Distribution network design: a literature review and a research agenda

Riccardo Mangiaracina, Guang Song and Alessandro Perego
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy

Introduction

Distribution network design (DND) aims to shape the structure of the distribution network, determining the number of echelons and – for each echelon – the type, size, number, and location of facilities where the product is temporarily stored on its way to the end customers (Perl and Sirisoponsilp, 1993; Ballou, 1977, 1995; Ambrosino and Scutella, 2005). These choices, driven by different contextual factors (e.g. the product and the demand features), have a strong impact on supply chain performance in terms of both logistics costs and customer service level. Through an effective DND, inventory, transportation, and facility costs can be significantly reduced while increasing (or at least maintaining) the service level (Ballou, 2001). As a result, the DND can be considered to be a key driver of the overall profitability of a firm. The globalization of economic activities and rapid developments in information technologies leads to shorter product lifecycles, smaller lot sizes and very dynamic customer behavior, therefore, a robust and well-designed distribution network has become more important (Melo *et al.*, 2009).

Received 18 February 2014
Revised 6 August 2014
20 November 2014
21 January 2015
Accepted 21 January 2015

Due to the different choices to be made and the enormous variety of available network alternatives, DND is a very complex task and requires a structured approach that can be split into at least three main steps (Rushton and Saw, 1992; Mourits and Evers, 1996): generation of the configuration alternatives and preliminary assessment, quantitative assessment of the generated alternatives, and detailed design and fine tuning. The aim of the first phase is to identify the possible network configurations and select a limited number of them based on a preliminary qualitative assessment. The second and third phases shift the focus to a quantitative analysis in order to identify the best specific configuration and to fine-tune it (e.g. finding the precise location of the facilities and allocating the flow of goods to them) (Mangiaracina *et al.*, 2012).

Some papers that present reviews of articles on DND were identified. These papers focus mainly on classifying the mathematical models. For example, Vidal and Goetschalckx (1997) reviewed the mixed-integer programming models for strategic production-DND and identified the main features of those models (e.g. assumptions, objective functions, and affecting factors). Beamon (1998) provided a focused review of mathematical modeling approaches, and four types of models were identified based on the nature of the inputs and the objectives. In addition, the number of articles considered in these previous reviews was limited. As an example, Bilgen and Ozkarahan (2004) reviewed optimization models for production-DND based on 35 published articles. Meixell and Gargeya (2005) identified the decisions, objectives, level of integration from production sites to end customers, and globalization variables by reviewing 18 research articles. As a consequence, the existing literature reviews did not take into account articles based on non-quantitative methods and classified only a limited number of both decisions and determining factors. Therefore, this paper aims to provide a comprehensive review of the literature on DND with five main objectives:

(1) to classify the research on the topic according to the main methods adopted, in order to provide an overview of the research to-date for both practitioners and academics;

(2) to determine which are the fundamental decisions based on those addressed in the literature;

(3) to develop a framework in which the factors that affect DND are categorized based on the variables used in both mathematical and conceptual models;

(4) to investigate how the determining factors influence strategic decisions in DND, providing practitioners with valuable insights that can facilitate the decision-making process regarding the distribution network structure; and

(5) to identify and suggest new and interesting directions for future research.

The paper first presents the methodology used to conduct the review, clearly describing the scope of the analysis, the selection process and the review method. Second it reports the results of the review based on the main categories. Last, it presents the summary of this review and its implications, reports the gaps identified and suggests potential directions for future research.

Methodology

The methodology used to conduct this research review was designed to be systematic and objective (Cooper, 1989). According to Tranfield *et al.* (2003), a systematic review contains three stages, namely planning, conducting, and reporting. A clear definition of the research scope is the basis of the first stage. In the second stage, a systematic search has to be conducted based on appropriate keywords and search terms, and the whole selection process consists of several steps (e.g. a systematic search, the selection of studies, and study quality evaluation) in order to ensure that the papers collected meet all of the pre-defined criteria as judged by the review team. Lastly, the review should include a detailed description of the findings of the collected papers, and suggest meaningful guidelines for practice. This research, therefore, was conducted by following a three-step methodology (shown in Figure 1), which is consistent with the structured approach proposed by Tranfield *et al.* (2003). This systematic review method has been employed in literature reviews of research papers in logistics and supply chain management (e.g. Shepherd and Gunter, 2006; Storey *et al.*, 2006; Grubic and Fan, 2010; Carter and Easton, 2011; Miemczyk *et al.*, 2012). Phase 1 consisted of the selection of the method used to gather the articles. Phase 2 entailed a thorough analysis of the selected literature. Finally, gaps in the research and potential areas for further investigation were identified in Phase 3.

Phase 1: article selection

The detailed selection process used to gather the articles necessary to conduct this research was based on the following stages (Srivastava, 2007):

- Classification context: this review considered the literature related to DND: first, in the downstream supply chain (i.e. from manufacturing plants to customers, as shown in Figure 2) and second, affected by the flow from up to downstream (and not by reverse flows). Reverse logistics, in fact, often requires specific facilities, such as collection centers (where customers bring the products) and/or recovery/manufacturing facilities (where returned products are refurbished/remanufactured) (Melo *et al.*, 2009).
- Definition of the unit of analysis: the unit of analysis was defined as a single academic article on the topic of DND in the logistics system published in an international peer-reviewed journal in English. Conference proceedings, working papers, research reports, and dissertations were not included. These choices are consistent with both the literature analyses found on the topic of DND (Burgess *et al.*, 2006; Seuring and Muller, 2008) and the methodology suggested by Webster and Watson (2002).

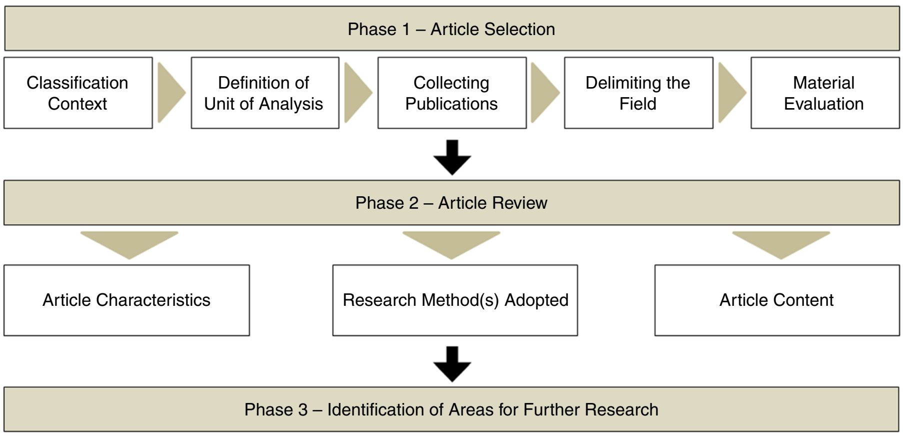

Figure 1.
Research methodology

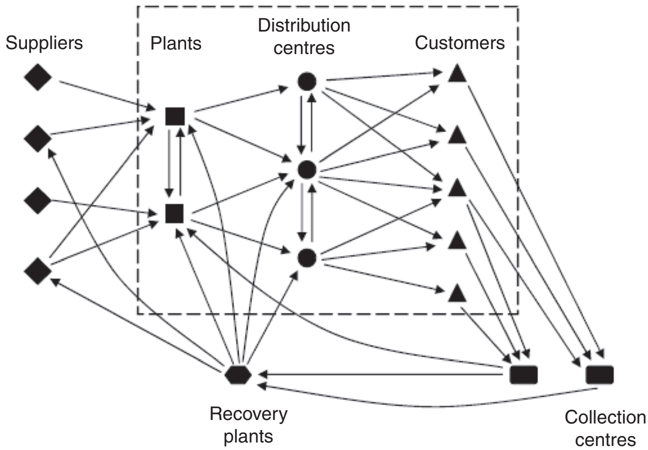

Figure 2.
Research scope

- Collecting publications: analogously to Perego *et al.* (2011), and consistently with the scope of analysis, a search by keyword using library databases (e.g. Scopus, Emerald, Science Direct, Wiley, etc.) was conducted. Taking into consideration that the terminology may have changed over time as the research on logistics and supply chain management evolved, keywords and strings – such as "DND", "logistics network", "supply chain design", and their combinations - were sought in the publication title and in the abstract with the subject area being limited to the Business, Management, and Economics field. The use of "distribution", "logistics", and "supply chain" – terms that have been used interchangeably at different periods in the literature – ensured that papers would not be overlooked due to any changes in terminology.
- Delimiting the field: based on a broad search, a vast number of papers (i.e. a total of almost 876 published manuscripts) was found, that focused on topics such as the identification of the supply chain strategy, the coordinating mechanism in the supply chain, or the supplier selection strategy, etc., which were not within the original scope of this study. Therefore, a further two-step selection process (i.e. based on the examination of both the titles and the abstracts) was carried out to screen these papers and to come up with a refined list of papers that conform to the scope of the research. First, the number of papers was restricted considerably by examining the titles and excluding those contributions that were out of scope. The result was a list of 212 papers. The selection process then proceeded with the analysis of abstracts in order to ensure that the central theme was relevant (Burgess *et al.*, 2006; Schoenherr, 2009). Abstracts were reviewed by a three-person team in order to confirm that the scope of the papers selected was consistent with the pre-defined topic, regardless of the methodology used or the type of journal. Papers whose scope was not clearly defined based on the abstract were read in their entirety and the team members discussed whether to include them in the final sample. Finally, 126 papers published since 1972 were selected for in-depth examination.
- Material evaluation: the literature was then analyzed and categorized within the classification context. During this stage, a number of key characteristics were identified as discussed below.

Phase 2: review method

In order to establish the review method, a number of methods adopted in previous papers that reviewed the literature were considered and analyzed (e.g. Carter *et al.*, 2007; Meixell and Norbis, 2008; Melo *et al.*, 2009; Natarajarathinam *et al.*, 2009; Pettit and Beresford, 2009). The contributions were classified using a three-pronged approach. First, the general characteristics of the collected papers and journals (i.e. year of publication, journal title, region/country addressed) were identified. Second, the papers were categorized based on the research method(s) adopted and the content of the article (i.e. the objectives and the main types of decisions addressed). Lastly, the factors that influence DND were taken into account.

The complete list of the papers examined, in chronological order, which presents the content and features of each paper, including basic information (i.e. authors, publication year, author's country, title of article, and journal), the main research method(s), and the type of decision issues tackled in the paper is available upon request from the authors.

General characteristics of the reviewed papers

As shown in Table I, the selected papers were published in four types of journals. More specifically 60 papers were published in "*Operations & Production Management*" journals, 28 papers were found in "*Logistics & Supply Chain Management*" journals, 22 papers were identified in "*Industrial & Manufacturing Engineering*" journals, and 14 papers in "*Transportation Management*" journals.

In order to reveal how attention to research on DND has developed over time, the 126 selected papers were grouped according to their year of publication (see Table II). Three of the selected papers were published in the period 1970-1979, and six were generated in the next decade. The topic of DND did not receive much attention until the 1990s, when 27 papers were published. The remaining 90 contributions were produced in the period 2000-2013. This significant increase, which started in the 1990s, is connected to the progressive rise of the global economy, which forced companies to reconsider their distribution policies in order to operate competitively in the global market (Ashayeri and Rongen, 1997). Consumers prefer to buy the best products and services at the lowest prices, ignoring where they are produced because of the rise of globalization (Canel and Khumawala, 1996). This trend pushed companies to acknowledge the importance of

Table I. Classification of identified journals

Type of journal	Number of papers	%
Operations & Production Management	60	49
Logistics & Supply Chain Management	28	22
Industrial & Manufacturing Engineering	22	19
Transportation Management	14	11

Table II. Year of publication

Year of publication	Number	%
1970-1979	3	2
1980-1989	6	5
1990-1999	27	22
2000-2013	90	71

logistics and to consider it as a top strategic issue (Lambert, 1992), further supported by its impact on costs, which range from 8 to 30 percent of sales (Ballou, 1995).

Table III presents a list of the top ten countries that produced the majority of the papers based on the affiliation of the first author. The USA stands out as the most productive country by far. It accounts for 44 percent of the papers, according to first authorship. Rounding out the top five countries, after US, are Great Britain, Italy, the Netherlands, and Taiwan. These top five countries account for 67 percent of the papers reviewed, and the top ten countries account for around 80 percent. This reflects the rise of global business development at multinational companies during the past two decades. The trend toward economic globalization in turn generated interest in academic research in the field of logistics in developed countries. In addition, it was also found that 17 papers out of 126 were written by single authors. The number of single author publications is limited: three such papers were produced before 1990, five papers in each of the periods 1990-1999 and 2000-2009, and four papers after 2010. On the other hand, although the majority of the papers were produced by research teams, 17 articles were written by multinational teams, 15 of which were published after the year 2000. It was also found that 13 papers out of 17 were written by authors from two countries, three articles were produced by authors from three countries, and one paper by researchers from four countries. In these collaborative studies, 19 countries were involved, of which ten are European, seven are from the Far East, and two are North American. Scholars from the US contributed the most to multinational teams, co-authoring eight papers. The closest cooperation took place between the US and China, with four papers. There are two possible reasons for the growth of international cooperation. First, the need to merge complementary fields of knowledge, such as competencies in advanced logistics and in-depth knowledge of a specific emerging market, which are not always available in the same country. For example, with the support of the Chinese government, a decision-making optimization model was developed by Chinese and American researchers to support delivery and ordering decisions for a Chinese petroleum and chemical company (Zhao *et al.*, 2010). Second, looking at paper citations (on Web of Science) after 2000 (i.e. when the majority of the joint research took place), it was interesting to note that the average number of citations of single country papers is 70, while the number of citations of cooperative international papers is almost 90. One could conclude that multinational teams represent an effective way for researchers to cooperate in gathering knowledge, discovering original breakpoints and, consequently, producing relevant research.

Country	Number of papers	%
United States	55	44
Great Britain	8	7
Italy	7	6
Netherlands	6	5
Taiwan	6	5
China	5	4
Finland	4	3
Sweden	3	2
Chile	3	2
Canada	3	2
Other	26	20

Table III. Top 10 countries by first authorship

For example, Klose and Drexl (2005) cooperated on the publication of an article summarizing the characteristics of optimization models used to solve the facility location problem in the distribution system, which is the only paper in the sample that was cited more than 500 times after 2000. Another example is a paper by Romeijn *et al.* (2007) that proposed a mathematical model to address the two-echelon inventory issue taking into account the trade-offs between several cost items (i.e. handling, transportation, and storage costs), which was cited more than 100 times.

As shown in Table IV, the 126 papers considered in this review were published in 26 different journals representing four different disciplines: *Operations Research & Management Science*, *Logistics & Supply Chain Management*, *Industrial & Manufacturing Engineering*, and *Transportation Management*. More than half of the total number of papers was published in six journals (i.e. *European Journal of Operational Research*, *Transportation Research Part E: Logistics and Transportation Review*, *International Journal of Logistics Management*, *Management Science*, *Omega*, and *International Journal of Production Economics*). Each of these six journals published at least ten relevant papers. Furthermore, although almost half of the identified papers are American (based on the first author's affiliation), Great Britain, which publishes 17 of the

Table IV. Distribution of articles in identified journals

	Country	Number	%
Operations Research & Management Science			
European Journal of Operational Research	Netherlands	14	11
Management Science	US	10	8
Omega	England	10	8
International Journal of Production Economics	Netherlands	10	8
Interfaces	US	5	4
Journal of Operational Research Society	England	5	4
International Journal of Operations & Production Management	England	2	2
Annals of Operations Research	Netherlands	2	2
Journal of Manufacturing Technology Management	England	1	1
Journal of Operations Management	Netherlands	1	1
Logistics & Supply Chain Management			
International Journal of Logistics Management	England	10	8
International Journal of Physical Distribution & Logistics Management	England	8	6
Journal of Business Logistics	U.S.	5	4
Supply Chain Management: An International Journal	England	4	3
International Journal of Logistics System and Management	England	1	1
Industrial & Manufacturing Engineering			
Expert Systems with Applications	US	5	4
IIE Transactions	England	5	4
Computers & Industrial Engineering	England	3	2
Decision Support Systems	Netherlands	2	2
Engineering Optimization	England	2	2
International Journal of Advanced Manufacturing Technology	England	2	2
Industrial Management & Data Systems	England	1	1
Computers and Operations Research	England	1	1
Production Planning and Control	England	1	1
Transportation Management			
Transportation Research Part E: Logistics and Transportation Review	England	13	10
Transportation Research Part A: Policy and Practice	England	1	1

journals identified, stands out as the country with the greatest number of journals. Five journals are published in the Netherlands, which is the second most prevalent country of origin, while four journals are American.

Research methods in the reviewed papers

The research methods used in each of the papers can be grouped into the following categories (Meixell and Norbis, 2008; Perego *et al.*, 2011):

(1) quantitative models, i.e. both analytical models – such as mixed-integer programming, genetic approaches, etc. – and simulation models;

(2) conceptual models, which also includes frameworks and/or general classifications; and

(3) empirical models, such as surveys, interviews and case studies.

Papers presenting quantitative models

As shown in Table V, from among the 126 papers considered, 108 are based on a quantitative approach/model, 13 are conceptual and five are empirically based.

In order to provide a more detailed picture of the quantitative studies, the 108 papers identified were further categorized according to:

(1) model type (optimization models, simulation techniques, etc.);

(2) model objective (profit maximization, cost minimization, or multi-objective, etc.); and

(3) main assumption of the model (single sourcing or multiple sourcing, unlimited capacity or limited capacity, single product or multi-commodity, etc.).

Not surprisingly, 68 papers considered mixed-integer programming models – a conventional modeling approach in logistics and supply chain management (Klose and Drexl, 2005) – with a wide variety of algorithmic formulations (i.e. linear or non-linear and single objective or multi-objective functions). Only four papers based on simulation were identified. Their aims were either to evaluate potential DND solutions, or to examine the impact of specific factors on distribution network performance. Some papers based on other mathematical approaches were also found. These other quantitative techniques include fuzzy goal programming (Selim and Ozkarahan, 2008), Ant Colony Optimization (Barcos *et al.*, 2010), linked-based integer math model (Lin, 2010), continuous function model (Dasci and Verter, 2001), and algebraic algorithms (e.g. Gumus and Bookbinder, 2004; Han and Damrongwongsiri, 2005).

The models were then grouped according to the type of objective function (see Table VI). With regard to the single objective function, cost minimization with a certain service level is the typical approach used in distribution network modeling. Indeed, 86 papers (i.e. nearly 80 percent of the quantitative papers examined) present quantitative models that aim to minimize total distribution costs, which include location, transportation and inventory costs

Type of models	Number	%
Quantitative models	108	86
Conceptual models	13	10
Empirical models	5	4

Table V.
Type of models

(Chopra, 2003). For example, Dogan and Goetschalckx (1999) studied the production-distribution allocation problem for the case of customer demand with seasonal variations and developed a mixed-integer programming model aimed at minimizing the total costs. The models presented in seven papers (i.e. 6 percent of the quantitative papers examined) attempted to maximize the customer service level, given a maximum level of costs. For example, Verrijdt and de Kok (1995) discussed the periodic review control policy for multi-echelon distribution networks in order to realize the predetermined target service level defined as item fill rate (i.e. the fraction of demand – in pieces – delivered from stock on hand). Another seven papers (i.e. 6 percent of the quantitative papers analyzed) present models whose main objective is to maximize profit, i.e. the difference between income and costs, or to maximize revenue. An example of this is the paper by Canel and Khumawala (1996), who developed a mixed-integer programming model to solve the capacitated and incapacitated multi-period international facility location problem. Another example is given by Melachrinoudis and Min (2000), who proposed a mixed-integer programming model in order to solve the multiple period relocation problem in which a single commodity is produced by one specific facility with no capacity constraints.

From the previous description, it seems clear that the single objective function, found in 92 percent of the quantitative papers analyzed, is the most widely used technique to support DND decisions. The main – and obvious – shortcoming of this approach is that it does not take into account the possible conflicts between different objectives. As an example, cost reduction could result in a push towards centralization of inventories, whereas concurrently the improvement of service level could provide motivation for holding products as near to consumers as possible.

Just eight papers (i.e. 8 percent of the quantitative papers examined) with multi-objective functions (i.e. the integration of different single objective functions to provide an integrated approach) were identified. In general, the multi-objective models identified take into account two objectives at the same time, trying to identify the best trade-off between cost minimization and target service level. An example of multi-objective modeling is presented by Melachrinoudis *et al.* (2005), who proposed a multiple criteria optimization model (i.e. minimizing annual operating costs while maximizing customer service represented by the customer's demand coverage) to solve the warehouse location problem. Similarly, Sabri and Beamon (2000) developed a multi-objective model to solve supply chain planning problem taking into consideration cost minimization, fill rate maximization, and the maximization of delivery flexibility.

Another important aspect of the quantitative studies is the diversity of the assumptions made. The majority of the mathematical models presented in the papers reviewed were based on the premise of single- vs multi-commodity, single- vs multi-sourcing, limited/unlimited capacity. The number of occurrences of the assumptions is shown in Table VII. In terms of the assumptions, 29 articles were identified that deal with distribution network decisions based on a multi-commodity (i.e. multiple products are delivered through the

Table VI.
Objective function

Objective function	Number	%
Cost minimization	86	80
Target service level	7	6
Profit maximization	7	6
Multi-objective	8	8

distribution network) premise and 13 that were based on the single-product assumption (i.e. only a single product is delivered through the distribution network). As an example of the former case, Miranda and Garrido (2004) proposed a simultaneous approach that incorporates inventory control decisions into typical multi-product facility location models. An example of the latter case is given by Amiri (2006), who concurrently addressed the location, number, and capacity of both production plants and distribution warehouses. The single-sourcing case is assumed in 13 papers. For example, Eben-Chaime *et al.* (2001) formulated a mathematical optimization model based on the single-sourcing policy in order to solve capacitated location-allocation problems. The unlimited capacity and single facility assumptions were found in six and five papers, respectively. Regarding the unlimited capacity situation, Melkote and Daskin (2001) presented a mixed-integer programming model to optimize facility locations and the underlying transportation network, with uncapacitated demand serving facilities. With regard to the single facility case, for example, Meepetchdee and Shah (2007) proposed a network design framework for a three-echelon network with one manufacturing facility based on a linear programming approach that also takes into account robustness (i.e. the functions of a network that can be implemented despite some damage) and complexity features (the ratio of actual number of links between the different nodes to the minimum number of links).

Conceptual research papers

A total of 11 conceptual research papers were identified, whose aim was to propose a classification/framework of both factors and models or to provide a holistic conceptual model to design the distribution network (see Table VIII).

More specifically, five papers were identified whose objective was to propose a classification framework (e.g. classification of factors influencing the distribution network structure, or classification of mathematical models addressing facility location problems). For example, Ballou (1977) identified three key decision areas (i.e. inventory policy, facility location, and transport selection), classified the decision issues in each area and explained the relationships between them. Another example is given by Chopra (2003), who proposed a classification framework for both the factors affecting the main choices in DND and the different types of distribution networks. Klose and Drexl (2005)

Assumptions	Number	%
Multiple products	29	27
Single product	13	12
Single sourcing	13	12
Unlimited facility capacity	6	6
Single facility	5	5

Table VII. Top five assumptions

Type of conceptual model	Number	%
Conceptual framework	8	62
General classification	5	38

Table VIII. Conceptual frameworks and classification classified facility location models (e.g. continuous location models, network location models, mixed-integer programming models), based on a literature review.

Another eight papers proposed conceptual models, providing guidelines for the design of a distribution network when the distribution channel must be harmonized with the features of the products, or models in which the distribution network is harmonized with the firm's business objective. For example, Payne and Peters (2004) developed a model to match the type of products and the type of distribution channels for the sake of cost reduction and service improvement. Similarly and more broadly, Lovell *et al.* (2005) proposed a framework for determining the structure of a distribution network and transport options based on product value density, throughput volume and product availability.

Empirical research papers

Only five empirical research papers were identified, based on surveys or case studies, whose main objective was to identify a specific trend or to support DND. In this research, empirically based papers are those whose primary methodological approach is on-site company interviews, company case studies, or surveys, and in which quantitative models, if used, are subsidiary tool. With regard to the identified empirical papers, first, Abrahamsson (1993) conducted three case studies to address the advantages of both centralization of warehouses and direct delivery to customers, two important trends in the European mechanical industry. Second, Abrahamsson and Brege (1997), based on five case studies, observed that total distribution costs are significantly reduced and customer service level is dramatically improved by centralizing physical and administrative activities. Next, Creazza *et al.* (2010) identified five main logistics network configurations at international freight transportation companies by conducting a series of interviews with the leading ocean container shipping operators. Survey research is another of the main methods used to conduct empirical studies. An example is given by Hilmola and Lorentz (2011), who identified three criteria (i.e. distribution costs, road transportation connections, and proximity of manufacturing units) used to determine the warehouse location, and observed that the size of warehouses increased gradually over the years based on a longitudinal survey investigation between 2006 and 2010.

Review of decision issues

Following the examination of the research methods, the analysis focused on the most important decision areas (i.e. distribution network structure and management policies) as pointed out by Ballou (1977) tackled in the selected papers. The main focus of the distribution network structure is the configuration of the network and facilities, whereas management policies include the activities carried out when facilities and infrastructure have been established. The three research methods outlined earlier have been taken into consideration as well, in order to analyze the relationship between decisions and research methods.

Strategic decisions on distribution network structure were tackled in 99 papers, and the most recurrent decisions addressed in these papers are shown in Table IX. "Facility location" is the most frequent decision, followed by "demand allocation to facilities" and "number of facilities". These top three decisions are each mentioned in more than 40 articles. In particular, 74 papers that addressed the problem of facility location were identified and the majority of them discussed both the location of plants and distribution centers/warehouses/depots, while the remainder only analyzed the location problem in relation to stocking and transit points. In general, this decision is considered in conjunction with some other issues, such as number of facilities, demand allocation, inventory level, and transport routing, since they act as modifiers to the location strategy (Ballou, 1977). The fourth and fifth ranked decisions are "capacity of facilities" and "number of echelons". In the former case, an increase in the capacity of facilities would decrease the number of facilities, leading to a drop in construction costs. Transportation costs also decrease due to fewer links between facilities until transportation economies of scale have been reached (Melkote and Daskin, 2001). In the latter case, the number of echelons usually indicates whether the distribution network structure is centralized or decentralized (Abrahamsson, 1993; Abrahamsson and Brege, 1997). A decentralized structure indicates that products are distributed from a plant to points of sale by passing through central and regional warehouses, whereas direct shipments take place in a centralized network. The choice between the two structures depends on the product value, demand level, and predictability of demand (Chopra, 2003). The majority of these top strategic network structure decisions are addressed through mathematical models in the quantitative papers. However, they are also taken into account in the non-quantitative research papers. As an example, the decision about the "number of echelons" has been tackled in the conceptual and empirical research papers, rather than in the quantitative papers.

In total, 75 papers that focus on strategic issues about management policies were identified and the most important decisions considered in these articles are listed in Table X. "Inventory level" and "transport routing design" are the issues most frequently discussed, with almost 40 papers each. As explained previously, these two decisions and facility policy (i.e. number, size, and location of stocking points) are the three main elements of strategic logistics planning (Ballou, 1977). "Safety stock allocation" and "fleet design" are addressed in 16 papers each. Generally speaking, the safety stock allocation problem has been discussed in relation to two decision issues – i.e. inventory level and item fill rate – since the stocking points in a distribution network must hold enough safety stock to guarantee the desired service level (Sourirajan *et al.*, 2009). The fleet design issue involves the selection of transportation mode, and customer delivery scheduling, with the aim of minimizing delivery time so as to minimize transportation costs (Mourits ad 1996;

Decisions	Number	%
Facility location	74	59
Demand allocation to facility	43	34
Number of facilities	41	33
Capacity of facility	11	9
Number of echelon	5	4

Table IX.
Top 5 strategic network structure decisions

Decisions	Number	%
Inventory level	40	31
Transport routing design	39	29
Safety stock allocation	16	14
Fleet design	16	13
Inventory policy	9	11

Table X.
Top 5 strategic management policy decisions

Stank and Goldsby, 2000; Chan, 2006). "Inventory policy" – referring to some alternatives such as push/pull inventory strategy, and the target level for the item fill rate – is mentioned in nine papers. As a typical strategic inventory issue, both pushing inventories into stocking points and pulling them in are related to the selection of a distribution strategy (i.e. lean vs agile), and network structure (i.e. decentralized vs centralized network). More specifically, the pushing strategy requires a decentralized network in order to obtain a cost saving, while the pulling strategy favors a centralized structure in order to fulfill service criterion (Ballou, 1977; Payne and Peters, 2004). The item fill rate acting as inventory service level has been examined in a few papers, as it affects the total inventory costs (Miranda and Garrido, 2009; Gebennini *et al.*, 2009). The majority of the contributions in this group were also from the group of quantitative research papers. In the conceptual research papers, the most pertinent themes are concentrated in the transport routing area, while this topic was not addressed in the empirical studies.

In conclusion, four key messages can be discerned. First of all, the majority of the articles focused on strategic decisions about network structure rather than management policies. Decisions about network structure are in fact tackled in both the operations and logistics/supply chain management fields, whereas management policy decisions are primarily addressed in the logistics and supply chain management area. Second, mathematical models have been widely used since the 1970s as the most popular method for dealing with both network structure and management policy decisions, with no major change in the last few decades. One of the reasons the number of empirical papers is limited could be that some journals (e.g. North American) had, in previous years, been reluctant to accept scientific works based on case study based methodologies. Third, among the mathematical models, those with multi-objective functions have been increasingly used, especially from the 2000s to the present. This trend indicates that distribution network decisions have to be taken against a more complex background. Lastly, some decisions are discussed only in the non-quantitative papers, such as the number of echelons, handling operations, and local transport. For instance, the number of echelons is taken into account in a theoretical way as a strategic decision issue in the non-quantitative articles (e.g. Chopra (2003) analyzed six different distribution networks, their performance, and the determining factors in the selection of those networks), whereas the same issue is analyzed as a constraint rather than as a decision in the quantitative papers. For example, Elhedhli and Gzara (2008) proposed a mixed-integer programming formulation to handle the location-allocation problem in a defined three-echelon logistics network.

Review of critical factors

This section discusses the main factors that affect distribution costs that were taken into account in the papers, these being very important in helping designers make the best decisions about DND. As a first step, the most popular factors were identified, and their effects on the DND were examined. As a second step, a framework was developed in which all of the factors mentioned in the papers were included, and subdivided into groups with common characteristics. Lastly, the relationships between those groups of factors and strategic decision issues were presented using a matrix.

Table XI presents the top five factors addressed in the reviewed papers. The demand level (i.e. total demand for a product in a specific time period, such as daily, weekly and yearly demand) is the factor most frequently discussed. It influences decisions such as transportation mode, and facility size and location, where economies of scale affect the total distribution costs (Vos, 1993). Cycle time (i.e. the number of days it takes to deliver an order from the moment the customer placed it until the customer receives the goods) is the second most popular factor. A decrease in cycle time increases the number of facilities, so that inventory and resulting inventory costs also increase (Chopra, 2003). Distance between nodes (e.g. the distance from plant to warehouse, or the distance from warehouse to client, or other patterns) is another critical factor. It is related to some strategic decisions (e.g. number and location of facilities), since multiple terminal configurations could reduce the mean distance traveled, but may result in a less efficient truck filling rate compared with the single node configuration (Lumsden *et al.*, 1999). The fourth most prevalent factor is demand volatility, which is a measure of overall demand variability and which provides a representation of the variability of the demand pattern in relation to the average demand. This factor influences the inventory policy in relation to the level of inventory centralization in the logistics network (Harrison and van Hoek, 2011). Finally, there is delivery frequency, which corresponds to the number of deliveries per unit of time (e.g. day, week, and month), which could change the average level of inventory at the stocking points (Perl and Sirisoponsilp, 1993).

The purpose of the follow-up analysis is to develop a framework for the categorization of all of the identified factors based on their common characteristics. First of all, some researchers maintain that a company needs to match the type of products it is selling with the type of distribution channels used to deliver the products (Fisher, 1997; Lee *et al.*, 2002; Payne and Peters, 2004). Ballou (1977) stated that product characteristics affect the structure of a distribution system. Rushton and Saw (1992) also proposed some main product factors that determine the structure of logistics chains, such as the value density of a product, the range of products and the risk profile. Second, many authors recognized the effect of customer service elements in designing distribution networks (Meshkat and Ballou, 1996; Canel and Khumawala, 1996; Gattorna and Walters, 1996; Christopher and Towill, 2001), because high service levels demand a decentralized distribution network and have a negative impact on all logistics costs, most of all on inventory costs. In particular, Chopra (2003) noted that customer service aspects influence the structure of the distribution network, and vice versa, and proposed some variables that have a significant impact on both logistics costs and customer satisfaction, such as delivery time (i.e. the time window between order release and delivery to customers), accuracy in filling orders, order visibility (i.e. the ability to track customer orders from placement to delivery), and returnability (i.e. the ease with which a customer can return unsatisfactory products). Third, Stank and Goldsby (2000) found that the characteristics of market demand also influence the transportation mode and truckload in the distribution process. It was shown that the supply chain structure should be consistent with the characteristics of the marketplace (Christopher and Towill, 2001) in terms of customer density (i.e. number of customers per square kilometer), delivery frequency, order size, demand variability, seasonality and demand level, etc. In addition, several other aspects have been added to this base locating theory (Korpela *et al.*, 2001). The main factor considered is the features of the supply line. For example, the number of plants, the average distance

Factors	Number	%
Demand level	82	65
Cycle time	27	21
Distance between nodes	19	15
Demand volatility	16	13
Delivery frequency	15	12

Table XI. Top 5 factors

between plants and customers, and the specialization level of the factory have been taken into account in many quantitative models (e.g. Ashayeri and Rongen, 1997; Gumus and Bookbinder, 2004; Ambrosino and Scutella, 2005). Creazza *et al.* (2010) also considered the effects of supply characteristics (e.g. number and location of suppliers, and number of supplied items) to evaluate a global logistics network configuration. Lastly, Lovell *et al.* (2005) stated that factors related to the commercial environment, such as customs, duties, trade areas, and legislation, could also influence the DND. Therefore, the factors identified from the 126 papers can be classified into five factor groups: product characteristics, service requirements, demand features, supply characteristics, and economic variables. These are listed in Table XII.

The links between the identified decision issues and the groups of factors from the articles collected were investigated. These relationships (reported in Table XIII) are based on the investigation of the effect of each factor in each different group on both the most popular strategic network structure and strategic management policy decisions. More specifically, many quantitative factors (e.g. product value, cycle time, demand level, distance between nodes, import duties, etc.) have been used in the mathematical models to deal with strategic decisions, while many qualitative variables (e.g. product substitutability, customer experience, returnability, seasonality, legislation, etc.) have been taken into account in the conceptual models. The number of papers that consider the factors in a specific factor group is presented in the bracket. Although these numbers cannot be considered as a proxy of the importance of each factor on decisions, they can indicate the existence of a relationship, at least in those cases in which they are particularly high. The sum of the numbers for each decision is higher than the results shown in Tables X and XI because the decisions are affected by multiple factors simultaneously. Demand features (i.e. demand level, demand volatility, seasonality, etc.) is the most popular factor group as it influences all of the main strategic decisions. The factors in this group have been widely used in mathematical models to solve location-allocation problems, to make inventory decisions, and to deal with transportation issues. For example, the total demand level can often strongly impact the network configuration, because the customer that accepts a full truck load shipment can usually be served directly from the plant (Ballou, 1977), or through a centralized distribution network. In this case, it is easier to deal with the inventory and transportation decisions, since fewer storage sites are involved and no additional delivery stops are required. Taking another example, demand volatility and seasonality directly influence facility and inventory decisions because greater variety leads to a reduction in service, which creates a need for larger and centralized inventory, and faster transportation modes to mitigate the service risk and the location of facilities closer to customers (Harrison and van Hoek, 2001; Payne and Peters, 2004; Lovell *et al.*, 2005). Another very important factor group is Service requirements (i.e. cycle time, delivery frequency, item fill rate, and returnability, etc.). It affects both the network structure and management policy decisions, as facility, inventory and transportation management all play a role in providing the required service level to the customer (Ganeshan and Harrison, 1995). For example, long cycle time can require fewer facilities but larger capacity at each location. On the other hand, short cycle time creates a need to locate more facilities with low capacity near customers. Moreover, returnability (i.e. the extent to which a customer can return dissatisfactory product) is expensive and difficult to implement in the centralized distribution network, which decreases customer satisfaction (Chopra, 2003).

The other three groups of factors (i.e. product characteristics, supply characteristics, and economic variables) have received less attention by the authors of the papers examined. This does not mean that they are less important, but perhaps that further

Factor group	Factor
Product characteristics	Product value density
	Weight-cubic volume ratio
	Product life cycle
	Level of competition
	ABC product characteristics
	Product type
	Product variety
	Product price
	Substitutability
	Product handling characteristics
	Shelf life
	Product margin
Service requirements	Cycle time
	Delivery frequency
	Average weight of shipment
	Average volume of shipment
	Item fill rate
	Capacity of vehicle
	Customer experience
	Order visibility
	Returnability
	Replenishment lead time
Demand features	Demand level
	Demand volatility
	Demand density (items/mile^2)
	Customer density (customer/km^2)
	Number of customers
	Seasonality
Supply characteristics	Production capability
	Distance between nodes
	Production batch size
	Limitations on raw material
	Economies of scale
	Production flexibility
	Production lead time
	Number of suppliers
	Location of suppliers
Economic variables	Legislation restriction
	Customs/duties
	Existing infrastructure
	Transport mode availability
	Interest rate

Table XII.
List of factors

investigation of those factors is needed. In any event, some interesting relationships have been highlighted. Product characteristics have a moderate effect on both strategic network structure decisions and strategic management policies. For example, competition level can determine the placement of storage sites and the delivery method, because intense competition pushes firms to provide and maintain higher service levels by locating warehouses in proximity to customers and using fast means of transportation (Ballou, 1977). The supply-based factors heavily influence network structure decisions but play a minor role in management policy decisions. For example,

Decisions	Product characteristics	Service requirements	Factor groups Demand features	Supply characteristics	Economic variables
Strategic network structure					
Facility location	X (3)	X (25)	X (54)	X (19)	X (5)
Demand allocation		X (13)	X (37)	X (8)	
Number of facilities	X (4)	X (19)	X (33)	X (10)	X (2)
Capacity of facility			X (15)	X (3)	
Number of echelons	X (4)	X (3)	X (4)	X (1)	
Strategic management policy					
Inventory level	X (4)	X (21)	X (31)	X (5)	
Transport routing	X (5)	X (11)	X (24)		X (3)
Safety stock		X (10)	X (14)		
Fleet design	X (3)	X (5)	X (14)		X (1)
Inventory policy		X (4)	X (8)		

Table XIII.
Matrix of decisions and factor groups

the distance between nodes is often used to determine the physical facility configuration given the transportation cost (Ashayeri and Rongen, 1997). Economic variables are usually mentioned when the distribution network is designed on a global level. The economic cost factors (e.g. duties, interest rate) and infrastructure (e.g. existence and quality of transportation mode) are the most important cluster that affect location decisions when international operations take place (MacCarthy and Atthirawong, 2003). Therefore, facility location and number of facilities in the network are directly determined by the cost-based factors, and infrastructure can influence transportation routing and fleet design.

Summary and implications

In this study, 126 research contributions on DND published between 1972 and 2013 were systematically examined using a three-pronged approach, taking into account general characteristics, research methods adopted, decision issues tackled, and the factors and related factor groups that affect DND. This exhaustive examination was conducted for the four journal groups identified (i.e. *Operations Research & Management Science*, *Logistics & Supply Chain Management*, *Industrial & Manufacturing Engineering*, and *Transportation Management*). With respect to the quality, a panel of three experts (i.e. scholars who published at least one literature review in their academic career) was asked to assess the results achieved. Their two main suggestions, which firmly position the paper within an established methodological framework for a literature review, have been incorporated in the methodology. The first recommendation was to mention other *Logistics and Supply Chain Management* literature reviews that adopted the same three-step methodology used in this paper. The second suggestion was to specify the number of papers found at each stage of the selection process.

Consistently with the objectives stated in the introduction, the literature review produced the following results:

(1) The research has been classified according to the methods stated. From among the 126 papers considered, 108 are based on a quantitative approach/model, 13 are conceptual, and five are empirically based. Among the quantitative papers, 68 used mixed-integer programming models and 86 aimed to minimize total distribution costs. The majority of the conceptual papers aimed to propose a classification/framework of both factors and models. The empirical research papers, based on case studies or surveys, aimed to identify a specific trend or to support DND.

(2) The main decisions addressed in the literature have been identified. Strategic decisions on distribution network structure were addressed in 99 papers, and the top five decisions are "facility location", followed by "demand allocation to facilities", "number of facilities", "capacity of facilities", and "number of echelons". Strategic issues about management policies were addressed in 75 papers and the top five decisions discussed were "inventory level", followed by "transportation routing design", "safety stock allocation", "fleet design", and "inventory policy".

(3) A framework in which the factors that affect DND are categorized based on the variables used in both mathematical and conceptual models has been developed. In all, 42 factors were identified, of which the top five are the "demand level", "cycle time", "distance between nodes", "demand volatility", and "delivery frequency". The factors were grouped into five categories, namely product characteristics, service requirements, demand features, supply characteristics, and economic variables.

(4) The links between the identified decision issues and the factor groups were investigated. It was found that demand features are the most critical factor group as these factors influence all of the main strategic decisions, and demand factors have been widely used in mathematical models to solve location-allocation problems, to make inventory decisions, and to deal with transportation issues. Another important group of factors is service requirements, due to its impact on both network structure and management policy decisions, as facility, inventory, and transportation all play a role in providing the required service level to the customer. Product characteristics have a moderate effect on both strategic network structure decisions and strategic management policies. Supply characteristics heavily influence network structure decisions, but play a minor role in management policy decisions. Finally, economic variables are the factor group with the greatest impact on decisions when international operations take place.

Although many aspects have been investigated, the literature review has shown that there are still some aspects that should be examined in further detail, in order to address the shortcomings that were identified in the academic research conducted to-date and to better support practitioners as they make decisions about distribution network structure and management policies.

Only a few empirical studies have been performed for the purpose of developing models that support DND

It was found that most of the literature (108 out of 126 papers, i.e. 86 percent) focuses on quantitative methodologies (such as heuristic-based approaches, mathematical programming-based models, and hybrid approaches). Mathematical models have some drawbacks. One is that these models are based on specific assumptions that could limit the validity of the results (e.g. single commodity or multiple commodity, single sourcing or multiple sourcing, capacited or uncapacited demand). Another is the difficulty in evaluating qualitative variables (e.g. legislation issues, customer experience, and infrastructure) that would result in a more comprehensive description of the system. With only some exceptions (e.g. Min and Melachrinoudis, 1999 provided a model for re-locating manufacturing and distribution facilities which considered some qualitative factors such as site characteristics, traffic access, quality of living, and local incentives, using the analytic hierarchy process (AHP); Kuo, 2011 combined analytic hierarchy/network processes (AHP/ANP) with an optimization model to deal with the facility location problem by taking into account the quality of infrastructure including traffic, information, and financial issues), these factors have not been considered in mathematical models. Empirical investigations could be a more effective way of doing so, from at least two points of view: first, they can be used to check the validity of the solutions obtained from mathematical models in the real-world environment and, second, the qualitative factors can be evaluated through interviews and questionnaires, based on the companies' experience on the subject.

Not all of the important factors influencing the design of the distribution network have been considered in the literature and the importance of the factors has not been assessed

DND is a very complex issue that is affected by a wide range of factors. In the literature, the factors affecting DND have been studied by numerous researchers, most of whom performed quantitative analyses. However, these quantitative studies do not take into account enough factors, particularly certain qualitative variables, such as legislation issues, returnability, and geographic and commercial environment. More specifically, qualitative factors have been considered in only 11 papers out of 126 (i.e. 9 percent). Another limitation is the lack of detail about the importance of the factors in making the different decisions, since no contribution was found that evaluates the magnitude of their impact on the decision issues related to the DND. Some papers were found that deal with the same decision issues using different factors and, as a consequence, practitioners could be confused about which factors should be taken into account to deal with a specific decision issue. Therefore, the authors believe that the factors affecting DND should be assessed in order to identify which ones are the most critical.

Little attention has been devoted to some critical strategic decisions, such as the number of echelons and type of facilities

In the first phase of the DND process, some strategic alternatives (such as the number of echelons, and the type of facilities in each echelon) should be taken into account because they influence management policy decisions and have long-term impacts on total distribution costs. Despite the importance of their impact on the performance of the distribution network, the number of echelons and type of facilities in each echelon are two decisions that have not been adequately taken into account in the extant literature (six out of 126 papers, i.e. 5 percent). More specifically, it was found that many mathematical models are proposed based on a specific distribution network structure (e.g. two-stage or three-stage network) and a pre-defined role for facilities (e.g. warehouse or transit point). However, when designing a distribution network these two issues are in fact decisions rather than assumptions. Therefore, it is also necessary to develop models whose objectives include the determination of the number of echelons and the type of facilities.

In order to fill these gaps, some potential lines of research should be considered. First of all, empirical studies could be conducted, in order to understand which factors are in fact used by industries and to assess the real values of these factors. With respect to the mathematical models, empirical studies would also take qualitative factors in a real-world environment into account. Second, based on an empirical investigation, a correlation analysis and a factor analysis could be carried out in order to first evaluate the degree to which each factor affects the distribution network, and to then select the most important ones. The identification of the core factors is fundamental to building simple tools (i.e. that consider a limited number of factors) that could help decision makers find the best solutions. Finally, given that the critical factors may be both quantitative and qualitative, an integrated method for making decisions about DND, particularly with respect to the strategic issues, could be developed. This is essential if the completeness required when designing a distribution network is to be achieved.

In conclusion, this review offers valuable insights for practitioners, which can be summarized as follows:

(1) A clear understanding of the main decisions to be taken when designing a distribution network: the main decisions have been presented by classifying the decision issues tackled most often in the literature with regard to network structure and management policies. This classification contributes value by providing both a structure that creates order among all of the different choices and a comprehensive list that provides practitioners with a full picture of the choices to be made when designing a distribution network.

(2) A comprehensive understanding of the main factors and factor groups that affect the distribution network structure: this paper provides not only a complete list of factors, but also a structured view of the elements that affect both the structure and the management of the distribution network, which have been classified into five main groups in order to help decision makers understand the nature of the distribution problem they have to deal with.

(3) A clear understanding of the relationships between the factor groups and the main strategic decisions: the existence of the relationships between the determining factor groups and the main strategic decisions is given in Table XIII. These relationships can serve as a guide both when designing a network – in order to understand whether all of the relevant factors have been considered – and when one or more factors change – in order to identify which decisions are impacted by that variation and need to be reconsidered.

(4) A guide to the models that can be used to support the different phases of DND: the optimization models were reviewed based on the main methods, assumptions, and objectives. In reality, firms operate under a range of different circumstances. Therefore, a firm must select a suitable optimization model, in which the assumptions and objectives reflect its actual situation, in order to design an optimal distribution network from both strategic network structure and management policy perspectives.

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