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Decision support and intelligent systems in the textile and apparel supply chain: An academic review of research articles

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ABSTRACT

This article provides a comprehensive review of research articles related to the application of decision support and intelligent systems in the textile and apparel supply chains. Data were obtained from 77 articles published from 1994 to 2009 in 35 journals. The articles were categorized according to their applicability into three basic sectors – textile production, apparel manufacture, and distribution/sales. They were further categorized into 16 subsectors based on their operational and management/control processes. A comprehensive list of categorized journal articles identified in this study provides insights and relevant references for both researchers and practitioners on the application of decision support and intelligent systems to various stages of a textile and apparel supply chain. In light of the developed classification framework, we identify gaps in extending the use of the decision support and artificial intelligent systems in the industry and suggest potential and applicable research areas for further consideration in this subject area.

1. Introduction

The increasing trend toward globalization and growing levels of international competition have compelled firms in the textile and apparel industry to build strong and responsive supply chains that will enable efficient and effective operations and to offer customers the best value with a view to achieving market leadership. A supply chain consists of a network of members (generally organizations) formed towards achieve a common aim of converting raw materials into final products and then delivering these products to intermediates and, ultimately, final consumers (Chopra & Meindl, 2007). Such a network is notable for the nature of the relationships among members, which enable information-sharing and add value to products and services by increasing internal coordination (Chandra & Kumar, 2000).

The application of information technology (IT) is a significant enabler of such opportunities. Porter and Millar (1985) argued that IT can create competitive advantages for companies to improve coordination and communication among trading partners, increase the availability of information for intermediaries and customers (e.g., the ability to track or trace products in the chain), and provide added value at various stages along the entire supply chain. Indeed, IT allows supply chains to achieve agility (Gunasekaran & Ngai, 2004); to reduce uncertainty, cycle-time, and inventory (Levary, 2001; Srinivasan, Kekre, & Mukhopadhyay, 1994); and to closely collaborate with networked members (Simchi-Levi, Kaminsky, & Simchi-Levi, 2003). Essentially, IT functions as the central nervous system of the entire network and provides direct benefits to individual members within a given supply chain (Auramo, Kauremaa, & Tanskanen, 2005).

In the textile and apparel industry, globalization is intensifying, with many companies either sourcing components overseas or moving manufacturing to countries with lower labor costs (Jones, 2002). Such a challenge is further complicated by the growing unpredictability of the global fashion market, which leads to rapid changes of customer demand in styles and in quantity. In short, the industry is characterized by unpredictable demand, short product life cycles, quick response times, large product variety, and a volatile, inflexible, and complex supply chain structure (Fischer, 1997). The application of IT introduces flexibility into such a supply chain, especially in terms of quick and accurate responses to meet rapid changes in the fickle market (Stylios, 1996).

When discussing the application of decision support and intelligent systems in this context, it is important to consider the role of IT in amalgamating a supply chain. These systems use data and mathematical models that possess the characteristics of flexibility, adaptability, memory, comprehension, and the ability to manage

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uncertain and constantly changing information (Krishnakumar, 2003). Because of their specific features, they can improve efficiency and effectiveness in supply chain management, particularly within such a competitive environment as the textile and apparel industry. Typically, these systems include several systems developed from the study of artificial intelligence (AI); which are expert systems (ES), genetic algorithms (GA), artificial neural networks (ANN), knowledge-based systems (KBS), and fuzzy-logic systems.

A scan of research review articles in the discipline indicates some studies that focus on the application of IT in various areas. For example, Stephanopoulos and Han (1996) provide an overview of the work done in seven specific areas and a review of intelligent systems in process engineering. Shen, Hao, Yoon, and Norrie (2006) review the application of agent-based systems in intelligent manufacturing. Nonetheless, despite the fact that a number of research studies of the textile and apparel industry and on fashion supply chains have been conducted (Bruce, Daly, & Towers, 2004; Chandra & Kumar, 2000; Romano & Vinelli, 2001; Şen, 2008), no comprehensive review of such applications has yet been conducted. Without that, the understanding of the current situation in the industry regarding the use of these technologies is hindered and will thus affect decisions with regard to research direction, in turn leading to gaps in potential misdirection of research efforts and negative impacts on the future development of the industry.

This study, therefore, aims to provide a systematic and comprehensive review of research articles in order to gain insights into the applications of decision support and intelligent systems in a textile and apparel supply chain. It also aims to develop a classification framework to analyze the extant literature in this subject area to provide a reference for researchers to maximize effort value in future research.

The remaining of this paper is organized as follows. First, we propose a classification scheme for analyzing the structure of a textile and apparel supply chain and for categorizing the articles relating to the applications of decision support and intelligent systems in the industry. Second, we describe the research methodology adopted in conducting the study. Third, we scrutinize those articles in relation to our proposed framework. Fourth, we provide a discussion on the practical implications of applying such systems in the industry and identify potential areas for future research; in particular, we highlight some new AI technologies that have a potential to be used in the textile and apparel industry, for example, mobile technology. Finally, we provide a summary and conclusion to describe the contributions as well as the limitations of the study.

2. A classification framework for textile and apparel supply chains and decision support and intelligent systems

To understand the application of decision support and intelligent systems in the textile and apparel supply chain, we first analyzed the structure of the industry, classifying it into three major sectors: textile production, apparel manufacture, and distribution/sales. We then identified the various decision support and intelligent systems which are applicable to the management of each of these sectors.

2.1. Structure of textile and apparel supply chain

A textile and apparel supply chain incorporates the flow of products, services, money, and information among suppliers, manufacturers, distributors, and retailers (Yi, Ngai, & Moon, 2011). Based on the classification systems considered by Forza and Vinelli (2000), Bralla (2007), and Şen (2008), we divided the textile and apparel supply chain into sectors of textile production, apparel manufacture, and distribution/sales. Furthermore, we analyzed the business practices of each sector in terms of operational processes and management/control processes. Accordingly, 16 subcategories were found (see Fig. 1), which form the basis of the classification framework adopted in this study.

2.1.1. Textile production

Textiles are the basic materials of apparel products (Moon & Ngai, 2010). The operational processes in the sector of textile production involve activities that turn raw materials (e.g., fibers) to finished textile products (e.g., yarns and fabrics). Three main subcategories are included: 'fiber-to-yarn', 'yarn-to-fabric', and 'coloring and finishing'. Fiber-to-yarn involves turning fibers into yarns by spinners, throwsters, and/or texturizers (Şen, 2008), while yarn-to-fabric converts yarns into fabrics or cloths through weaving, knitting, or some forms of nonwoven process. Coloring and finishing are additional processes applied to textile products in order to create special visual and/or tactile effects.

The management/control processes in this sector involve activities that support the production of textile products and can be further classified into 'textile inspection and evaluation' and 'textile production management'. Textile inspection and evaluation comprises all inspections and evaluations during the entire textile production process, including quality inspection, textile property evaluation, and error identification. The main purpose is to ensure that the quality of the finished textile products are up to a level that is agreeable with the clients. Textile production management refers to planning, organizing, monitoring, and controlling production activities like scheduling, line balancing, and shop floor layout as well as the general management of information flow, human resources, organizational behavior, environmental control, cost control, and other management-related activities.

2.1.2. Apparel manufacture

Apparel manufacture encompasses the processes of transforming textile products, such as fabrics and yarns, into finished garments according to specific design requirements. The operational processes in garment manufacturing can be subcategorized into 'product design and development', 'material management', 'garment making', and 'pressing, finishing and packing'. Product design and development involves activities in bringing aesthetic or natural beauty concepts into a garment product and then transforming these concepts into a physical prototype; that is, the first sample (Tate, 2004). Material management refers to the activities of sourcing and purchasing needed materials from suppliers; and then evaluating and processing these materials before cutting and sewing in the later stages. Garment making is the main process in making-up a garment, which includes spreading/cutting, sewing, buttoning/buttonholing, and some other special sewing processes (Bralla, 2007). Pressing, finishing and packing are the final processes undertaken to ensure the finished garments are at the required state for delivery and/or retail.

Management/control processes in this sector can be classified into subcategories of 'garment inspection and evaluation' and 'garment production management'. The former is a process undertaken to ensure that final products delivered to customers are up to an agreed quality standard, which include activities like detecting garment defects (Kuo, Lee, & Tsai, 2003; Yuen, Wong, Qian, Chan, & Fung, 2009), checking sizes (Croyle & Lin, 1996), and assessing seam puckers (Mak & Li, 2007). The latter supports the operations of garment manufacturing, including activities like production scheduling and routing, machine layout, work study, line balancing, and other general management issues.

2.1.3. Distribution/sales

The final stage of a textile and apparel supply chain is distribution/sales, which involves moving the finished garment products

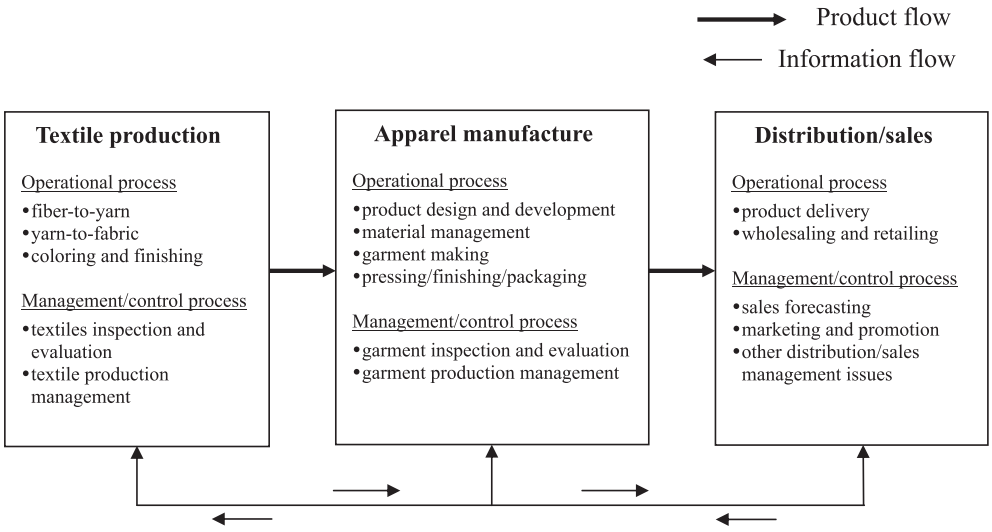


Fig. 1. Classification of textile and apparel supply chain research.

from the point of production to the point of consumption. The operational processes here are classified into 'product delivery' and 'wholesaling and retailing'. Product delivery is the physical process of sending a buyer's order through various channels to designated destinations and/or to retail stores at final, where the garments are displayed and purchased by final consumers. The major functional activities include product consolidation and mixing, transportation, dispatching, and delivery scheduling and routing. Wholesaling and retailing represent the various reselling processes along the distribution channel. Wholesaling involves activities related to the sale of merchandise/service to retailers and/or other resellers, while retailing to the ultimate consumers. The major functional activities include sourcing and purchasing the right merchandise, maintaining and controlling the inventory, providing services to customers, and approaching and developing client bases.

There are also some related management/control activities in this sector, like 'sales forecasting' which refers to making predictions based on past sales performance and analysis of expected market conditions; 'marketing and promotion' which involves such activities as devising sales strategies, promotion and advertising, and managing customer relationships; as well as 'other distribution/sales management issues' which includes the management of transactions, third-party collaboration, finance and accounting, product/service quality, and other general management issues.

2.2. Application of decision support and intelligent systems

There are a number of decision support and intelligent systems available to the market. In this study, we focus on the most common systems applicable to the operations and management of a textile and apparel supply chain.

2.2.1. Expert systems

Expert systems (ES) are computer-based systems which superficially provide information similar to that expected from a human expert (Turban & Aronson, 2001). The application of ES in the textile and apparel industry can help manufacturers reduce environmental costs by identifying the most appropriate processes and equipment (Metaxiotis, 2004), and devise more efficient and objective planning in their production (Ford & Rager, 1995). Moreover, in fashion retailing, a fashion mix-and-match ES can be developed to automatically provide customers with professional and systematic mix-and-match recommendations, so as to enhance customer satisfaction and, sequentially, to improve sales (Wong, Zeng, & Au, 2009b).

2.2.2. Genetic algorithms

Genetic algorithms (GA) are population-based evolutionary searching techniques. These algorithms use probabilistic search methods based on ideas drawn from natural genetic and evolutionary principles (Chamber, 1995). GA is particularly suitable in solving scheduling and machine layout problems encountered in the textile and apparel production (Chan, Hui, Yeung, & Ng, 1998; Hsu, Hsiung, Chen, & Wu, 2009; Lin, 2009; Min & Cheng, 2006; Wong, Chan, & Ip, 2000; Wong, Kwong, Mok, Ip, & Chan, 2005; Wong, Mok, & Leung, 2006). Particularly, GA can be applied to control fabric loss arising from the variance of yardage found in individual fabric rolls during the spreading process (Hui, Chan, Yeung, & Ng, 2007). In fashion design, GA is able to deal with the continuous changes of fashion and to reflect personal tastes using human response as a fitness value (Kim & Cho, 2000). Also, GA can be applied to product design in providing multi-solutions for design problems and in determining design schema (Lin, 2003). Furthermore, GA is useful for product packing optimization as well as product assortment management (Leung, Wong, & Mok, 2008).

2.2.3. Artificial neural networks

Artificial neural networks (ANN) are computational models based on the structure and function of biological neural networks (Liao, 2004). Rather than using traditional computer algorithms, ANN provides answers using heuristics that are similar to the human brain. Due to its robust and adoptive nature, ANN has been applied in textile and apparel chains in many ways. In the dyeing process, ANN can be modified to predict the duration required to achieve a precise depth of shade and to correct any errors related to inconsistent dyeing results (Senthilkumar, 2007; Senthilkumar & Selvakumar, 2006). In determining textile quality, ANN can help eliminate human subjectivity because human judgment is influenced by eyesight, concentration, and personal preference (Hui, Lau, Ng, & Chan, 2004; Wong, Li, Yeung, & Lee, 2003). In retail processes, ANN can be used to investigate the correlation between the level of sales and other significant factors, such as design elements, that may affect market demand; and, in turn, to forecast sales performance in a more accurate way (Sun, Choi, Au, & Yu, 2008). This approach is particularly prominent in fashion retailing because a

versatile sales forecasting system is a crucial requirement in meeting complex and fickle market demand (Thomassey & Happiette, 2007).

2.2.4. Knowledge-based systems

Knowledge-based systems (KBS) are rule-based systems (Mahapatra, 1997) that incorporate a database of expert knowledge with couplings and linkages designed to assist information retrieval in response to specific queries and to make quick and effective decisions (Laudon & Laudon, 2002; Wiig, 1994). In a textile and apparel supply chain, KBS can diagnose manufacturing problems, such as those related to cotton dyeing (Hussain, Wardman, & Shamey, 2005a; Hussain, Wardman, & Shamey, 2005b). Moreover, this approach is helpful in solving management issues such as subcontracting, throughout various stages of a supply chain (Narayanan, Olson, & Jayaraman, 1994).

2.2.5. Decision support systems

Decision support systems (DSS) are computer-based systems intended to help decision makers utilize data and models to identify and solve problems (Rauscher, 1999); practically to automate a variety of tasks and to facilitate optimal decision-making within a given supply chain. At the decision support level, DSS can be applied to the design and control of an integrated maintenance management system for a textile mill (Tu & Yeung, 1997). Also, DSS can assist decision-makers of a garment manufacturer in selecting efficient ways to reduce total manufacturing costs; such as to control the cost of materials by developing feasible cutting order plans with respect to materials, machines, and labor (Wong & Leung, 2008).

2.2.6. Fuzzy-logic systems

Fuzzy-logic is a form of multi-valued logic that uses the mathematical theory of fuzzy sets to deal with reasoning that is approximate rather than accurate (Liao, 2004). It is sometimes, though not exclusively, implemented using ANN. Fuzzy-logic can provide solutions to problems that involve the need to deal with approximations, uncertainty, and insufficient information (Kablan, 2009). In the fiber-to-yarn process, fuzzy-logic systems can predict the spinnability of a yarn based on fiber quality and machine settings (Sette, Boullart, & Van Langenhove, 2000). These systems can also evaluate the mechanical and physical properties of knitted fabrics of various structures (i.e., knitting, tucking, and welting) based on individual knitting actions and tightness factors, so as to provide an alternative method to compare the results of various hand tests (Park & Hwang, 1999). In the design of garment patterns, fuzzy-logic systems can help to improve a wearer's perception of the fit of a garment and to achieve a balance between the style of garments and the comfort of the wearer (Chen et al., 2009). Such a balance is difficult to achieve using existing pattern generation methods because these methods cannot provide suitable estimations.

2.2.7. Hybrid systems

Hybrid systems are those which employ a combination of multiple approaches and techniques from artificial intelligence. In this study, we define hybrid systems as those systems that combine any two or more of the above-mentioned decision support and intelligent systems. Through the combination use of these AI technologies, the performance and benefits of the resulting systems can be strengthened and maximized. Thus, a growing number of applications of hybrid approaches are found in various areas in the textile and apparel industry. For example, hybrid systems were used to improve the forecasting systems of a distribution network (Thomassey, Happiette, & Castelain, 2005a; Thomassey, Happiette, & Castelain, 2005b), to help textile and apparel manufacturers achieve higher accuracy rates when evaluating their products (Wong, Li, & Yeung, 2004; Yuen et al., 2009), to monitor the performance of a textile product (Sette & Boullart, 1996), to integrate and control major textile processes effectively (Kim & Vachtsevanos, 2000), to provide 'fashion coordination' recommendations for fashion retailers (Wong, Yuen, Fan, Chan, & Fung, 2009a), and to assist a manufacturer in the selection of a suitable enterprise resource planning (ERP) system (Cebeci, 2009).

3. Research methodology

To identify articles in the extant literature that are relevant to our study, we adopted a framework developed by Ngai, Xiu, and Chau (2009) for selection criteria and evaluation process. As shown in Fig. 2, this framework includes four phases: (1) online database search, (2) initial classification by the first researcher, (3) independent verification of the classification results by a second researcher, and (4) final verification of results by a third researcher.

Initially, we selected five dominant online databases (i.e., ABI/INFORM, Academic search Premier, Emerald Fulltext, Science Direct, and IEEE/IEE Electronic Library), and confined the review to the extant literature exclusively found in journal articles referenced by these databases. This is because peer-reviewed journals are the most common forum in which researchers publish the findings of their work. We excluded conference papers, theses, dissertations, newspapers, textbooks, and unpublished papers; if these have relevant and efficacious content, they are likely to be a precursor to a subsequent journal publication.

Using keywords to direct the search, we selected those articles only related to the applications of decision support and intelligent systems in the textile and apparel industry; we filtered the articles by using the keywords 'yarn', 'textiles', 'apparel' and 'distribution and sales'. The systems included in the search were ES, GA, ANN, KBS, DSS, and fuzzy-logic systems. Overall, 77 journal articles were obtained from 35 journals. The sample was limited to 15 years, spanning from 1994 to 2009. In this way, the review focused on the core of academic research activity and, as such, is arguably a valuable indicator of state-of-the-art research relevant to current industry features and priorities.

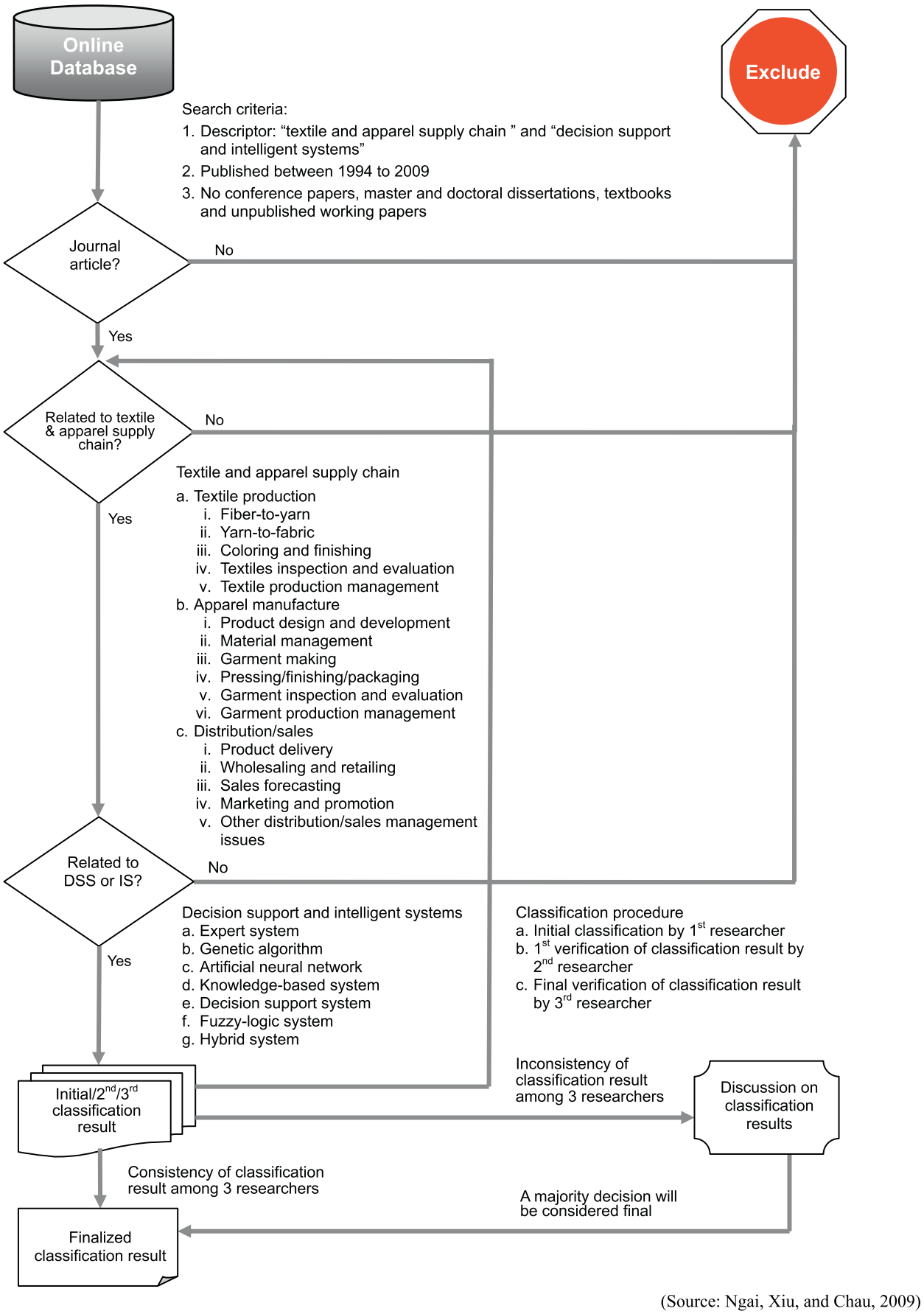
To develop a classification framework, each article was reviewed and analyzed in detail by three independent researchers to reduce bias. Specifically, each reviewer provided his/her views on: (1) the stage of the textile and apparel chain specified in each paper; (2) the decision support and intelligent systems adopted; (3) the objectives of each paper; and (4) the main contributions to the understanding of the role of IT in the management of a supply chain. Further, each article was classified according to the year of publication and type of journal.

4. Analysis and findings

According to our proposed framework, we classified the identified articles in terms of the application areas in various stages of a textile and apparel supply chain, the adoption of decision support and intelligent systems to each specific area, the year of publication, and the type of journal. Table 1 presents the detailed distribution of the 77 articles.

4.1. Distribution by application area

As shown in Table 2, the total number of articles in the three basic sectors of 'textile production', 'apparel manufacture', and 'distribution/sales' are 37, 29, and 11, respectively. Out of them all, the subsectors of 'fiber-to-yarn' and 'garment production management' receive the greatest attention from the researchers, with 11 (14.28%) and 10 articles (12.98%), respectively. For 'fiber-to-yarn',



(Source: Ngai, Xiu, and Chau, 2009)

Fig. 2. Framework of selection criteria and evaluation process.

Table 1
Classification of the reviewed literature.

Stages in a supply chain	Processes		Applied AI systems	References
Textile production	Operational process	Fiber-to-yarn	Genetic algorithm	Sette and Boullart (2000)
			Artificial neural network	Wu, Fang, Nuttle, Wilson, and King (1995b), Majumdar & Majumdar (2004), Üreyen and Gürkan (2008a), Üreyen and Gürkan (2008b), Yin and Yu (2007)
			Fuzzy-logic system	Sette et al. (2000)
			Hybrid system	Majumdar, Majumdar, and Sarkar (2005), Sette, Boullart, and Van Langenhove (1996), Huang and Tang (2006), Dayik (2009)
		Yarn-to-fabric	Artificial neural network	Çay, Vassiliadis, Rangoussi, and Tarakçıoğlu (2007), Lin (2007), Stylios and Powell (2003), Faur-brasquer and Le Cloirec (2003), Brasquet and Le Cloirec (2000)
			Hybrid system	Ucar and Ertugrul (2002)
		Coloring and finishing	Artificial neural network	Senthilkumar and Selvakumar (2006), Senthilkumar (2007), Timofei, Kurunczi, Suzuki, Fabian, and Muresan (1997)
			Knowledge-based system	Hussain et al. (2005a), Hussain et al. (2005b)
	Management/control process	Textiles inspection and evaluation	Genetic algorithm	Durand, Devos, Ruckebusch, and Huvenne (2007)
			Artificial neural network	Kuo et al. (2003), Sette and Boullart (1996), Kumar (2003), Park, Hwang, Kang, and Yeo (2001), Hui et al. (2004)
			Fuzzy-logic system	Park and Hwang (1999)
			Hybrid system	Park, Hwang, Kang, and Yeo (2000)
		Textile production management	Expert system	Ford and Rager (1995), Metaxiotis (2004)
			Genetic algorithm	Min and Cheng (2006), Hsu et al. (2009)
			Decision support system	Tu and Yeung (1997)
			Hybrid system	Cebeci (2009), Kim and Vachtsevanos (2000)
Apparel manufacture	Operational process	Product design and development	Expert system	Yang, Zhang, and Shan (2007)
			Genetic algorithm	Kim and Cho (2000), Lin (2003)
			Artificial neural network	Wong et al. (2003)
			Fuzzy-logic system	Lau, Hui, Ng, and Chan (2006), Wang, Li, and Wong (2005); Chen et al. (2009)
			Hybrid system	Luo, Hou, Li, and Wang (2007); Wong et al. (2004)
		Material management	Artificial neural network	Gong and Chen (1999)
		Garment making	Genetic algorithm	Anand, McCord, Sharma, and Balachander (1999), Hui, Ng, and Chan (2000), Wong et al. (2000), Yeung and Tang (2003)
			Artificial neural network	Hui et al. (2007), Bahlmann, Heidemann, and Ritter (1999)
			Hybrid system	Zoumponos and Aspragathos (2008)
		Pressing/finishing/packaging	Nil	Nil
	Management/control process	Garment inspection and evaluation	Artificial neural network	Wong et al. (2009a)
			Hybrid	Yuen et al. (2009)
		Garment production management	Genetic algorithm	Lin (2009), Chan et al. (1998), Wong et al. (2006), Wong et al. (2005)
			Knowledge-based system	Narayanan et al. (1994)
			Decision support system	Wong and Leung (2008)
			Hybrid system	Pan, Leung, Moon, and Yeung (2009), Mok, Kwong, and Wong (2007), Kwong, Mok, and Wong (2006), Wong, Kwong, Mok, and Ip (2006)
Distribution/sales	Operational process	Product delivery	Genetic algorithm	Leung et al. (2008)
		Wholesaling and retailing	Expert system	Wong et al. (2009b)
			Artificial neural network	Wu et al. (1995a), Wu, Yang, and Wei (2004)
			Hybrid	Wong, Zeng, Au, Mok, and Leung (2009c)
	Management/control process	Sales forecasting	Artificial neural network	Au, Choi, and Yu (2008), Sun et al. (2008), Thomassey and Happiette (2007), Frank, Garg, Sztandera, and Raheja (2003)
			Hybrid system	Thomassey, Happiette, and Castelain (2005a), Thomassey, Happiette, and Castelain (2005b)
		Marketing and promotion	Nil	Nil
		Other distribution/sales management issues	Nil	Nil

Table 2
Detailed distribution by decision support and intelligent systems.

Stages in a supply chain	Decision support and intelligent systems							
	Expert system	Genetic algorithm	Artificial neural network	Knowledge- based system	Decision support system	Fuzzy-logic system	Hybrid	Total
Textile production	**2**	**4**	**18**	**2**	**1**	**2**	**8**	**37**
Fiber-to-yarn		1	5			1	4	11
Yarn-to-fabric			5				1	6
Coloring and finishing			3	2				5
Textile inspection and evaluation		1	5			1	1	8
Textile production management	2	2			1		2	7
Apparel manufacture	**1**	**10**	**5**	**1**	**1**	**3**	**8**	**29**
Product design and development	1	2	1			3	2	9
Material management			1					1
Garment making		4	2				1	7
Pressing/finishing/ packaging								0
Garment inspection and evaluation			1				1	2
Garment production management		4		1	1		4	10
Distribution/sales	**1**	**1**	**6**				**3**	**11**
Product delivery		1						1
Wholesaling and retailing	1		2				1	4
Sales forecast			4				2	6
Marketing and promotion								0
Other distribution/sales management issues								0
Total	4	15	29	3	2	5	19	77

most research focused on predicting the properties of the fiber or yarn. This is understandable as the quality of raw textile materials determines the quality, and thus the value, of a final apparel product, and therefore becomes a key concern in the industry. For 'garment production management', attention was particularly put on line balancing, production scheduling, and certain production operations. This is probably because cost, time, and quality of producing a garment are the essential cost factors of a garment. The adoption of the decision support and intelligent systems in these areas can help to better and more easily handle and control such complex and costly production processes. Conversely, some other subsectors receive less attention, particularly those of 'pressing, finishing, and packaging', 'marketing and promotion', 'product delivery' and 'material management', which have no, or just a few, research articles published in the journals in the selected database.

4.2. Distribution by system type

Fig. 3 presents the distribution of articles by system types. It can be seen that ANN is the most commonly used single system, being mentioned in 29 out of the 77 selected articles (i.e., 37.66% of all), while the second is GA (15, 19.48%). ANN systems are employed at various stages in almost all processes along the entire textile and apparel supply chain, particularly related to the subsectors of 'fiber-to-yarn', 'yarn-to-fabric', and 'textile inspection and evaluation', each comprising 6.49%, (i.e., five out of 77) of all the selected articles. Meanwhile, articles that use GA to address issues related mainly in apparel manufacture, particularly in the subsectors of 'garment making' and 'garment production management', each of which takes up 5.19% (four out of 77). Another noticeable finding is that the adoption of the hybrid approach is also very common (i.e., 24.67%, or 19 out of 77), indicating that combining various AI technologies to solve a single, or a few, specific problems is widely adopted.

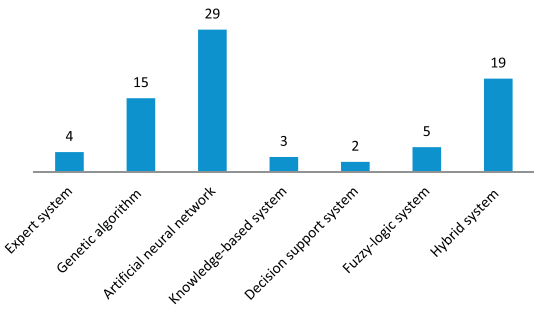


Fig. 3. Distribution by decision support and intelligent systems.

4.3. Distribution by year of publication

Fig. 4 shows the distribution of the published articles across the study period; that is, 1994–2009. The average number of papers published in each year is around 5.2. Overall, it can be seen that at least one paper was published each year with the highest rate of 8, 8, 10, and 10, in the years 2000, 2003, 2007, and 2009, respectively. As a whole, the number of publications that consider using decision support and intelligent systems in textile and apparel supply chains shows an upward trend over time during the period studied. This indicates that the benefits of using these systems to enhance the efficiency of the industry is becoming well known and has attracted increasing attention from both the industry and academics. We anticipate that this uprising trend will continue in the forthcoming future as more new AI technologies emerge, and the pressure to improve the performance of supply chain management rises.

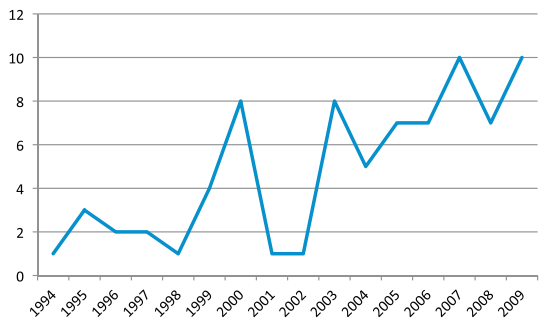


Fig. 4. Distribution of articles by year.

Table 3
Journals on decision support and intelligent systems in textile and apparel supply chain.

Journals	Number of articles
1. Textile Research Journal	12
2. International Journal of Clothing Science and Technology	10
3. Expert Systems with Applications	9
4. Engineering Applications of Artificial Intelligence	4
5. Dyes and Pigments	3
6. International Journal of Production Economics	3
7. The International Journal of Advanced Manufacturing Technology	3
8. Computers in Industry	2
9. European Journal of Operational Research	2
10. Fibers and Polymers	2
11. Pattern Recognition	2
12. Robotics and Computer-Integrated Manufacturing	2
13. Analytica Chimica Acta	1
14. Applied Mathematics and Computation	1
15. Applied Soft Computing	1
16. Chemical Engineering and Processing	1
17. Chemical Engineering Science	1
18. Coloration Technology	1
19. Computers & Industrial Engineering	1
20. Computers & Mathematics with Applications	1
21. Computers & Structures	1
22. Decision Support Systems	1
23. Elsevier Ergonomics Book Series	1
24. IEEE Transactions on Industrial Electronics	1
25. Information Management & Computer Security	1
26. Information Sciences	1
27. International Journal of Operations and Quantitative Management	1
28. International Journal of Production Research	1
29. International Transactions in Operational Research	1
30. Journal of Applied Polymer Science	1
31. Journal of Intelligent Manufacturing	1
32. Journal of Manufacturing Systems	1
33. Journal of Materials Processing Technology	1
34. Journal of the Chinese Institute of Industrial Engineers	1
35. Journal of the Textile Institute	1

4.4. Distribution by journal

As noted, a total of 35 different journals from different disciplines were included in this literature review. Table 3 lists all these journals and shows the distribution of articles published in each journal. Out of these, *Textile Research Journal* is the greatest source of articles, sharing 15.58% (12 out of 77); while the second and third largest sources are *International Journal of Clothing Science and Technology* and *Expert Systems with Applications*, with 12.99% (10) and 11.69% (9) respectively. *Textile Research Journal* is a monthly publication that provides information on fundamental and applied research in the textile-related physical, chemical, and engineering sciences. The *International Journal of Clothing Science and Technology* is the only journal solely dedicated to the science and technology of clothing. This journal addresses all aspects of the science and technology of clothing in terms of objective measurement techniques, control of fiber and fabric, computer-aided design systems, product testing and sewing, and so on. *Expert Systems with Applications* is a refereed international journal that focuses on information related to expert and intelligent systems applied in industries, governments, and universities worldwide.

5. Discussion and implications

In light of the proposed classification framework, the distribution of the applications of the decision support and intelligent systems in the textile and apparel supply chain identifies a number of gaps in the extant literature, which in turn provide a basis for suggesting research agenda in the subject area.

5.1. Gaps and implications

A considerable number of articles in this study focus on the application of the decision support and intelligent systems in the subsectors of 'fiber-to-yarn', 'garment production management', 'product design and development', 'textile inspection and evaluation', and 'garment making'. Comparatively, the other subsectors, such as 'pressing, finishing, and packaging', 'marketing and promotion', 'product delivery, and 'material management' have attracted less attention. Nonetheless, these operations are equally important to the success of a textile and apparel supply chain. The exploitation of using AI technologies may be helpful in improving the performance of these areas and, in turn, benefitting all sectors along the supply chain.

Moreover, most of the applications of the decision support and intelligent systems are confined to certain individual function areas. As AI technologies can offer advantages in managing information flow, which is an important factor in enhancing supply-chain integration, greater use of these technologies will make it easier to handle communication and share relevant information among all members, making a true integrated supply chain possible. In this way, competitive advantages can be created for the entire supply chain, instead of focused on individual subsectors, with suboptimal aggregated performance.

The research also reveals that the application of the decision and intelligent systems in the textile and apparel industry is not well-balanced. Probably due to the adaptive characteristics and the ability to capture non-linear and complex input–output relationships (Kosko, 1994), a large portion of the articles reviewed in this study is related to the adoption of ANN (i.e., 37.66%). Likewise, the adoption of GA system is also common in textile-related research activities (19.48%), as GA is particularly useful in solving optimization problems (Imai, Shintani, & Papadimitriou, 2009). However, the other systems, such as DSS and KBS, receive less attention, only 2 (2.5% of all) and 3 (3.8% of all) articles were mentioned respectively; despite the fact that, based on their characteristics, these two types of technologies could be particularly suitable for retailer operations and customer relationship management. Although fewer identified articles are related to this area, this number does not imply that the application of DSS and intelligent systems in this line of research is less mature than elsewhere. Both industrial and academic researchers should therefore consider these technologies too.

Results of this study also indicate that many researchers published their research work in a few focused journals such as *Textile Research Journal*, *International Journal of Clothing Science and Technology* and *Expert Systems with Applications*. For the other journals, each held four or fewer articles. Nonetheless, most of these journals are respected by academics, and therefore should also be considered as potential publication venues by researcher in this subject area.

5.2. Potential research areas

Based on the projection of future needs from current industry trends and on the gaps apparent in the extant literature, we have identified some potential areas for further research in the application of AI-related systems in textile and apparel supply chains.

The first focused area relates to new trends in information integration associated with the technologies examined. These can help to improve business performance (Weber & Pliskin, 1996) and build partnerships with supply chain members (Grover & Saeed, 2007). In the textile and apparel industry, system integration –

which includes the integration of ERP, electronic data interchange, radio frequency identification (RFID), and other application software – can be applied to manufacturing processes, product design, and/or quality management. To help improve the overall performance of textile and apparel supply chains, researchers should examine the use of these new technical solutions.

The second potential area for future research is the inclusion of emerging mobile technologies, such as RFID and wireless sensor network technologies as well as cloud computing. These technologies will provide new opportunities for the application and extension of decision support and intelligent systems in the textile and apparel industry. Moreover, recent technological advancements, such as the smartphone, mobile tablet, and other mobile technologies, are becoming increasingly popular among consumers. Accordingly, it is reasonable to conclude that industry users may consider using these devices to enhance their working efficiency and effectiveness, particularly in areas of quality control, such as fabric defect detection, goods inspection, and the evaluation of finished products, among other applications. However, we also perceive that this development may be hindered by many technical, personal, and operational issues, such as data security, network connectivity, job stress and anxiety, and costs. When implementing these new technologies, valuable research activity can be applied to both sides of this area.

Another potential research area relevant to the textile and apparel supply chain is the use of electronic commerce (EC). Given the growing interest in EC (Ngai & Wat, 2002), connections among supply-chain partners are becoming more common than before, as information can be transferred more efficiently among them. Considering the short product life cycles and the need for a rapid response in the industry, related decision support and intelligent systems should be developed to support EC for the purposes of communication, collaboration, and coordination of supply-chain activities.

Traceability and visibility are two focus areas in supply chain management, both of which can be enhanced by RFID technology. RFID technology has existed for many years but has only recently begun to be used in the textile and apparel industry. Given that the cost of RFID implementation is now decreasing, RFID systems can be used in various different stages and processes throughout the supply chain; for example, they can be used to trace and monitor progress during the weaving and coloring processes (Ngai et al., 2010). Surprisingly, neither of these two areas has made much use of RFID or other intelligent systems in the past. Moreover, RFID technology can help companies to transport goods more effectively and efficiently.

Last but not least, researchers should also seek to use AI technologies to enhance their efforts to 'go green'. In terms of sustainable development and environmental concerns, the textile and apparel industry is now exploring the green path (Moon & Lai, 2012; Yeung & Yeung, 2011). The supply chain can be made more energy-efficient by using more renewable energy sources, such as solar energy and recycled materials in addition to reducing water usage and carbon emissions, among others. There is a need for an energy and utility decision-support system that can systematically collect energy and utility information from applications involved in textile or apparel manufacturing processes (Ngai et al., 2012). Decision support and intelligent systems are necessary elements in achieving environmental goals in this aspect and should be applied in the support of eco-friendly practices.

6. Conclusion

The application of AI technologies continues to attract the attention of academic researchers and industrial practitioners. This paper presents a review of 77 significant scholarly articles published in 35 academic journals in five online databases from 1994 to 2009 that relate to the applications of decision support and intelligent systems in the textile and apparel supply chains.

Using a categorizing process of journal articles, this literature review shows that technology trends are developing and/or evolving rapidly. The use of the decision support and intelligent technologies in the textile and apparel supply chains is thus growing. By analyzing the extant research with actual paper output, research gaps are shown, particularly in the areas of RFID, mobile computing, EC decision-making technologies and sustainability development. Such gaps, we contend, increase the risk of hindering research-directed development of the industry as a whole. Our recommendations in this study hence denote excellent opportunities for researchers wishing to make valuable academic and practical contributions to this subject area.

Despite these significant contributions, this study has some limitations. First, the findings are based on data from academic journals only. Some other trade/commercial journals/magazines may have interests in this area too. Second, the article search was limited to five databases, although others might also have covered the topic area. The third potential limitation is the time span. We limited the study to a 15-year period because we considered major journals' recent coverage to be appropriate to this analysis; nonetheless, such a short time span may not cover all related research. Last, publications in languages other than English were excluded. Research on the application of decision support and intelligent systems in textile and apparel supply chains can also be found in other languages.

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