Logist. Res. (2009) 1:53–65
DOI 10.1007/s12159-008-0009-y

REVIEW PAPER

Logistics research: a 50 years' march of ideas

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Received: 22 November 2008 / Accepted: 28 November 2008 / Published online: 14 January 2009

Abstract Logistics—as a field of the Applied Sciences addressing issues from the worlds of business and the economy—is now more than 50 years old. This essay makes an effort to review, reflect, and interpret what researchers have done and thought in this field so far, what kind of impact their ideas apparently made, and where the "march of ideas" about logistics research might lead in the future. The first part of the review presents data that recently have become available about the quantitative impact of logistics in an international comparison between countries. From this review some hypotheses are derived about the growth opportunities for the field in the future and the challenge of maintaining the dynamics of the development of logistics in maturing, post-industrial economies. In the second part the qualitative evolution of scientific logistical thinking—the "march of ideas" of the last 50 years—is reviewed, mapped and, again, interpreted with respect to the question, where the "next" challenges, new ideas, and directions may be found to further advance the "Science of Logistics".

Keywords Logistics research · Epistemology · Quantitative measurements · Instrumentation · Industrialization · Flow dynamics · Cross-organizational integration

This essay is about the progress of the "Science of Logistics". It is trying to contribute to the understanding of the process of the formation and advances of the field by pausing for a moment after about 50 years of rather diverse and dynamic developments. An effort is made to describe, reflect and interpret what researchers have done and thought in the names of "Logistics" and of "Supply Chain Management" (SCM), and what kind of impact their ideas possibly made in their efforts to shape and move the field ahead. It is a review of the past "50 years' march of logistical ideas". With some hindsight and growing distance from the points of departure, it is assumed, the important milestones and turns in the development of the field may be seen more clearly than "on the march". Past progress can be assessed with more certainty, and a better vision of what course the field might take in the future may result.

Developments will be traced in two different ways:

First, a highly aggregated look at the state of logistics and its impact upon the "real world" is taken by reviewing some quantitative data that have become available recently. From this, some inferences on the pace and direction of the diffusion of logistical activity in given countries and industries are drawn, i.e.—to stay in the picture—on the motivating forces and the pace of the "march" of logistics.

Following this look at quantifiable aspects of the development of logistics, the qualitative evolution of scientific logistical thinking during a 50-year time span is considered in more detail: what kinds of major issues have been addressed between the 1960s and today? What kinds of ideas which are promising answers and solutions to those issues have been suggested by the different members and groups of the scientific community of logisticians? And, to the extent this can be identified, which are the scientific roots that inspired those ideas?

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Eventually, some concluding thoughts on what this analysis suggests for the future development of the Science of Logistics and its future impact are submitted.

1 The march of logistics: some comparative observations on the quantitative growth and the diffusion of logistical activities at national and industry levels

The task of "measuring" the volume of logistical activities at the aggregated level of countries and industries in order to assess their impact relative to all economic activity is a difficult one. It has hardly been addressed in the past. Reliable answers to the question about the logistics sectors' impact and—still more challenging—to the question of a potential relationship between the volumes and impact of logistical activities in the "real world" on one side, the evolution of "Logistics Science" as a body of ideas and knowledge on the other side, have not been available so far.

1.1 What comparative data suggests: a correlation between the growth of logistics and the "Wealth of Nations"

In a recent—although quite preliminary—effort several studies that provide answers at least to the "measurement" question were reviewed and reconciled as best as possible [39].[1] The data focus on the volumes of "material" logistics activities of moving, storing, handling physical goods, that are quantifiable in tons, miles, numbers of jobs, and reflected in monetary expenses for those activities at national and industry levels.[2]

The study related the

- level of economic development in the countries included (respectively the "wealth" of those countries), as measured by the Gross Domestic Product (GDP) per capita in Euros, to the
- size and development of each country's material logistics sector, as measured by per capita logistics spending in Euros.

The result of this analysis is shown graphically in Fig. 1.[3]

The positive correlation between relative logistics expenditure and relative national wealth that shows for the left-hand-side section of the graph of Fig. 1 (marked "Diffusion and Growth") may be interpreted quite simply: It could be just another confirmation of Adam Smith's historical finding on the primary cause for the "Wealth of Nations". The more Division of Labour is practised in an economy, the better off the respective people will be! Spelling this interpretation out in more detail:

The Division of Labour in the context of today's global economy means that processes of value creation are increasingly shared between countries. Economic activity is dispersed between ever more specialized "tiers" and centres of activity, leveraging favourable "economies" wherever they are found on the globe. The number of nodes and links in modern "Supply" and "Value" Chains increases. More transfer activities between the tiers, nodes and actors involved are required!

Global Division of Labour has effects along several dimensions:

- a "geographical" dimension of placing, respectively dislocating activities across the globe. More and longer transportation links are needed, increasing the absolute volume of transport activity and demanding higher levels of transport speed, frequency, reliability, etc.;
- the "time" dimension because of the fact that activities which are dispersed between many centres of activity in complex value chain structures are performed on different schedules, and at different speeds, which means that there is more need for differentiated "pacing", i.e. for more buffering, storage, inventories, and adjustments of goods flow velocities;
- a dimension of alternative "arrangements of objects", because there is more need to sort, arrange and rearrange goods and information as they move between the tiers of the value chain in order to adapt to differing capacities, lot size requirements, assortments of materials at each centre of activity—i.e. there is more need for parsing, picking, packing, consolidation and deconsolidation activities.

This is nothing but a complicated way of saying that the increasing integration of an economy into global economic cooperation and the global Division of Labour requires

[1] This analysis was based primarily on data assembled or estimated about "national logistics expenditures" by Bowersox and Calantone [8] and Bowersox et al. [9], Armstrong et al. [2], Wilson [38, 83].

[2] In the German language "material" logistics is of often referred to as "TUL" logistics (=Transport, Umschlag, Lagerung). Sheffi and Klaus [67] referred to this as "PPP"-logistics, i.e. logistics as the sum of physical "Placing" activities—transporting, moving objects from one point in a geography to another—of "Pacing"—taking care of the time-related activities of storing, buffering, warehousing, inventory keeping—and "Parsing"—arranging and rearranging objects by parcelling, deconsolidating, picking/packing, sorting, consolidating. This notion of material logistics traces back to Marshall's [50] and Weld's [78] discussion of the creation of economic "utilities".

[3] This chart was originally published in Klaus [39; p. 346]. Countries are identified by their international vehicle license plate symbols Trend-lines have been added for the argument following.

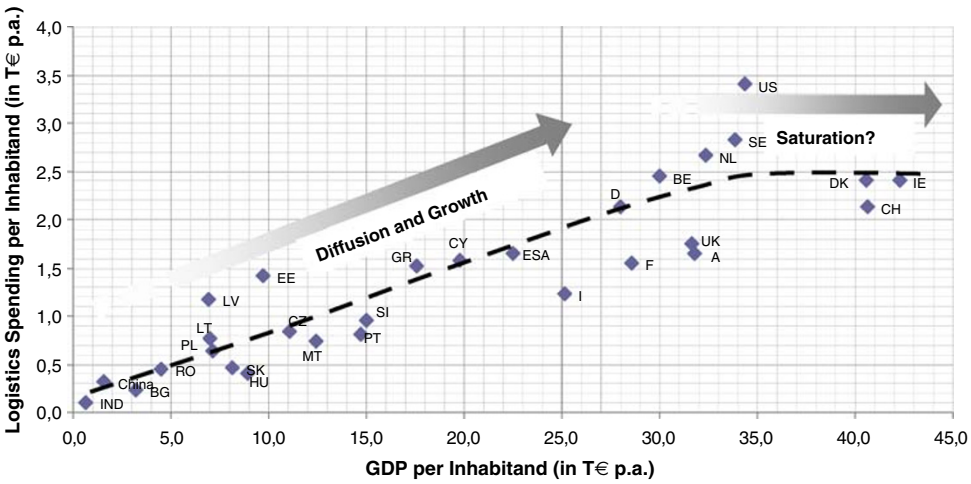

Fig. 1 A relationship between levels of economic development of national economies and the volume and value of material logistics activities

ever more logistics as a condition for increasing the wealth of the participating nations. The "rich" countries in the upper right sector of Fig. 1, such as the US, the Netherlands (NL), Denmark (DK), Ireland (IRL), Switzerland (CH), have economies that are most advanced with respect to their global integration. They also have relatively high logistics expenditures.[4] The "poorer" countries at the lower left sector in Fig. 1, such as India and China, Bulgaria (BG), operate at lower levels of national and global Division of Labour and have relatively lower levels of logistical activity.[5]

This fundamental relationship may also hold at the level of industries within a country: industries with traditionally lower levels of Division of Labour, such as the agricultural and crafts sectors, provide relatively lower contributions to national wealth and require relatively less developed and lower cost logistics activities. Industries with highly developed, widely spread Division of Labour, such as most Hi-Tech and modern mass-production assembly industries, contribute more to national wealth and demand more sophisticated and more expensive logistics.[6]

So far, the argument just corroborates what Fig. 1 suggests—that there may be a positive correlation between relative national logistics expenditures and material "wealth" levels of countries and industries.

1.2 On the pace of growth and diffusion logistics: two hypotheses

For the intention to learn about the pace of the "march of ideas" in logistics, a few more inferences may be drawn from the observations in Fig. 1:

In those lesser developed countries and industries where there is potential for more Division of Labour there will be growing demand for added capacity and sophistication of logistical activities. Any progress in the development of the "Science of Logistics" which helps to expand the capacities for "placing", "pacing", and "parsing" materials and goods, may directly contribute to wealth creation.

From this observation a first hypothesis is derived: the most dynamic future for material logistics and related scientific efforts will be in countries that are not yet fully integrated into the networks of international Division of Labour, and in sectors of economies like the agricultural, craft, and other industries that have not yet fully exploited the respective opportunities! These "markets" for the Science of Logistics have not been explored and served very well in the past. They should be addressed more in the future.

The second hypothesis drawn from Fig. 2 suggests: where a level of "saturation" with respect to Division of Labour in an economy—or an industry—will be reached, the growth and impact of material logistics will reach limits. In mature economies "global" integration is approaching maximum levels. If, in addition, the consumer population and the industrial workforce is stagnating or even declining in mature countries, as is the case in most

[4] Some of the variance around the trend line in Fig. 1 may be explained by the very different geographical structures of these countries. Geographically spread out countries like the US and Sweden with significant amounts of natural resources to be moved require above average transportation expense. Geographically compact, very densely populated and resource-poor countries such as Switzerland and Denmark are below average.

[5] An additional factor explaining the relatively low spending on logistics in "poorer" countries, of course, which is not accounted for in Fig. 1, is a relatively lower wage cost level—but the general trend shown will not be affected.

[6] This relationship will be more complicated in reality, because it is also contingent on the typical value density factors in an industry. For the purpose of this discussion these additional contingencies are neglected.

parts of Western Europe and Japan, physical consumption, the material needs for production supplies, and consequently the needs for industrial distribution activities will not grow further.

This argument potentially explains why in the demographically and economically mature countries, which are placed in the upper right corner of Fig. 1, the "march of material logistics" may come to a halt.

If logistical ideas and the "Science of Logistics" want to maintain their momentum and impact in the context of matured economies and industries, new fields of application will have to be found, which shall be discussed later in this essay.

2 March of ideas: a brief history of logistics as a step-by-step accumulation of ideas, research questions and suggested answers

So far in this essay, "logistics" has been referred to as the sum of the material, quantifiable activities of "placing", "pacing", and "parsing" goods and things.[7] In this second part of the discussion, the review of logistics is continued as a description and interpretation of a "march of ideas"—an attempt at the historical epistemology of logistics.

The level of detail of the following discussion is intended at a middle range: it should say more about the substance of ideas than the frequently suggested categorizations of logistics into three or four development phases provide.[8] But is should also avoid the little structured jungle of technical concepts and terms that were discussed in the field of logistics over time, such as "Materials Requirements Planning (MRP)", "Just-in-Time (JIT)", "Vendor Management Inventory (VMI)", "Collaborative Planning, Forecasting and Replenishment (CPFR)", etc.

The primary criteria for clustering the ideas, research questions and answers into distinct phases in a way that serves the purpose of this essay will be their historical context and their association with certain scientific communities.[9] Logistics Science is a cross-disciplinary field, stimulated and informed by a wide range of other, older sciences, ranging from Economics, Mathematics, to the younger fields of Business Administration, the Organization Sciences, and Engineering. Each of these fields has its own perspective and prefers its own set of methods. The logisticians of the first generations—if they did not operate in purely pragmatic, a-methodical ways—brought with them the perspectives and methods from the fields and institutions where they came from, since there were no indigenous logistics courses and institutions. And even among the younger generation academics in logistics, who received their education in Logistics and SCM programs and departments, the style and direction of their work is still influenced by their roots in either "Marketing Science", "Economic Modelling", "Operations Research", "Scientific Management Studies", "Engineering", the "New Institutional Economics", "Management and Organization Theory", or other affiliations. Logistics, significantly more than other fields, is embedded in a diverse network of intellectual relationships—which also explains the difficulty for logisticians to establish their own, distinct scientific identity.

On the basis of these considerations about the appropriate level of detail and a historical and disciplinary logic of clustering materials, six sets of ideas, their approximate time of entry into the "marching band" of the evolving Science of Logistics, and their likely roots in "classical" academic contributions from other sciences are suggested. In the following discussion and Fig. 2 through 7 each entry is labelled by a descriptive term—"Awareness", "Industrialization", "Engineering Instrumentation", "Flow Dynamics", "Cross-Organizational Integration". Reference is made to those "classical" contributions in the literature which laid the foundations of the respective ideas, and to those "milestone" contributions that marked a major change and expansion in thinking about logistics.

2.1 Creation of "Awareness" for logistics research needs and the institutionalization of the field

The early phase of creating awareness for the need and promise of doing systematic research in the field of logistics—in both in the business community and in the academic field of management studies—has been described in numerous textbooks and articles, such as Stock and Lambert's [73] and Ballou's [6]. The start of the "logistics march of ideas" is located and dated rather uniformly to the US in the early 1960s.

The historical motivation for this happening at that time was the "Marketing Revolution"[10] that had started from the United States after World War II. No longer was the capacity to efficiently produce scarce goods a decisive factor for business success. Rather, the ability to attract and service customers who have many alternative choices to satisfy their needs became the key. And being identified as

[7] See footnote 2 above!

[8] Such as the "functional", "physical distribution", "supply chain/cross-functional" and a "global supply network" phase. Recent examples are in Baumgarten [5] and Ballou [6].

[9] The choice of these criteria is inspired by Rheinberger's [63] argument that the study of the development of scientific knowledge should reflect to historical context and the means and methodologies through which the process of knowledge generation takes place. The analysis is deliberately qualitative and interpretive rather than based on formal methodology (as, e.g. in Charvet's [13] recent article).

[10] Described by Keith [35] in an article of the same title!

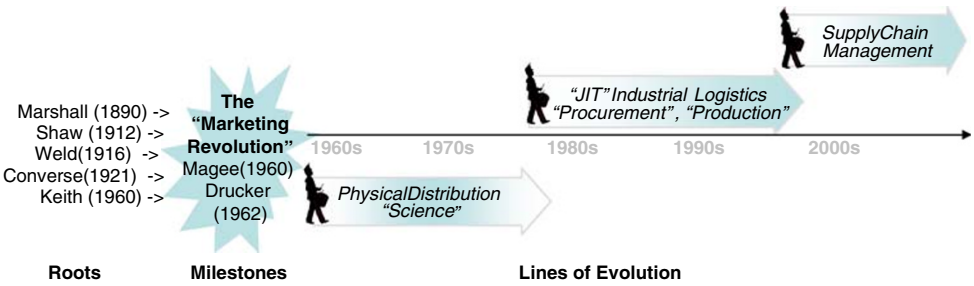

Fig. 2 The creation of "awareness" for logistics: the foundation of physical distribution "science", and the emergence of "industrial logistics" and "supply chain management" as new pillars of the fields identity

one crucial element of Marketing, the activities of transporting and warehousing—"Physical Distribution" to customers—which formerly were rather peripheral concerns to management and academic research, became the nucleus for the emerging field of logistics.

Milestones in the creation of awareness and the beginning of the institutionalization of what became "Marketing Logistics" and "Business Logistics" were Magee's [48] *Harvard Business Review* article on "The Logistics of Distribution" and Drucker's [20] *Fortune* article on "The Economy's Dark Continent". Smykay et al. [71] published the first textbook on "Physical Distribution Management"—marking the entry of the field into the academic world. There had been earlier efforts to create awareness for the importance of Marketing and Distribution by authors such as Shaw [66], Weld [78], and Converse [17]. But it seems to have been Drucker's article and popularity in the broad management community which, for the first time, drew really wide ranging attention to the need for systematic scientific work in exploring "the logistics of distribution". Rather soon other authors followed. "Physical Distribution" and "Logistics" were institutionalized in more academic institutions and professional associations such as the National Council for Physical Distribution Management (later to become the Council of Logistics Management and recently the Council of Supply Chain Management Professionals). With several years delay, from about 1970, parallel developments of logistics research, publications, and institutionalization also evolved in Europe[11] and in other parts of the world.

By the 1980s the power of Marketing and Distribution issues for drawing attention to the emerging field seems to have been exhausted. The new idea of "just-in-time" and "lean" industrial procurement and production became a new centre of interest and a new pillar of the field of logistics' sense of identity—to be discussed below in the section about the Toyota Production System (TPS) and "Flow Dynamics".

Starting in the 1990s another major shift took place in the perception where the heart of the field is—"SCM". Now the issues of cross-functional and inter-organizational integration became the major attention-getters for outsiders and insiders, causing a sequence of "waves" of interest that peaked in the mid-1990s around the concept of Efficient Consumer Response (ECR), around the turn of the millennium around "E-logistics". Today "Supply Chain Risk" and the "Greening" of Logistics seem to have become the ideas that are drawing most popular and academic interest.

2.2 Initial "Instrumentation" of logistics research through operations research and modelling methods

The first "Awareness" wave of logistics research related to Marketing and Physical Distribution was primarily descriptive and exhortative in the sense that the structures of well-managed distribution systems were described. Appeals for a systematic, "holistic" treatment of the issues of transportation and warehousing were made.[12]

But soon the need for deeper, more structured and more truly "scientific" analyses was recognized. Some prior work from the military environment,[13] the simultaneous rise in progress and popularity of the field of Operations Research (OR), and new possibilities of running large scale models and mathematical calculations on computers in the 1960s and 1970s lead to a rapid expansion of OR-related work in logistics.

Much of this work addresses geographical aspects of logistical systems design and optimization, building on foundations as far back as the nineteenth century, such as the famous model of the "Isolated State" by the economist von Thünen [75], Launhardt's [41] and Weber's [77] classics on industrial location decisions. A long line of more recent OR work about vehicle routing and scheduling started with Clarke and Wright [15] and was continued in more comprehensive approaches to the analysis of transportation systems and how they should be optimized [49].

[11] The first monograph of this kind in Germany, possibly in all of Europe, was Pfohl's [56] dissertation.

[12] A frequently quoted early source is Lewis [45], which demonstrated the savings potentials which can be realized by taking a "total cost" perspective.

[13] Early examples are Morgenstern's [51] "Note on the Formulation of the Theory of Logistics" and publications by the RAND Corporation (e.g. [25]).

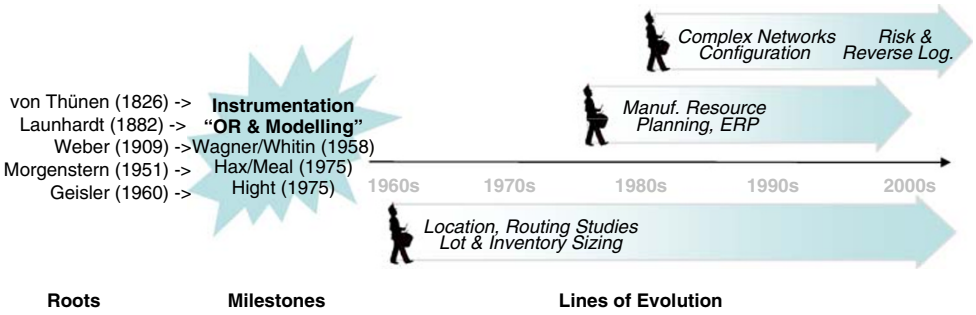

Fig. 3 The "instrumentation" of logistics: integrating modelling techniques and operations research

Another line of OR and work is concerned with object-quantity dimensions of logistical operations, determining optimal order sizes, lot sizes, inventory levels and related scheduling arrangements in production and distribution. Pioneering contributions in this area were Magee [47], Wagner et al. [79], Hax and Meal [29], and Wight's [81] work about MRP.

More recently much work is about the development of integrated solutions, seeking the joint optimization of geographical, time, quantity and monetary aspects of planning through concepts like Manufacturing Resource Planning (MRP II) and Enterprise Resource Planning (ERP) systems development.[14] Recently the integration of the additional issues of "Reverse Logistics" and "Risk" considerations is adding still another level of complexity to the modelling and optimization challenges in logistics. An innovative approach that is tried by some of the "instrumentation" researchers is in the use of models from nature for the solution of very complex decision problems [19] (Fig. 3).

The "instrumentation" of logistics trough mathematical methods, through ever more advanced statistical and modelling techniques and increasingly powerful support from Informatics, is still dynamically moving forward. It may be the most rigorous and best documented stream of logistical research through the prestigious journals of the OR-associated researchers, such as *Operations Research*, *Management Science*, *Mathematics of Operations Research*. The "quantitative logistics" community is a tightly knit subgroup among logisticians.

2.3 The "Industrialization" of logistics services

From the 1970s and 1980s onward, when the consolidation and institutionalization of logistics in functional departments and the professionalization and concentration of "Third Party" transport and Logistics Service Provider organizations rapidly advanced, the challenges and potentials of their perpetual rationalization became a new concern. The concepts of the "Industrialization" of logistics services were gradually being discovered and adopted among leading logistics organizations, marking another milestone and a new stage along the "march of logistics ideas". Stimulation for this powerful development primarily came from "best business practices" of successful service and retail companies. The person who first drew attention to the idea and potentials of the "Industrialization of Services" was Levitt [43, 44] (Fig. 4).

The academic predecessors who paved the way for the idea in the Scientific Management literature were Babbage [3], Taylor [74], Ford [22], Shewhart [68] and Deming [18]. Their themes were the realization of Economies of Scale through product standardization and production-lines, statistical quality controls, brand-name mass-marketing of services, and the rationalization of service process structures. With regard to the latter, a remarkable early contribution in Europe to the study of industrial organization and process structures by Nordsieck [52] was rediscovered.

Pioneers in the "Industrialization of Logistics Services" were some extraordinarily successful transport and retail companies such as UPS, FEDEX, and WALMART. The line of research which followed their example is documented primarily in case study descriptions and business strategy discussions.[15] The ideas and practices of "Industrialization" were extended by such contributions as Camp [12] on "Benchmarking" and Hammer [28] on "*Process Reengineering*", which for a period of time stimulated a lot of research and publications. Industrialization concepts are making use of the full range of OR instruments that were discussed in the preceding "Quantitative Methods Instrumentation" section, and also of the "Flow Dynamics" and "Cross-institutional Integration" concepts and research discussed below.

[14] e.g. Wallace [76]. This concern also was the basis of the impressive growth of ERP software providers such as SAP.

[15] Examples are in Sasser [64]. A discussion about the most recent logistics segment taking up the "industrialization" path—after the parcel—and international express services, LTL services, worldwide container-line services seems to become the truckload-industry as discussed in Klaus and Müller [37].

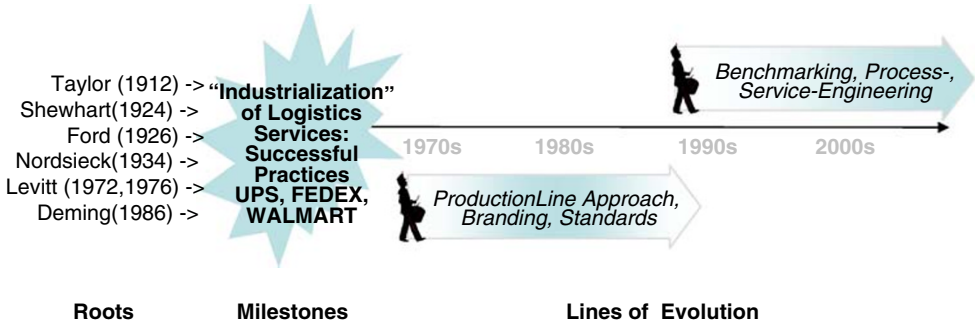

Fig. 4 Bringing the ideas and concepts of "industrialization" to logistics

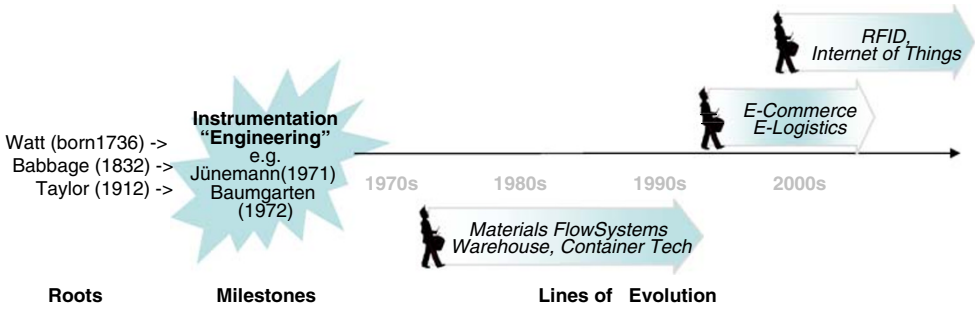

Fig. 5 March of the engineers: the "instrumentation" of logistics through logistics hard- and software

2.4 The instrumentation of logistics through "hard" engineering technologies

Another path and stage in the "march of logistics ideas"—in parallel with "Industrialization"—developed in response to the rapid growth, professionalization and concentration of the logistics functions within large industrial, retail, and logistics service provider organization. The "Engineering Instrumentation" of the field started through engineers who specialized on research and development of "hard" equipment and systems for logistics operations. Initially this happened quite separate from mainstream "Business Logistics". The work of the early logistics engineers addressed the demands for better productivity and upwards scalability of logistical operations through the development of mechanized and automated transport, warehousing, packaging, and other equipment (Fig. 5).

This early development is traceable rather clearly in Central Europe: one of the pioneers is Reinhardt Jünemann, a mechanical engineer by education, who did dissertation research in the engineering of warehouse operations in the early 1970s [33]. Later his work expanded to industrial materials flow equipment, picking–packing, and container hardware systems, and the integration of the technologies of OR, computer-assisted planning, controlling, etc. [34]. In the 1980s Jünemann founded the first dedicated research institute to Logistics Engineering, the Fraunhofer "Institute for Materials Flow Systems and Logistics (IML)" at Dortmund. Parallel initiatives, including also the first creation of a dedicated academic program that jointly teaches know-how of Engineering and Management ("Wirtschaftsingenieur"), were taken by Helmut Baumgarten at the Technical University of Berlin. Baumgarten [4] did early work about standardized container systems. He became one of the founders of "Bundesvereinigung Logistik (BVL)" in 1978, which from its beginning followed a mission of integrating the disciplines of Business Administration and Engineering in the field of logistics.

Today research and development in the area of "hard" Logistics Engineering technologies is a firmly established and indispensable line of work which is getting increasingly integrated with other lines of logistics research and development. Beyond the established, continuously ongoing R&D work done in the areas of "hard" transport equipment, container and warehouse design and operations issues, attention in recent years has been given to related in-plant engineering systems developments, sometimes referred to as the "Intralogistics" segment.[16] With the emergence of the Internet "E-Logistics"—attempting to utilize the technological possibilities of the Internet to better meet the needs of ever more diversified and volatile logistics demand—received a lot of attention for several years. Today, most interest is in the development and application of RFID-technology for applications in logistics. A vision of an "Internet of Things" [11] is now trying to integrate the possibilities of the technologies of the Internet, of RFID-based "intelligent objects" and of

[16] Compare the definition of Intralogistics by CeMAT, the world's e world's leading fair for Intralogistics based at Hannover.

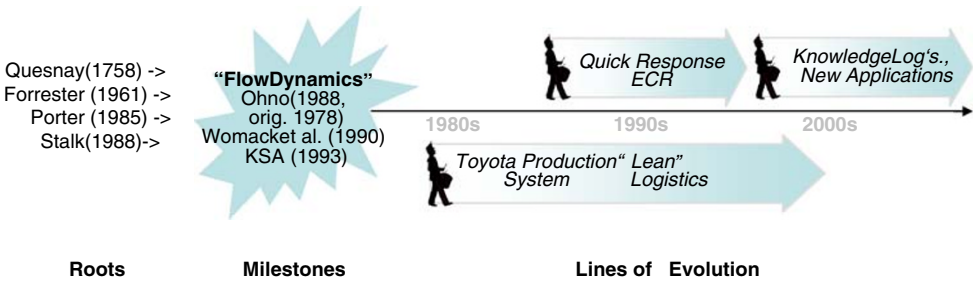

Fig. 6 The discovery of Toyota Production System and "flow dynamics"

decentralized, semi-autonomous control systems (to be discussed in the next section).

2.5 Toyota system and the mastery of "Flow Dynamics"

Not before the early 1980s, revolutionary new insights into the configuration and operation of logistical systems were first noticed in the West which Japanese managers had quietly implemented in Japanese industry after World War II: The "Toyota Production System (TPS)". Taiichi Ohno had originally published his book about TPS in Japanese in 1978 [53]. But it took years until the power of the ideas which it offered were discovered and fully appreciated in the US and Europe.

At the heart of Ohno's ideas was the conceptualization of industrial production as a flow system. Machines and workers are arranged in the sequence of the manufacturing process—the idea that Henry Ford had realized first in 1913 with the installation of his line for the assembly of a standardized mass-product.

Ohno's path-breaking contribution which moved the concept "beyond large-scale production"[17] was based on several additional ideas. The most important one is control of the "flow dynamics" strictly by customer demand rather than by a preset, rigid clock rate. Synchronization of the flow across multi-stage sequences of activities, which may be interlinked in complex and flexible ways, is achieved by passing on demand signals from the end of the chain in "backwards", upstream direction from stage to stage, and by making sure that demands signalled are met "just-in-time". TPS allowed for quantum leaps in productivity, inventory reduction, and the ability to handle a significant degree of product variety at the same time. The rigidity and complexity of centralized "synoptic" planning systems was substituted by sequences of simple loops of demand signals and just-in-time supply responses which could be nested and changed in many ways.

After its discovery in the West, the powerful idea of organizing industrial production logistics as demand-driven flow systems was continually being refined and adopted to other industries. Among the voices who contributed most to the diffusion of the concepts of "flow" thinking and Toyota Production System were Schonberger [65], Goldratt [26], Wildemann [82],[18] Shingo [69], and Womack et al. [84][19] (Fig. 6).

Adaptations of some of the basic ideas of flow dynamics followed in the fashion industries through the "Quick Response" and then through the worldwide ECR initiatives in the broader consumer goods and retail industries [40]. A new focus in general management discussions on "Value Chain Management" [58], "Time-Based Management" [72], also Hammer's [28] already mentioned discussions of "Process Reengineering" at that time may both have been facilitated by the discoveries and successes of Japanese-style flow management, and may have served as a source of still more awareness for phenomena of flow dynamics (e.g. [21]). Creative applications of flow thinking and the concept of demand-driven control of flow dynamics are now found in fields far away from "material" logistics, such as Knowledge Management ("Knowledge Logistics" by Lullies et al. [46] and the "Logistics of Events" [7]).

The mastery of flow dynamics has become a key concern of logisticians. With this and an ongoing increase in the complexity of global supply chains—to be discussed in the next section of this article—additional research questions came up, such as the discussions about the "bullwhip" effect [42], i.e. the difficulties of the governance and control of flow dynamics.

With hindsight, several predecessors and early foundations to "flow" thinking, flow system design and flow dynamics issues are found. The earliest example is the French economist and physiocrat Francois Quesnay's [61, 62] description of the economy as a circular flow system that can be modelled after the human blood circulation system. In the 1950s, the father of "Systems Dynamics", Jay Forrester, and his MIT research group, had already begun to study and describe the phenomena of flow

[17] i.e. the subtitle of his 1988/1978 book!

[18] Goldratt [26] novel "The Goal"which claims to have sold more than a million copies may be considered the best-selling book on logistics of all time.

[19] Wildemann was the first to popularize the concept in German industry, helping to start the "just-in-time revolution" in European industry too.

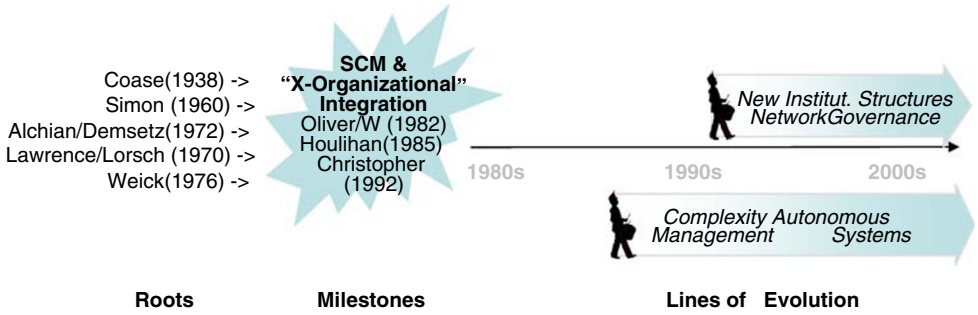

Fig. 7 "Cross-organizational integration"—the logistics of supply chains

dynamics in industrial contexts [23]. Apart from this line of research, there has been parallel, more technical work in Europe about flows in transport systems (e.g. [59]) and materials flows (as discussed above in "Engineering Instrumentation").

2.6 "Cross-Organizational Integration": the logistics of supply chains

The first academic arguments for the idea of extending the horizon of logistics research from an enterprise and "intra-" logistics focus to the relationships in inter-organizational chains and distributed networks of suppliers, customers and other stakeholders took place in the 1980s [31, 36]. But it took 10 years more until—rather suddenly—SCM fully caught the fascination of logisticians, and became a major topic for practitioners and research. In some countries "SCM" even began to replace "Logistics" as the denominator of the field and stimulated a discussion about which term should be considered the broader, overarching one, which one should be considered a sub-aspect.[20]

The SCM discussion motivated the community of logisticians to address new issues of the full complexities of the design, planning, operation, and control of value chains and networks that extend beyond individual enterprises and their immediate supplier- and customer relationships. The concern with "cross-organizational" issues has significantly opened and enriched the research agenda in the field of logistics to a new range of questions and new ideas,[21] as indicated in Fig. 7.

New conceptualizations of the issues of the design and management of complex Supply Chain structures and new answers to the issues raised are primarily drawn from the fields of Systems Theory, Organization Theory and the "New Institutional Economics".

First, there is the recognition that the critical levers for successful SCM are not in the efficient planning, mobilization, and control of goods, materials, and information flow networks alone. There are intricate issues of interpersonal relationships, contractual arrangements, of the coordination and governance of the actors and activities involved in the network of supply chain relationships. Otto [54] summarized recent research on the multiple levels of networks and network relationships that SCM management must consider. His model identifies four layers of those relationships: the familiar "materials flow" and "information flow networks", the "social relationship" networks, and the network of "institutional", i.e. contractual, formal-organizational arrangements. Recent discussion suggests that a fifth "money" or "value flow" network layer should also be considered (e.g. [57]).

Among the research challenges that are posed by an advanced, multi-dimensional notion of SCM are the issues of

- how to chose and allocate the most efficient coordination mechanisms in complex supply chain relationship-networks, such as "Markets" and "Hierarchies" [16], or "Clans" [55],
- finding the right degrees of complexity that can be handled within "tightly coupled", hierarchically controlled organizational units (e.g. Hagel [27]),
- the identification of best combinations of "loose" and "tight" coupling mechanisms between network actors and units when high degrees of uncertainty and environmental turbulence need to be accommodated [70, 80],

[20] The influential American "Council of Logistics Management (CLM)" renamed themselves in 2005 to "Council of Supply Chain Management (CSCMP)", implying that "logistics" covers a subset of SCM-issues only. A recent discussion of this perspective is in Frankel et al. [24]. In this paper, as will become clear, "Logistics" and "Flow Management" are considered to be the broader, more generic concepts, and SCM is one—if very important—field of application of logistical concepts and ideas.

[21] It may be critically noted in this context, that some authors and practitioners are applying the new "SCM" terminology when they deal with nothing but the long familiar narrower logistical issues of procurement in dyadic supplier–manufacturer relationships or of manufacturer–customer relationships, leaving open the question whether there is truly new content of ideas in their uses of the SCM terminology.

last not least

- applying the right incentives and controls in "team work" [1], and "principal–agent" [32] relationship networks where information is unevenly distributed between the participants and hierarchical control not available.

Resolutions to those issues of complexity management and of the governance of networks of loosely coupled actors are of highest practical relevance in SCM. While—implicitly—most SCM authors assume that "more is better" with respect to the degrees of integration and control of the actors in a supply chain, difficult questions are raised about this assumption: for which situations and segments of complex supply chain networks is this assumption true, for which does it not hold [10]? In the design of a supply chain the right "granularity" must be found: how far should the "Division of Labour" and the narrowing of "Core Competencies" [60] be carried? How much flexibility and "agility" is right, and what does it cost [14]? How does a "principal" compensate his "agents"—the suppliers and outsourcing partners—in order to motivate them to do their best, yet not overpay them—and how should the gains and benefits of successful SCM be distributed among the actors and activities?

The concern with cross-organizational integration in logistical chains and networks has brought a tremendous enrichment of the issues that now are systematically being addressed, and of the ideas which are considered for their solution.

3 The "March of Ideas" in logistics research: current frontiers and the question of where to go next?

In the first part of this discussion on the growth and diffusion of "material" logistics, some observations and hypotheses were presented, which relate to the path and pace of the diffusion of logistical activities at the aggregative level of countries and industries. A preliminary analysis of available data suggested that there is a surprisingly clear correlation between relative national logistics expenditures—i.e. the level of "material" logistical activities—and the "wealth" levels achieved in those countries. The study of national logistics growth data also suggested that economically mature countries may reach a state of saturation with "material" logistics, when the integration into global economic cooperation and international Division of Labour cannot be increased much further and when "material" industrial production levels cannot rise any more.

The first conclusion and hypothesis derived from these observations was, that a "Science of Logistics" doing research related to the material activities of "placing", "pacing", "parsing" goods and services in the future should focus on the specific challenges and demands of economically less mature countries and industries, which have been receiving relatively little attention in the past. The second hypothesis which followed was, that in maturing countries and industries the "march of material logistics" may end in stagnation, if new directions and ideas for innovative applications for logistics are not found that have relevance and potential impact upon the "wealth of nations"—especially of those which are rapidly moving into the post-industrial stage.

The question where those new ideas and directions may be found provided motivation for a review of the past 50 year's "march of ideas" in logistics. Figure 8 is an attempt to graphically summarize the observations on the various lines of development in logistics research—a mapping of the "march of ideas" as it has been drawn-up in the second part of this essay.

Along the centre line of idea developments, labelled the "Awareness" string, the exhibit shows the three major foci that seem to have created ever broader attention to logistics: It started out with concern for "Physical Distribution" and "Marketing Logistics". In the 1980s the primary fascination of the logistics community shifted to "JIT" systems and the issues of "Industrial Logistics". And now, since the 1990s, most interest is centering around the terms and promises of "SCM".

Based on the interpretations chosen in this essay, five additional lines of ideas and research have been adding new substance and enriched the "march of ideas" of logistics research in various ways at various points in time:

- the "OR and Modelling Instrumentation" line of logistics research contributed through the introduction and evolution of modelling and Operations Research techniques, based on mathematics and formal economics, added quantitative tools and methods, thereby enhancing the scientific rigour and respectability of the field;
- the "Industrialization" line of research and development in logistics, which is rooted in the field of Scientific Management, and driven by the examples of very successful, large logistics operators, helped the field to develop its identity as an important industry and to assert its relevance to management;
- the additional line of "Engineering Instrumentation" research and developments—i.e. the engineering of specialized hardware and software equipment, components, and systems—brought the opportunities and challenges of truly interdisciplinary cooperation to the logistics, which so far had been delimited to management, OR, and economics research;

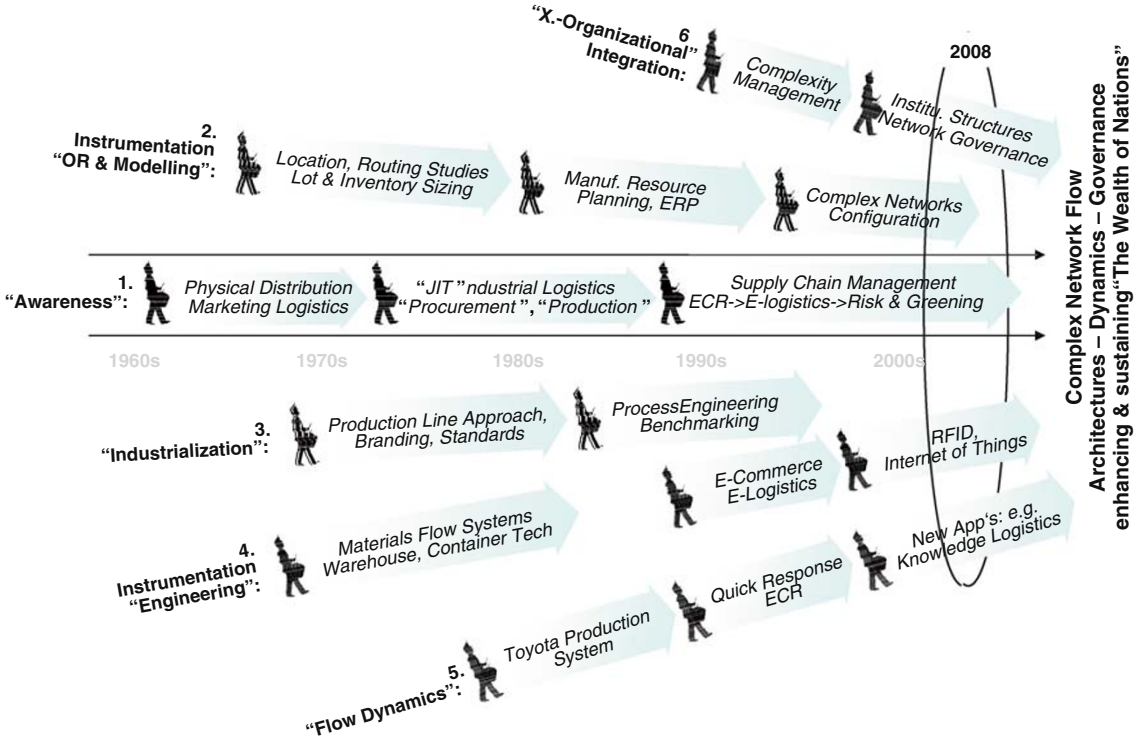

Fig. 8 The march of ideas in logistics research—current frontiers and next developments?

- the line of research about the "Dynamics of Flows" that was stimulated by the discoveries and successes of TPS, opened the research horizon of logistics to new issues of the dynamics of flows and systems;
- lastly, the research stream around the issues of "Cross-Organizational Integration", that has been stimulated by the fascination with the "Supply Chain Management" terminology, made the field move into the issues of complex systems architectures, the possibilities and limits of the governance of those systems, drawing on research foundations in Complex Systems and Organization Theory, and modern Institutional Economics.

The current state of the field is symbolized by the "2008" oval in Fig. 8: it is meant to show how the originally disjunct ideas and lines of discipline-bound research have been converging and started to interact. At the same time, the position of the oval intends to show that there is still distance to cover until the research streams of "Modelling and OR", of "Complex Systems, Organization Theory, and Institutional Economies", where academic rigour and deep specialization are primary concerns (shown in the upper part of Fig. 8), and the more pragmatic, business oriented, "relevance" seeking research streams of "Industrialization,", "Engineering", and "Flow Dynamics" will truly have reached a satisfactory level of integration. To advance their interaction should be a primary goal for the future "Science of Logistics" (or of "Supply Chain Science"[22] if this term will be preferred),[23] which might define itself as

> the science of complex network flows—concerned with the architectures, dynamics, and successful governance in ways that are helping to enhance and sustain "The Wealth of Nations".

A final suggestion that may be derived from this mapping of the "march of logistics ideas"—and a possible answer to the claim that growth and innovation opportunities in the "old" material logistics field of application might end in stagnation in a gradually maturing, materially saturated world—is that attention could be directed to "complex network flows" other than material ones: Unresolved—or only partially resolved—challenges, that may be successfully approached with the tools and insights of logistics, may be found in the non-material areas of "knowledge management"—how to better organize, mobilize, control flows and inventories of ideas and knowledge by creatively applying concepts such as JIT, VMI, of "loose coupling" and "Agency Theory" to

[22] Hopp [30] used this term for his recent book publication.

[23] To help advance the convergence and integration of these streams of research is the mission which the *Logistics Research* journal has given itself.

knowledge networks. There may be "people logistics", i.e. better organizing the flows of people through the complex networks of, e.g. health care systems, public transport systems, educational or other complex service systems, or the "logistics of complex events".[24] The onward march of logistical ideas still holds a lot of opportunity and promise!

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[24] Most of those issues have been addressed in one way or another already, but.

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