p. 299).

In 1941 and 1942, the mathematicians Frank Hitchcock and Tjalling Koopmans independently conceived the Transport Model (Hitchcock, 1941). Tjalling Koopmans, who obtained a doctorate as a mathematical physicist in the 1930s, developed the forerunners of the Transport Model during World War 2. As a statistician with the United States Combined Shipping Adjustment Board, he observed bottlenecks in the transport chain of worldwide shipping routes during World War 2 and asked himself which routes' capacity could be reduced if additional shipboard space was needed for another route (Koopmans, 1942). He transformed these bottlenecks into a simple transportation model in which the marginal costs of transport would be able to control the optimisation of shipping routes. He substantiated his model with statistics from the German Reich Statistics Office in Berlin, which had published the entry and exit quantities for the 15 most important ports in the world in 1928 (the port of Hamburg was missing from Koopmans' publication) to give his work a semblance of empiricism. However, Koopmans did not have the transport prices in world trade and was unable to solve the model without this data. He showed that marginal costs were able to have a controlling effect that would lead to the optimum, irrespective of competitive conditions. The optimum is a transport plan in which the sum of transport costs is minimal compared to all alternative plans. Koopmans published his model in the prestigious journal Econometrica in 1949 (Koopmans, 1949), and in 1975 he was awarded the Nobel Prize in Economic Sciences for it (together with Russian mathematician Leonid Kantorovich for his discovery of Linear Programming).[14] In 1970, Martin Beckmann published Tjalling Koopmans' scientific papers in one volume with Springer-Verlag Berlin, which paved the way for Koopmans to receive the Nobel Prize in 1975 (Koopmans & Beckmann, 1970). A solution procedure for the Transport Model in the context of Linear Programming was developed by Abraham Charnes and William Cooper in 1954. This procedure came to be known as the stepping stone method. The authors disclosed that their work was commissioned by the Office of Naval Research (Charnes & Cooper, 1954). How the Navy profited from the Transport Model, however, remained unknown.

The Transport Model abstractifies the real world in different steps. It matches different suppliers of a homogeneous good with different buyers and assumes constant

14 See the press release of the Swedish central bank at: https://www.nobelprize.org/prizes/economic-sciences/1975/press-release/ (accessed on 1 December 2019). The German Society for Operations Research falsely claims on its website that Dantzig received a Nobel Prize, see www.gor-ev.de/or-2008-in-augsburg. (accessed on 30 May 2018).

transport costs per tonne from supplier i to buyer k. In a process of simplification, the diversity of goods is eliminated, and only one homogeneous good is considered. It thus does not matter to buyers what supplier provides them with the good. Deciding on a source of supply is, however, an important decision for management in the real world. This type of decision cannot be made using the Transport Model. A homogeneous good means that different goods cannot be transported on the same ship, which is an absurd simplification whose only purpose is to ensure an elegant mathematical formula. The Transport Model also disregards changes in freight rates over time, which occur in the real world. What are ships supposed to do in the world of the Transport Model when they are at sea and freight rates change? Are they supposed to return to port, only to be put to sea again according to a newly optimised plan? The Transport Model also disregards the economies of scale that exist in the transport industry, where freight rates for one tonne are greater than for 1000 tonnes.[15] This drastic simplification of economic reality in the Transport Model is in clear contrast to the way in which OR portrays itself. OR promoter Martin Beckmann, for example, claims that OR is particularly applicable in complicated decision-making situations: "Mathematical methods are increasingly used in the fields of economics and social science, in particular in areas that concern decision-making in complicated situations. Because operations research deals with the application of mathematical models to economic decisions, it has developed rapidly... because of this demand." (Beckmann, 1979, foreword).

An algorithm was used to determine the minimum cost of the transportation problem. This algorithm is based only on integer numbers – i.e. decimal numbers are excluded – since it involves only the operations of addition and subtraction and no divisions, which would lead to decimal numbers. This limitation to simple addition and subtraction was ideal for operations research because a plethora of textbook examples could be produced by pen and paper; i.e. they did not require the use of computers as did larger Linear Programming formulations. These examples were also perfect as exercises in university courses, in which transport tasks were used to give students the impression that applications exist and that the pen-and-paper technique was not based on computers. Dorfman et al. highlighted this simple procedure with pen and paper as a particular characteristic of the Transport Model (Dorfman et al., 1958, p. 106). Churchman et al. even assumed that such simple calculations could allow ordinary office workers to solve larger problems (Churchman et al., 1957, p. 298). This shows that, in 1957, the authors still thought of themselves as being in a pre-computer era.[16]

15 In his presentation at the 2008 annual meeting of the German Society for Operations Research in Augsburg, Richard Vahrenkamp called attention to the fact that economies of scale were being ignored.

16 For more on computer use in commercial data processing during the 1950s, see Campbell-Kelly, Martin and William Aspray (1996, p. 131–134) and Haigh, Thomas (2001, p. 75–104).

Illustrations were also used to promote the Transport Model. One example of this is a map of the United States that George Dantzig included on page three of his "Linear Programming" to highlight the economic importance of this book (cf. Figure 1). In addition to a French edition (1966), the book was published in German in 1966 by Springer-Verlag and had a major influence on the European OR community. In it, Dantzig shows a map of the United States with the locations of five warehouses and three fish canneries. He also shows transport connections between these locations and the transport costs per tonne. It comes as a surprise that Dantzig chose the canning industry as an example in a highly industrialised and technologically advanced country like the United States and not, for example, the aircraft industry. It is possible that Dantzig was referencing John Steinbeck. One year before the publication of Dantzig's book, John Steinbeck had won the 1962 Nobel Prize in Literature for his novel "Cannery Row", which was published in 1945 and focuses on the fish canning industry in Monterey on the American west coast. Monterey appealed to Dantzig because the U.S. Navy had operated the world's largest OR department there since 1953.[17] Dantzig invented the locations of the warehouses on his office desk; they were not based on an empirical research project with a fish canning company. This is underlined by the fact that he failed to provide a source for his map. This supports the suspicion of the invention. Source citation is mandatory in scientific papers.

The map appears to radiate the authority of an important problem in spatial economics, but this impression is misleading. A literature search done by the author has revealed that not even a single paper on the application of the Transport Model in the real world has been published, apart from papers published in the communist bloc between 1945 and 1990 (see section 7). There are no known examples in the literature of transportation companies (sea, air, rail and road) in the capitalist world which have used the Transport Model to optimise their routes. The Transport Model remains a drastically over-simplified model in the world of OR, which failed to find application in the physical world. It was, therefore, not included in the Linear Programming software packages for mainframe computers offered by Univac and IBM in the MPS format, as it did not exist in the real world (Dürr & Kleibohm, 1983, p. 212). Even in 2015 and contrary to all empirical findings, William Thomas described Transport Model as a success story in his history of operations research (Thomas, 2015, p. 181).

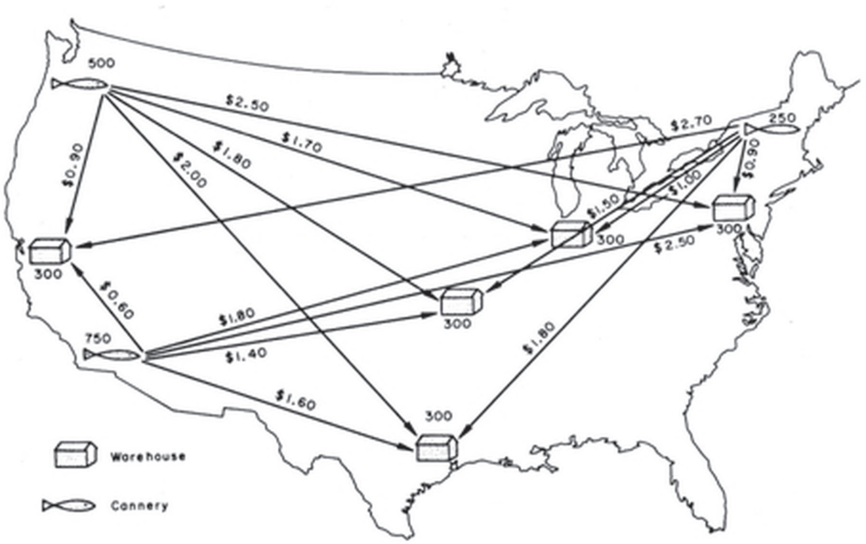
Unlike the Western world, the countries of the Eastern Bloc were dazzled by the promises of the Transport Model. In the 1960s, they implemented it on mainframe computers to solve transportation problems in the primary sector of the economy (see section 7). There was, however, opposition to the implementation of its solu-

17 Remarks by Saul Gass during the 2008 annual OR meeting of the German Society for Operations Research in Augsburg, see http://www.gor-ev.de/or-2008-in-augsburg. (accessed on 30 May 2018).

tions in the Eastern Bloc. This opposition stemmed from the fundamental question of how rationalisation gains by cost reduction were to be distributed compared to the original state of traditional transport connections. As long as all shippers and all recipients belong to one company, it can be assumed that rationalisation gains that were generated by seeking the minimum cost can be credited to either the shipper or the recipient. The situation is different if there are different players both on the shipper and on the recipient side, and negotiation processes arise. Koopmans did not consider such a situation in his Transport Model; he only naively sought minimum costs without thinking of the social context.

At universities, Transport Model was useful because it provided material for OR textbooks, lectures, exercises and written examinations that students were able to work on with pen and paper and without using computers. Students were given the impression that the theory had applications.[18] The Transport Model was attractive as a textbook subject because it made it possible to compare supply and demand in a table.

Figure 1. Dantzig's Map With Three Fish Canning Factories, Freight Rates and Five Warehouses in the United States (Dantzig, 1966, p. 3)



The abstract model of Linear Programming could thus be illustrated with the help of a table. On page 283 of their 1957 book, Churchman et al. excitedly demonstrated how the complicated approach of Linear Programming could be

18 Professor Knut Haase of the University of Hamburg still presented Transport Model in his operations research online lecture in 2017: https://lecture2go.uni-hamburg.de/l2go/-/get/v/22402 (accessed on 1 December 2019).

simplified using the Transport Model and thus be made accessible to management personnel with little mathematical knowledge. The Transport Model was, therefore, an important marketing tool for operations research: Look – operations research is really quite simple! This was the message. The Transport Model is representative of other basic theorems of operations research in which the artificial content of Cold War research can be seen. This artificial content was unsuitable for use in commercial enterprises and thus remained in the academic arena. I have argued this point elsewhere (Vahrenkamp, 2019b).

GDR as a Laboratory for Operations Research

When it comes to the institutionalisation of operations research, differences can be seen between East Germany (German Democratic Republic – GDR), a country in the former Eastern Bloc, and West Germany (Federal Republic of Germany – FRG). While OR in FRG developed in the political and intellectual culture of NATO and the Cold War era, in GDR, this development took place during the reform era of the 1960s. After the massive expansion of Stalinist economic policy in GDR in the 1950s, the country experienced an intense crisis when a large number of refugees fled to FRG. This brought GDR to the brink of economic ruin. Walter Ulbricht, the head of the East German Communist Party, changed the country's economic policy after the border to West Berlin had been closed off in 1961 and suddenly focused on reforms (Steiner 1999). The 1960s can be interpreted as a reform era for GDR, and operations research was employed in this context. Instead of using operations research only to maximise mathematical functions on mathematical sets, the reformist fraction of the Party even considered operations research to be an organisational science with which large socialist concerns such as the Association of People's Enterprises could be properly managed in the "New Economic System" of the 1960s (Glaessner 1977). The Party expected OR to provide guidance for management, as Herbert Simon had already proposed. From 1967 onwards, universities offered courses in Marxist-Leninist Organisational Science, in which OR played a large role (Schulze 2007). The East German Communist Party had founded large concerns called Associations of Publicly Owned Enterprises in the 1950s in such a rush that it lacked the methods to manage these large conglomerates. Marxist-Leninist Organisational Science appeared to provide a solution to this problem.

In 1968, Hannelore Fischer – who acquired her postdoctoral qualifications at the University of Freiberg and was probably the only female OR researcher with the rank of professor in Germany, if not in the whole of Europe[19] – published the book "Modelldenken und Operationsforschung als Führungsaufgaben" (Model thinking and operations research as leadership tasks) in the document series on the socialist economic management of the Central Institute for Socialist Economic Management. In this book, she described the coordination of individual companies within an Association of Publicly Owned Enterprises, a subject which belongs to the fields of management accounting and financial accounting but not to OR. The tables for the costs and profits of individual enterprises were to be consolidated into a single table (Fischer 1968, pp. 72–90). Fischer's approach could not be implemented because the individual enterprises were not prepared – the data set was not harmonised among the enterprises, and the software for processing this data was not harmonised in the various enterprises. This dual harmonisation remains an unsolved problem in business informatics: technical data structures meet social power structures. The Central Institute for Socialist Economic Management also gave high priority to a 1969 book by Hannelore Fischer which was almost 950 pages long and titled "Operationsforschung in der sozialistischen Wirtschaft: mit bewährten Modellen aus der Praxis" (Operations research in the socialist economy: With tried and tested models from practical experience), in which she gave examples for the application of OR in practice, such as the use of critical path analysis with 389 activities for the construction of the Schwedt crude oil refinery, which was essential for providing GDR with crude oil from Russia (p. 360).

Another particularity of OR in GDR compared to FRG was the fact that the Transport Model had actually been implemented in various economic sectors. The fact that the Transport Model had not been put to widespread practical use in the West did not prevent its use in the Eastern Bloc. With de-Stalinisation, computers were recognised as useful instruments for the planned economy, and the entire Eastern Bloc experienced almost a boom of transportation optimisation in the early 1960s.[20] Unlike in the capitalist world, the Eastern Bloc embraced methods of computer-assisted transportation optimisation, such as route planning and the Transport Model, since they appeared to correlate with the simplistic approaches of the planned economy. As scholars in economic policy at universities in FRG liked to stress, the planning approaches of centrally administered economies were characterised by oversimplification (Eucken 1990, p. 78). Western markets were characterised by a wide variety of commodities, while Eastern markets were limited

19 See the author's entry on Hannelore Fischer in Wikipedia. The elaborate conference report of the first IFORS conference in Oxford in 1957 includes a three-page index with photographs of all 250 participants and a list of participants by country. According to the former, around 10 of the participants were female, including Dr. Anna Maria Restelli of the Centro per la Ricerca Operativa at Bocconi University in Milan, whose superior, Francesco Brambilla, however, is listed as a professor; see Davies (1957, p. 523).

20 Hofmann, Karl, Dieter Schreiter and Horst Vogel: Optimierung der Lieferbeziehungen und des Transports, Berlin 1964. These authors and Potthoff (1961) provide extensive bibliographies including sources from Poland, Hungary, the USSR and Czechoslovakia.

to only a few types of goods. OR researcher Hannelore Fischer reported on one of her projects that dealt with the use of the Transport Model in forestry. She examined 130 forestry enterprises that felled trees and transported them to 20 sawmills around Königs-Wusterhausen. For this purpose, she collected data on logging and transportation capacities (Fischer 1969, pp. 410–427). Hardwood and softwood trees were examined separately to achieve sufficient abstractification. ZRA1, a mainframe computer produced by Zeiss in GDR, required 20 hours of computing time to find the allocation of transportation resources with the lowest costs. The computer was set up at the Potsdam-Babelsberg observatory. It used Vogel's approximation method to solve the transportation problem. This computer program was written at the data processing centre of the East German railway. Examples of abstractification in the GDR coal sector can be found in Vahrenkamp (2019a).

While this discussion of the dissemination of OR in GDR is restricted in scope, what is particularly interesting is the resistance of enterprises to rationalisation proposals based on OR algorithms. Similar incidents in Western European countries are not mentioned in the case studies. The question here is how rationalisation gains should be distributed among the various players when the Transport Model is applied. This is a controversial topic that has already been discussed above in the section on the Transport Model and is a criticism of Koopmans' approach, which is detached from the social context. GDR can be seen as a laboratory where these questions were negotiated. They are not mentioned in the West because private enterprises were able to reap the gains of their rationalisation efforts. The Stalinist economic policy of the 1950s, when truck fleets were expropriated from enterprises, resulted in strong resistance from those enterprises in the 1960s when route planning for the rationalisation of delivery routes to retail shops was to be introduced (Vahrenkamp 2015). The Stalinist truck policy of the East German Communist Party disrupted the social environment for the distribution of rationalisation gains which could be made using route planning software. The planners were mostly mathematicians, and they were tasked with optimising delivery routes to retail shops in the cities. They were surprised time and again by the lack of interest of the retail trade and delivery companies in their approaches (Vahrenkamp 2016). The East German Transport Ministry decided to take action against the hesitant attitude of delivery companies by starting a widespread educational campaign. Training programmes on optimising transportation were offered for delivery companies as early as March 1963 in Weimar and June 1964 in Zabeltitz.[21] Mathematical transportation optimisation clashed with the politicised and centralised truck policy of the East German Communist Party.

21 Der Verkehrspraktiker: Mangelndes Interesse, volume 8, 1964, issue 3, p. 7. Versuchs- und Entwicklungsstelle für Kraftverkehr (ed.): Methodik für die Optimierung der Transporte mit Kraftfahrzeugen, Dresden 1964, foreword.

When it came to route planning, GDR was approximately 20 years ahead of FRG. Companies in FRG first underwent a process of concentration during the years of the *Wirtschaftswunder* and grew to sizes for which the use of route planning software appeared profitable. It was also only in the 1980s that the computers available in West German companies were large enough (around 300 kB) for route planning software such as the TRAFFIC software package from Siemens. This software was used in particular in financially sound companies in the beverage and dairy processing industries. Problems with abstractification also occurred in route planning in FRG, as had been the case in GDR. Shops wanted to have the same drivers every time since drivers had access to the shops' premises. This access was sensitive and needed trust. This wish for the same driver, however, was not considered in route planning software. It was also difficult to design delivery routes to include shops with different delivery cycles.[22] Software developers significantly expanded the route planning software packages and turned them into truck fleet management systems that included route accounting, vehicle costs, and personnel planning. The software developers demanded high licencing fees, and their product promised only minor cost savings that were difficult to quantify. This prevented the widespread use of such software until the 1990s.[23]

At the beginning of 1969, the later Party leader Erich Honecker had still positively emphasised the goals of operations research in a greeting address from the Politburo to the Central Committee of the Party.[24] Then he went into opposition to Walter Ulbricht and cancelled the reforms. After Walter Ulbricht's economic reform failed at the end of the 1960s, operations research retreated to quiet academic spaces. In 1971, Werner Dück and Manfred Blieferich published a standard work on operations research in a three-volume edition that can be considered a remake of Henn and Künzi's book. Volume 1 contains, as in Henn and Künzi's book, only the mathematical foundations of analysis and linear algebra. Volume 2 covers game theory. When the reform era of GDR came to an end, the boom in transportation optimisation also subsided. Dück and Blieferich wrote of the supposed relevance of the Transport Model. However, they were only able to justify it tautologically in their work: "In economics, great importance is attached to Transport Model... because of its national economic importance."[25] The authors used the word "economics" to refer to the national economy. They were also unable to point to any

22 For more information on the use of route planning in the beverage and dairy processing industries, see Lück, Wolfgang: Logistik und Materialwirtschaft, Berlin 1984, pp. 437–473. For details on the problem of using the same driver, see ibid., p. 458 and Vahrenkamp 2016, p. 16.

23 Vahrenkamp, Richard: Markstudie Tourenplanungssoftware, in: Deutsche Verkehrszeitung of 17 October 2006.

24 Fischer 1969, p. 6, foreword by professor Hellmut Koziolek.

25 Dück et al., Operationsforschung, Berlin 1971, vol. 2, p. 186.

plausible applications of the Transport Model. In GDR, too, operations research moved towards mathematics, following a path mapped out by Henn and Künzi.

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