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Health Care Supply Chain Research: Where Are We Going?

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ABSTRACT

Led by the Obama administration, health-care laws, regulations, and policies have recently undergone dramatic changes with the hopes of improving universal access to quality health care. Such changes, however, pose unprecedented challenges of controlling ever-rising health care costs, while sustaining the high level of health care services. To cope with these challenges, the health-care community and policy makers have long sought innovative solutions that can allow them to streamline health care practices and enhance productivity to the full potential. Though often overlooked in the past, an innovative solution that was increasingly put forward by many managerial experts is the adaptation of supply chain principles for health care that are designed to reduce wasteful spending, strengthen connectivity among health care partners, and increase visibility of needed care and resources. In an effort to help health care professionals add value to their systems, this paper traces the evolution of health care supply chain research, synthesizes the past and current research efforts to develop viable health care solutions and then proposes promising future research themes that can fine-tune these solutions.

KEYWORDS health care · supply chain management · research synthesis · trend analysis

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1. INTRODUCTION

As of 2012, an American spends the average of \$8,233 a year for health care services as compared to the OECD average of \$3,268 [46]. In 2010, healthcare expenditures in the United States (U.S.) reached

nearly \$2.6 trillion a year which accounted for 17.6% of the national GDP [23, 46]. Four years later in 2014, U.S. health care spending increased 5.3% following growth of 2.9% in 2013 to reach \$3 trillion, or \$9,523 per person. The faster growth experienced in 2014 was primarily due to the major coverage expansions under the Affordable Care Act, particularly for Medicaid and private health insurance [11]. The US health care expenditures are expected to reach nearly 20% of GDP, or approximately \$4.3 trillion, by 2020 [24]. In fact, health care expenditures in the U.S. are the highest of any developed country. The country with the next highest health care spending is Switzerland, at 11.4% of GDP [45]. To make it worse, health care spending in the U.S. shows no sign of abatement as evidenced by the fact that health care spending per person has grown faster than the nation's economic output per person by about 1.5 percentage points per year, on average, for the past few decades [14]. Under current laws, U.S. federal health care spending is on pace to exceed all discretionary spending including defense, education and training expenditures by 2016 [21]. Despite a growing concern over skyrocketing health care expenditures, the U.S. did not spend its health care capital efficiently. It was reported that an estimated one-third of health care expenditures in the U.S. did not improve health care services [22]. To minimize this wasteful spending, both the business community and the government sector should first identify the main sources of health care inefficiency and then sought innovative ways to improve productivity. One of the major culprits for health care waste includes the health care industry's reliance on the archaic and dysfunctional supply chain system that contributed to redundant distribution channels, excessive/obsolete inventory, and limited access of essential medical supplies and pharmaceutical products [40].

For example, according to the UPS Pain in the Healthcare Supply Chain Survey [64], the surveyed healthcare companies identified managing and containing supply chain costs as their number one concern, with 60% of the respondents reporting that they were very or extremely concerned about rising

supply chain costs in the health care industry. Similarly, the survey conducted by KPMG Healthcare and Pharmaceuticals [34] reported that a vast majority (97%) of the surveyed executives in the pharmaceutical, biotech, and medical device industries listed supply chain costs as their biggest concern. As such, the health care supply chain is in urgent need of a sweeping transformation that can lead to a greater efficiency and the subsequent cost savings in increasingly complex and regulated environments. Recognizing the need for such transformation, a growing number of health-care organizations have begun to take supply chain initiatives as their strategic weapons. Following this health care industry trend, the interest of academia on health care supply chains has also begun to increase substantially in the last decade. This growing interest sparked a series of new lines of research dealing with various supply chain activities that have important managerial implications. Though the supply chain terminology and concepts are relatively new, there exist the extensive body of literature on health care supply chain related topics including emergency vehicle deployment and health care facility location for the last several decades. With the emergence of health care supply chain research, there are ample opportunities for further related studies and scientific investigations. To identify these opportunities while avoiding the duplications of past research efforts, the main objectives of this paper are to: (1) classify the past literature on health care supply chain management (HSCM) through the structured taxonomy; (2) develop a frame of references; (3) chronicle the evolution of the HSCM research for the last 30 years; (4) identify the emerging trends of HSCM research; (5) and point the direction of future research.

2. RESEARCH FRAMEWORK

Despite the lack of attention paid to HSCM research, its root can be traced to the 50's and 60's long before the introduction and popularity of supply chain management principles. For instance, Morrill and Earickson [43] developed a theoretical model that could determine the size and location of Chicago hospitals based on the demography, travel time, and residence characteristics (e.g., income) of the neighboring population. Similarly, taken from central place theory, Schultz [54] proposed a mathematical model which could optimize social benefits of medical centers in the metropolitan area by increasing their accessibility to local residents. Following suit, a number of scholars such as Toregas et al. [62] and Calvo and Marks [7] developed various forms of mathematical models (including a location set covering model launched in the 60s) that aimed to determine the optimal size and locations of health care facilities including emergency care facilities. Given this rich history of the HSCM literature, it is

important for us to examine, evaluate, and integrate prior studies related to the topic of HSCM. Without the effort to synthesize prior HSCM research, we may end up duplicating what has already been studied, fail to develop a new theory built upon the previous efforts of others, and experience difficulty in identifying emerging research agenda that were often overlooked in the past. This effort begins with the retrieval of past research works on HSCM through the on-line literature search, a summary of research outcomes, critiques of prior research works, identification of key research themes and popular research streams, and integration of past research efforts. To elaborate, we first defined HSCM in the broadest possible sense so that we could conduct thorough literature searches and determine how HSCM literature was evolved from the theoretical underpinnings of other related social science, medical science, economics, business and engineering fields. To demystify the HSCM terminology, we would like to define HSCM as an incorporation of value imperatives into every aspect of health care supply chain activities encompassing sourcing, product design and development, manufacturing, location, transportation, packaging, storage, retrieval, disposal, and follow-up health care services [40]. Herein, the examples of value imperatives include a greater access to health care providers (e.g., hospitals, medical clinics, home care centers, outpatient care facilities, nursing homes), efficient distribution of pharmaceuticals, medical supplies, and medical equipment, quick (or emergency) response logistics, group purchasing for volume discounts, new product development and promotion, product (e.g., drug) recalls, compliance with health care regulations (e.g., Affordable Care Act, The Patient Safety and Quality Improvement Act of 2005, Rule on Hospital Inpatient Value-Based Purchasing) and standards (e.g., ISO 9000 standards, OSHA standards), product labeling (regarding contents and side effects), safer (child-resistant) packaging, and disintermediation of health care products (e.g., shipping drugs directly from pharmaceutical manufacturers to health care providers). To systematically locate past research works relevant to the above definition of HSCM, we utilized several literature search methods specified below.

2.1. Literature Search Media

Prior to locating past research works relevant to HSCM, we need to choose the target populations that will be the references of this literature review. Our target populations are primarily articles published in refereed scholarly journals that fit into the definition of HSCM made earlier. Excluded are parts of the book chapters, book reviews, dissertations/theses, working papers, white papers, and proceeding papers presented in the academic conferences. We also excluded published articles that dealt with generic health care issues but had no direct bearing on supply chain management. The thorough review of those

articles (especially planning and scheduling of healthcare services) can be found in Dobrzykowski et al. [16]. In other words, our literature review primarily focuses on the prior studies addressing health care issues associated with the managerial activities of sourcing, making, and delivering. To avoid the reference biases, the primary means to find the target publications includes a variety of reference retrieval sources: on-line keyword searches through Google, Google Scholar, Thomson Reuter Web of Science, SciVerse Scopus, EBSCO Host Basic Search, and Dow Jones Factiva; the educational database search via the Academic Source Complete (ASC) and Electronic Journal Center (EJC) of Ohio Link, University Summon Library; EBSCO Business Source Complete database; keyword searches through the ABI/INFORM Research™ database and the Procite© database in which the past literature has been classified according to content- and methodology-oriented criteria; the perusal of tables of contents of the key academic journals (e.g., Journal of Business Logistics, International Journal of Physical Distribution and Logistics Management, International Journal of Logistics: Research and Applications, International Journal of Logistics Management, International Journal of Logistics Systems and Management, Journal of Operations Management, International Journal of Production Research, International Journal of Production Economics, International Journal of Operations and Production Management, Journal of Supply Chain Management, Supply Chain Management: An International Journal, and Logistics Research) in the fields of supply chain management; and tracking articles listed in the reference sections of widely cited HSCM articles. It should be noted that although prior studies [e.g., 9, 19, 50] examining the supply chain trends primarily reviewed three oldest and high profile supply chain journals such as Journal of Business Logistics, International Journal of Physical Distribution, and Supply Chain Management: An International Journal, we decided to add newer but emerging supply chain journals to capture a new schools of thoughts and more diverse research focuses. Examples of keywords that we used include: “health care supply chains”, “medical supply chains”, “hospital supply chains”, “drug/pharmaceutical supply chains”, “health care logistics”, “health care/medical facility planning”, “medical supply”, “emergency vehicle routing and scheduling”, and “ambulance deployment.” Due to the sheer size of the initial search results – For instance, ASC alone produced more than 400 entries, we perused the abstracts of only the published articles to see if they contained any keywords related to supply chain management and then screened them one by one. To delimit the number of publications, we excluded articles that did not incorporate health care initiatives into any aspect of supply chain management (i.e., sourcing, making, and delivering)

or the ones that failed to address health care issues from a supply chain perspective. For example, publications that discussed health care policy, health care regulations and standards, health care service quality, health care human resources (including hospital staff or surgery/treatment scheduling) or public health but had no direct ties to sourcing, making, and delivering activities were omitted from the list. In other words, content analysis was performed to examine any relationships between the concept of health care management and that of supply chain management in the context of the published article. Since the term ‘supply chain management’ was rarely used prior to 1980s, we primarily focused on articles published in 1980’s and later. The complete literature search through the multiple media specified above yielded a total of 246 articles considered relevant to HSCM categories as of June 15, 2016.

2.2. The Taxonomy of the HSCM Literature

To provide an organized look at the published literature and review it in a systematic fashion, we develop the taxonomy of the HSCM literature. This taxonomy will help the researcher identify hot/emerging research fields of HSCM, neglected areas of research, and overall research trends. In terms of the subject areas of research, this study classified the published HSCM articles into seven areas of applications. These seven categories are developed by taking into account a sufficient number of published articles (at least a total of 11 hits) in each cluster of categories and the typical breakdown of key supply chain activities (sourcing, making, and delivering):

- Emergency planning which primarily deals with the process of preparing, planning, and coordinating an exceptional, unpredictable medical event that exceeds the capacity of normal resources and response time windows. Such an event can be exemplified by medical attention needed for a patient suffering from a sudden heart attack, gunshot wounds, personal injuries caused by the car/plane crash and terrorism, the infectious disease outbreak, and the natural disaster. Emergency planning often involves deployment of medical staff and dispatch of ambulances for a quick-response medical care (e.g., paramedic care).
- Process improvement which primarily aims at identifying an opportunity for continuous improvement by keeping non-value adding activities (e.g., duplicated purchases, overlapped diagnostics tests, excessive medical equipment and supplies, underutilized hospital beds, billing errors, insufficient blood supplies, inadequate public health planning) off the health-care supply chain. The common tools used for health care process improvement include: process mapping

(including value stream mapping), activity analysis, and performance benchmarking. Also, papers which investigated the bullwhip effect in the health care supply chain may belong to this category.

- Network design which deals with health-care logistics issues related to transportation, storage, and packaging of medical equipment, supplies, and pharmaceuticals. This category also includes papers dealing with health-care facility location-allocation problems which are concerned with the medical service coverage of potential patient bases in a given community (e.g., metropolitan areas, municipalities).
- Inventory control which assures the instant availability of needed medical supplies and drugs/pharmaceuticals, while determining the optimal level of inventories and/or developing inventory investment, replenishment and classification schemes. This application area includes cycle counting, vendor-managed inventory (VMI), and time-phased inventory planning such as material requirement planning (MRP).
- Purchasing which focuses on sourcing issues related with health care supplier-buyer relationship, group purchasing decisions, supplier evaluation/selection, and supplier development and certification.
- Information technology which configures information infrastructure and communication architecture needed for tracing, storing, and analyzing data related to patient medical records or clinical procedures and then transmitting such data to health care supply chain partners (e.g., medical clinics, hospitals, pharmacies). Also, articles that examined the use of radio frequency identification (RFID) in a hospital setting for patient and medical asset tracking may belong to this category.
- Security which pays attention to corporate social responsibility (CSR) related to health care or drug safety. In particular, with a growing concern over counterfeit, fake, or substandard drugs, this category of papers are often concerned with the secure, safe distribution of essential drugs and medical supplies.

In terms of the research methodologies the papers are categorized into the following areas:

- Conceptual: Those expository or tutorial studies which discuss the strategic importance of supply chain initiatives to health care management and summarize emerging trends and/or existing health care management concepts under a supply chain context based on qualitative or descriptive analyses. This category of research also includes the effort to define, describe, and develop methods for the management of health care supply chains without using quantitative methods [19].

- Case study: Those intensive studies primarily focused on the idiosyncratic nature of a single or several real-life examples that reflect the relevance/irrelevance of certain theories or prescriptions. Case studies as a research methodology explain, explore, or describe a phenomenon of interest. This requires a methodologically rigorous and accurate representation of actual data and multiple sources of evidence. Thus, the purposes, presentation of data, and methods for gathering data may differ among cases [17]. However, real-life contexts under special focus of the case study are not perfect representation of the population and thus can be questioned for generality and consistency [20].
- Exploratory: Those employing descriptive data analyses based on the questionnaire survey data which intend to identify the most prevalent health care practices and synthesize the common opinions of practitioners regarding health care supply chain initiatives. This type of methodology which often relies on the summary statistics is less concerned about theory building or theory refinement than making observations and inquiries about common supply chain practices in the health care sector (see, e.g., [44] for an application of an exploratory study to the logistics area).
- Empirical: Those based on a social science research tradition which aims to develop, advance, and refine theories through hypotheses testing by employing rigorous statistical data analyses such as a structural equation model or other forms of confirmatory data analysis including path analysis which helps find cause/effect relationships among a set of variables. This type of methodology is needed to test theory-driven hypotheses and then build theories in the HSCM literature (see, e.g., [53] for a methodological foundation of an empirical study).
- Analytic: Those employing quantitative tools such as integer programming, dynamic programming, goal programming, non-linear programming and other techniques such as simulation, systems dynamic modeling or soft systems methodologies (SSM) (see, e.g., [61]). Generally, an analytic method refers to the systematic way of solving health care managerial problems (e.g., emergency vehicle dispatch, health care facility location and layout) using computer technology, operations research, and statistics.

3. THE ANALYSIS OF PRIOR HSCM LITERATURE

The detailed analysis of prior HSCM literature can provide us with a glimpse of what was investigated,

observed, and discovered, which areas of concern are overlooked by past studies, how those studies are typically conducted, and where those studies are published. With this in mind, we summarize the detailed analysis of the past HSCM literature published for the last 30 years.

3.1. Key Publication Outlets

Based on this preliminary search, the academic journals in business, medicine, and in other related areas where HSCM issues are published were identified. Those are listed in Table 1. Although some specialty journals exclusively devoted to health care issues such as *Annals of Emergency Medicine*, *Air Medical Journal*, and *Resuscitation* made the top-ten list, many traditional supply chain journals such as *International Journal of Logistics Systems and Management*, *Supply Chain Management: An International Journal*, *International Journal of*

Services and Operations Management, and *International Journal of Physical Distribution and Logistics Management* round out the top-ten list. This fact implies that a supply chain discipline has been embraced by health care professionals as an important managerial tool, while health care service has emerged as one of the hottest topics in the supply chain field. On the other hand, there are a growing number of specialty journals exclusively dedicated to health care issues which cover HSCM issues as shown in Table 1. Examples of those journals include: *International Journal of Health Care Quality*; *American Journal of Health Care Quality*; *Journal of Pharmacy Practices*; *Journal of Emergency Medicine*; *American Journal of Health System Pharmacy*; *Health Care Management Science*; and *Operations Research for Health Care*.

Table 1. A List of Popular Publication Outlets for HSCM Research

Journal Name	Number of HSCM articles published	Popularity Ranking
International Journal of Logistics Systems and Management	13	1
Supply Chain Management: An International Journal	10	2
Annals of Emergency Medicine	9	3
International Journal of Services and Operations Management	9	3
Socio-Economic Planning Sciences	8	5
European Journal of Operational Research	7	6
International Journal of Physical Distribution and Logistics Management	5	7
Air Medical Journal	5	7
Computers and Operations Research	5	7
Resuscitation	5	7
Annals of Operations Research	4	11
Computers and Chemical Engineering	4	11
International Journal of Health Care Quality	4	11
International Journal of Production Economics	4	11
American Journal of Medical Quality	3	15
Decision sciences	3	15
International Journal of Logistics: Research and Applications	3	15
International Journal of Production Research	3	15
Journal of Operations Management	3	15
Journal of Pharmacy Practice	3	15
Journal of Emergency Medicine	3	15
Management Science	3	15
American Journal of Health System Pharmacy	2	23
AORN Journal	2	23
Benchmarking: An International Journal	2	23
Computers and Industrial Engineering	2	23

Health Care Management Science	2	23
Home Health Care Management and Practices	2	23
Industrial Engineering and Chemistry Research	2	23
Interfaces	2	23
International Journal of Logistics Management	2	23
International Journal of Operations and Production Management	2	23
International Journal of Pharmaceutical and Healthcare Marketing	2	23
International Journal of Productivity and Performance Management	2	23
Journal of Business Logistics	2	23
Journal of Global Business Issues	2	23
Journal of Rural Health	2	23
Logistics Information Management	2	23
Journal of Public Procurement	2	23
Journal of the Operational Research Society	2	23
Omega	2	23
Operations Research for Health Care	2	23
Pre-hospital Emergency Care	2	23
Transportation Research Part E	2	23
Transportation Science	2	23
Accident: analysis and prevention	1	46
American Journal of Business	1	46
American Journal of Public Health	1	46
BMC Emergency Medicine	1	46
Business Process Management Journal	1	46
Chemical Engineering and Research Design	1	46
Clinical Pharmacology and Therapeutics	1	46
Corporate Environmental Strategy	1	46
Decision Support Systems	1	46
Disaster Prevention and Management	1	46
Electronic Commerce Research	1	46
Emergency Medicine Journal	1	46
Emerging Infectious Disease	1	46
Engineering Applications of Artificial Intelligence	1	46
Health Affairs	1	46
Health Care Management Review	1	46
Health Management Technology	1	46
Health Care Financial Management	1	46
Health Service Management Research	1	46
Health Care Management Forum	1	46
IEEE Intelligent Systems	1	46
IEEE Transactions	1	46
International Journal of Electronic Business	1	46
International Journal of Electronic Health Care	1	46
International Journal of Health Geo-graphics	1	46
International Journal of Health Planning and Management	1	46
International Journal of Information Management	1	46
International Journal of Integrated Supply Management	1	46

International Journal of Management	1	46
International Journal of Operational Research	1	46
International Journal of Quality and Reliability Management	1	46
International Journal of Services and Standards	1	46
Journal of Business and Industrial Marketing	1	46
Journal of Consumer Marketing	1	46
Journal of Epidemiology and Community Health	1	46
Journal of Health Care Marketing	1	46
Journal of Health Management	1	46
Journal of Homeland Security and Emergency Management	1	46
Journal of Hospital Marketing and Public Relations	1	46
Journal of Public Health	1	46
Journal of Purchasing and Supply Management	1	46
Journal of Service Science and Management	1	46
Journal of Supply Chain Management	1	46
Management Research Review	1	46
Mathematical and Computer Modeling	1	46
Operations Research	1	46
Production Planning and Control	1	46
Review of Business Research	1	46
Supply Chain Forum	1	46
Supply Chain Management Review	1	46
The American Journal of Medicine	1	46
The Service Industry Journal	1	46
Thunderbird International Business Review	1	46

NOTE: Journal outlets (with the only one HSCM article) listed in this table are not exhaustive

After identifying key publication outlets, we examined which research methodologies have been primarily used and which application areas were most popular in those outlets. Given the diversity of these outlets, Tables 2 and 3 only summarized mainstream supply chain journal outlets which published at least five HSCM articles. These journals are International Journal of Logistics Systems and Management, Supply Chain Management: An International Journal, International Journal of Services and Operations Management, and International Journal of Physical Distribution and Logistics Management. Table 2 shows that two most popular research methods are case studies and analytic methods. However, it should be noted that HSCM articles published in both relatively new International Journal of Logistics Systems and Management and International Journal of Services and Operations

Management tilted toward analytic methods, whereas well-established, highly rated Supply Chain Management: An International Journal and International Journal of Physical Distribution and Logistics Management rarely published HSCM articles adopting analytic methods. This contrasting difference may have something to do with these journals' editorial policies and focuses. In terms of application areas, process improvement is the favorite theme of the HSCM articles published in these four supply chain journal outlets by accounting for 54% of HSCM publications in these journals, whereas emergency planning is the least popular application subject. Also, notice that network design did not receive much attention all but International Journal of Logistics Systems and Management. As such, academicians who would like to publish HSCM articles should consider their fits into one of these journals before submitting their HSCM articles to one of these journals.

Table 2. Research Methodologies in Selected Supply Chain Journal Outlets

Research Methods	International Journal of Logistics Systems and Management	Supply Chain Management: An International Journal	International Journal of Services and Operations Management	International Journal of Physical Distribution and Logistics Management	Total
Conceptual	1	3	1	0	5
Case Study	3	4	2	2	11
Analytic	6	0	4	1	11
Exploratory	1	3	0	2	6
Empirical	2	0	2	0	4

Table 3. Application Areas in Selected Supply Chain Journal Outlets

Application Areas	International Journal of Logistics Systems and Management	Supply Chain Management: An International Journal	International Journal of Services and Operations Management	International Journal of Physical Distribution and Logistics Management	Total
Emergency planning	0	0	1	1	2
Process improvement	8	4	6	2	20
Network design	3	0	0	0	3
Inventory Control	2	4	1	0	7
Purchasing	0	2	1	2	5

3.2. The Research Classification

According to the taxonomy developed earlier, the extant literature on HSCM was categorized with

respect to its focused research area and methodology as recapitulated in Table 4.

Table 4. The Breakdown by the Research Area and Methodology

	Conceptual	Case Study	Exploratory	Empirical	Analytic	Total
Emergency planning	22	10	18	0	29	79
Process improvement	19	15	6	9	14	63

Network design	1	2	0	0	36	39
Inventory control	3	4	2	1	8	18
Purchasing	7	3	5	0	1	16
Information technology (IT)	11	4	2	0	4	21
Security	8	1	0	1	0	10
Total	71	39	33	11	92	246

In terms of the research application area, emergency planning turns out to be the most popular theme with a total count of 79 papers (32%) out of 246 HSCM papers. In particular, studies dealing with emergency responsiveness involving paramedical assistance, ambulance location, deployment, and dispatch became a dominant subject in emergency planning. Built upon earlier pioneering studies conducted by Fitzsimmons [18] and Swoveland et al. [59], these articles are mainly concerned with the location, allocation and dispatch of ambulances to a medical emergency with a quick response. A subject of the process improvement is the second most popular theme with a total of 63 articles (26%). A good example of the HSCM studies focusing on process improvement includes Colletti [13] who proposed ways to eliminate non-value adding administrative and material delivery processes in the hospital supply chain through hospital-wide information sharing. Also, as a way to reduce non-value adding waste throughout the supply chain, Sethuraman and Tirupati [55] came up with cures for the chronic bullwhip effect resulting from fluctuating demand for surgery and nursing services at the hospital and the diagnostic laboratory. Their proposed cures include: a development of common data bases, alignment of incentives for data sharing, and forging strategic alliances with medical specialists which would improve the hospital's and the lab's operating efficiency and flexibility. Similarly, Samuel et al. [51] analyzed the bullwhip effect inherent in the hospital supply chain using a system dynamics simulation model and then mitigated the bullwhip effect by improving patient application and capacity planning processes. Recently, Weraikat et al. [69] focused their attention to the control of pharmaceutical waste by developing a nonlinear mathematical model which aimed to facilitate leftover pharmaceutical returns and

improve the sustainability for a real pharmaceutical reverse supply chain.

In terms of the research methodology, analytic studies representing the hard core of the traditional operations management paradigm (e.g., location planning, facility network design, treatment/surgery scheduling) or that of industrial engineering (e.g., queuing theory, simulation) takes up the overwhelming majority with a total count of 92 articles and the conceptual papers comprise the second largest with a total of 71 articles. Though perceived to be less rigorous than analytic or empirical studies due to its expository nature, conceptual papers seem to be almost on a par with analytic studies. The popularity of the conceptual papers for HSCM disciplines reflects the fact that HSCM research is relatively young and still evolving and thus its theoretical foundation has not been built firmly at this point. In other words, a conceptual piece of work is still needed as part of preliminary studies which may help SCM professionals understand key research issues associated with HSCM before embarking on more rigorous studies.

Figure 1 shows the trend in the number of published HSCM articles by the year of publication. Reflecting the growing strategic importance and popularity, the number of HSCM papers has steadily increased over the last 30 years. In particular, we have seen a significant increase in HSCM research for the last decade. More specifically, we have witnessed a sudden surge in the number of HSCM publications in 2009, signaling the explosive growth potential of this line of research. This trend seems to continue for the last three years (i.e., 2010, 2011, and 2012) until it tapered off and have been on the wane since 2013, as the number of HSCM publications dropped to less than ten a year during the recent past (2013-2016).

Figure 1: The Number of Papers Published Each Year

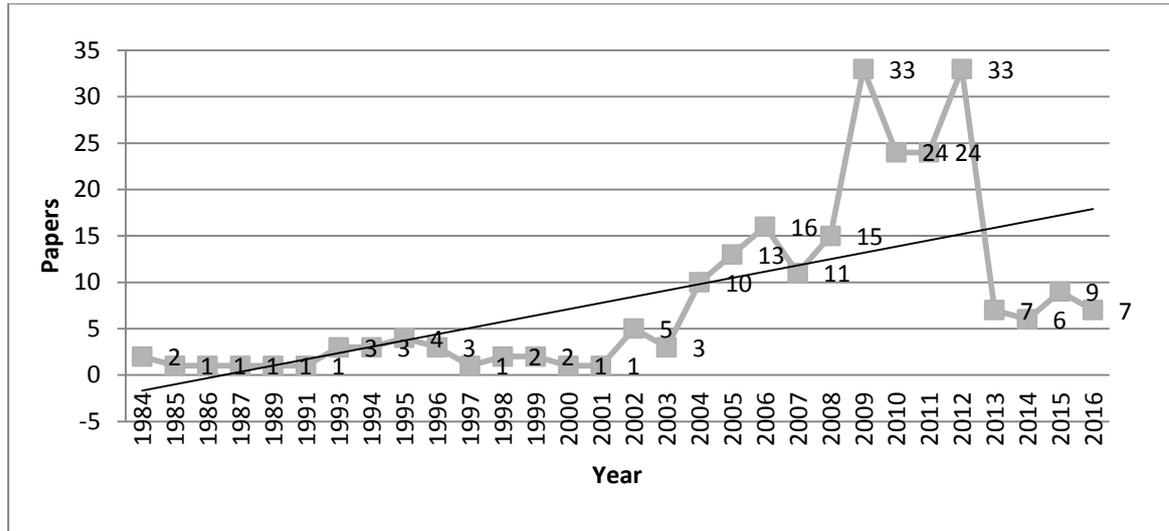
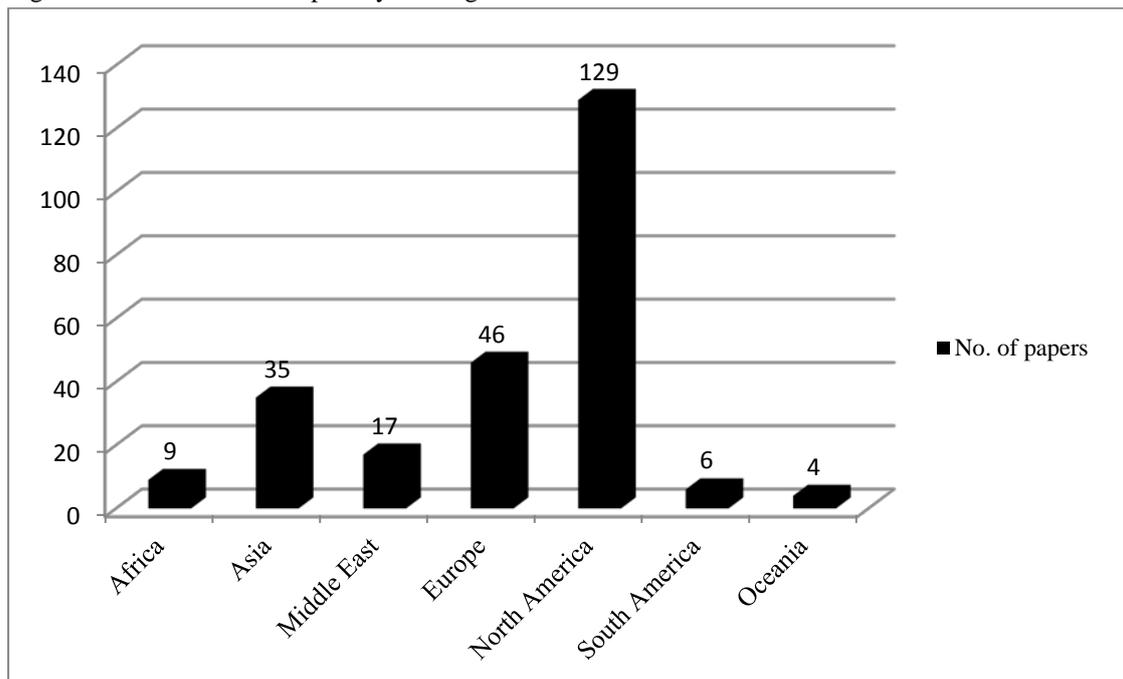


Figure 2 shows the number of HSCM publications by the geographical region. Although HSCM research was represented by more than 40 different countries and every continent across the globe, indicating a wide-spread interest of HSCM research, North America (especially U.S. and Canada) dominated the HSCM research with a total of 129 papers accounting for 52% of the HSCM publications for the last three decades. In particular, the U.S. alone produced a total of 116 papers. Europe is the second largest producer of HSCM research with a total of 46 publications. Among the European countries, the United Kingdom (U.K.) accounted for nearly half (46%) of these publications. One thing to note here is that a

majority (67%) of the U.K.'s HSCM research seems to gear toward the U.K.'s pharmaceutical industry problems and issues stemming from national health services (NHS) that are publicly funded through taxation. Likewise, the African region's HSCM research seems to focus on the pharmaceutical distribution and public health issues tied to infectious disease (e.g., malaria) outbreaks (e.g., [39, 41]). As these examples illustrate, there may be region-specific interest in certain health care subjects. However, with the limited number of HSCM publications at this juncture, we did not find any more patterns of HSCM research which characterized region-specific issues.

Figure 2: The Number of Papers by the Region



Original Article

Figure 3 shows the number of HSCM publications by the research methodology. Overall, an analytic method is the most favored research methodology, which was followed by conceptual and case study methods. In particular, the number of analytical papers surged from the year 2006 onward, whereas conceptual papers tapered off after peaking in 2009. Especially, we have witnessed a dramatic surge in the number of analytical papers in 2010 and 2012 until the popularity of analytic research slowed down in 2013. A growth of analytical papers in the recent past is due in part to a continued interest in the health care network design and emergency planning in the aftermath of a series of high-profile natural disasters and terrorist attacks. In contrast, a sharp decline in the number of conceptual papers for the last six years implies that expository papers that simply explain why the supply chain

management concept is essential for improving health-care services, describe how the health care supply chain should be managed based on anecdotal evidence, and narrate what the fundamental HSCM issues are from a pedagogical standpoint are no longer appealing given a plethora of such papers for the last 30 years. Also, as the HSCM field has established itself as the target of more scientific inquiries, its research methodology seems to shift toward more rigorous and widely accepted methods such as model-building analytic and survey-based exploratory/empirical studies. Indeed, Figure 3 shows a continued popularity of analytical studies relative to other research methodologies and a gradual increase in exploratory studies for the last six years which substitute for a decline in conceptual studies.

Figure 3: The Number of Papers by the Methodologies

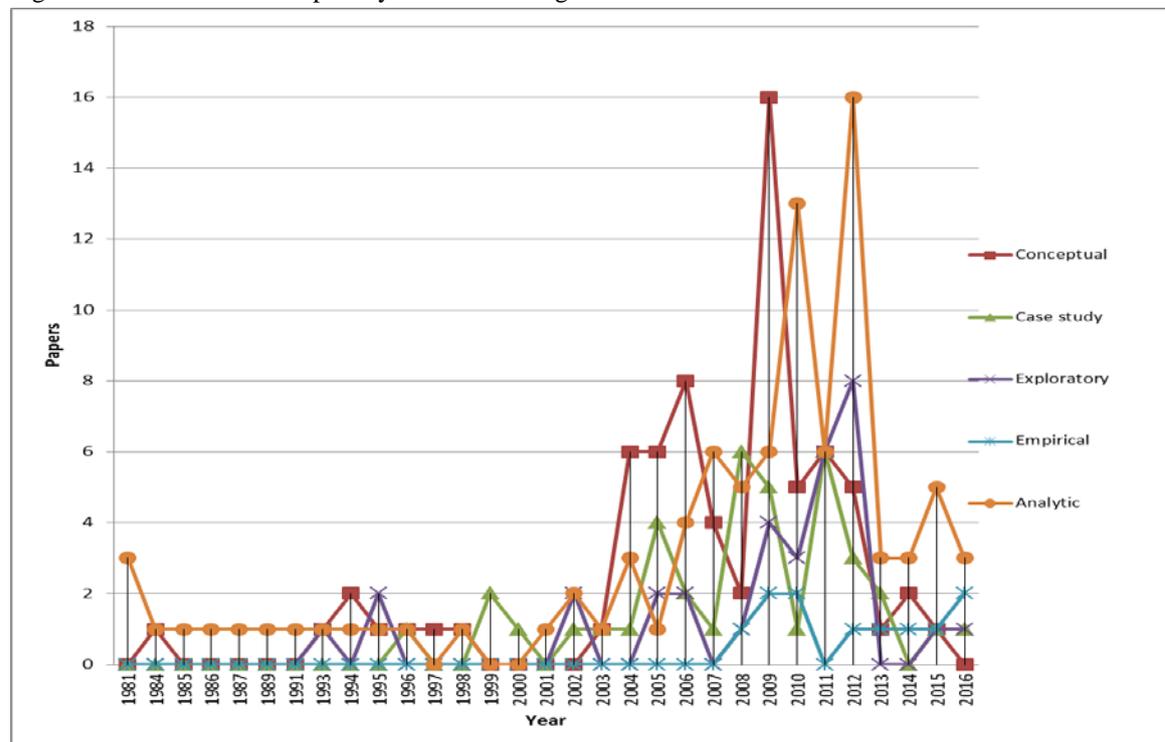


Figure 4 shows the numbers of papers by the research areas published each year. The papers dealing with the emergency planning issues show the most visible growth between 2004 and 2012 in particular. Although emergency planning has been a classical subject of health care studies for more than several decades, the renewed interest in emergency planning reflects the increased public attention paid to growing terrorist threats (e.g., 9/11 incidents, recent Paris, Brussels, and Orlando terrorist attacks), catastrophic natural disasters (e.g., Hurricanes Katrina and Sandy), and infectious disease outbreaks (e.g., West-Nile disease resurgence, Zika virus outbreaks in Latin America,

and Valley Fever outbreaks in the U.S.) and the subsequent needs for emergency responsiveness including quick patient rescues and paramedic cares. As such, unlike traditional emergency planning problems focusing on emergency vehicle deployment for an individual paramedic care, new emergency planning problems dealing with the risk of terrorism, natural disasters, and infectious disease outbreaks affecting a wider region and a greater population base required a new set of models and algorithms along with new problem definitions. These problems have emerged as a popular subject of HSCM research. For example, pioneering this line of research, Kaplan et al. [28]

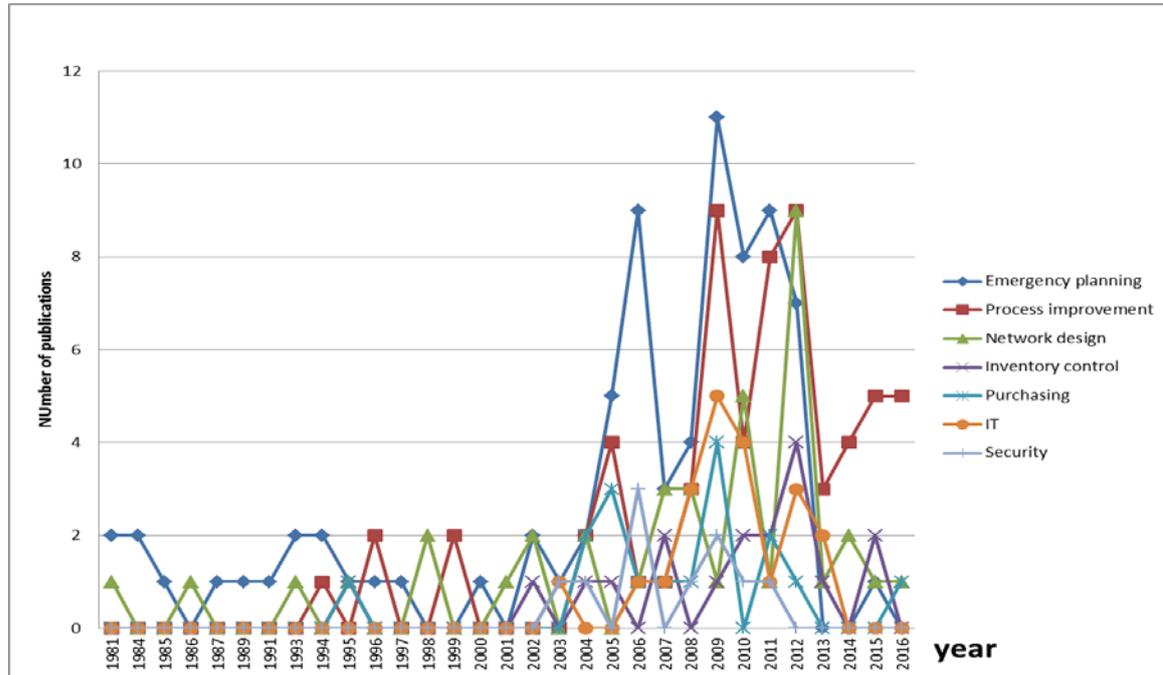
proposed a mass vaccination model that was designed to minimize fatalities resulting from a smallpox attack. Craft et al. [15] developed a series of mathematical models including a dose-response model to respond to bioterror anthrax attacks. More recently, Tang and Lau [60] discussed emergency logistics responses to potential avian influenza outbreaks in Hong Kong. Coping with more frequent natural disasters, Jotsi et al. [27] developed a simulation model for the dispatch and routing of emergency vehicles in a post-disaster environment. Lin et al. [37] also presented a multiple objective integer programming model and heuristics for solving the problem of delivering prioritized items in disaster relief operations.

In addition, process improvement seemed to bring more attention to HSCM researchers in 2009 and afterward. This upward pattern reflects the health care organization's increased efforts to control mounting health care costs by reducing waste or any other non-value adding activities throughout the health care supply chain. For example, in an effort to provide patient-centric health care services, Villa et al. [66] analyzed the movement of patients through different sets of process sequences (so-called "patient flow logistics") comprised of outpatient clinics, emergency departments, operating rooms, wards, intensive care units, and post-acute care settings and then re-designed these process sequences in such a way that scarce health care resources were better utilized and collaboration efforts among different units were maximized. Similarly, Lillrank et al. [36] broke down the health care supply chain involving patient diagnosis and organ transplantation into a series of connected processes and then developed standardized process routines that could smooth the flow of critical patient information throughout the supply chain. With the goal of reducing costs and facilitating information flows across the hospital supply chain, Su et al. [57] analyzed the four stages of logistics innovation processes: (1) setting interactive environments among the internal health care units; (2) collecting logistics process data; (3) developing a feedback loop to identify improvement processes; (4) creating inter-organizational learning environments among the hospital supply chain partners. Based on these analyses, they initiated new logistics innovation processes which made the hospital supply chain leaner than before and improved relationships with hospital suppliers and internal units.

On the other hand, after peaking in 2009, the HSCM research dealing with inventory control issues has begun to decline for the last several

years. The HSCM studies focusing on inventory control were often concerned with the management of pharmaceutical inventories crucial for timely patient treatments (e.g., [3, 4, 29, 47, 49, 65]). This type of research might have lost its steam in the recent past due in part to the increased adaptation of just-in-time (JIT) principles to the pharmaceutical and hospital industries [30]. Also, the emergence and advancement of radio frequency identification (RFID) technology for pharmaceutical and hospital industries might have contributed to more efficient tracking and control of inventories and thus decreased the need for traditional inventory control and planning techniques such as the variations of the economic order quantity (EOQ) model [5, 6, 8, 33, 48]. Reflecting the growing popularity of RFID in the health care industry, 13 (62%) out of 21 HSCM papers dealing with IT-related themes focused on the role of RFID in HSCM. For instance, Wang et al. [68] investigated the potential merits of RFID (e.g., cost savings, improved patient safety and medical services, greater supply chain visibility) for the Taiwanese hospital. Later, Tzeng et al. [63] evaluated the business value (e.g., effective communication, asset utilization, patient safety, supply chain integration) of RFID for the hospital supply chain. Kumar et al. [33] examined how RFID could improve the decision making process and subsequently enhance the efficiency of health-care supply chains. Likewise, Carr et al. [8] investigated the health care organization's intention to adopt RFID to improve its supply chain efficiency and then identified various factors (e.g., perceived adoption risk, technical compatibility, perceived usefulness, organizational resistance, RFID training support, ease of use) influencing the RFID adoption decision. Predicated on laboratory experiments, Swartz et al. [58] verified the merits of RFID for monitoring patient cares (patient conditions) and ordering medical supplies in the medical supply chain. Despite the huge benefit potentials of IT (including RFID) for a supply chain setting as noted by Auramo et al. [2], Min and Shin [42], and Jones et al. [26], however, it is somewhat surprising to find that the IT theme so far has not drawn much interest among scholars studying HSCM [67,71]. The IT themes gradually gaining traction in HSCM research include: an examination of the role of information and communication technology in enhancing cooperation among health care supply chain partners (e.g., [38]); development of the enterprise-wide decision support system (DSS) for a health care supply chain (e.g., [35, 40]); use of RFID for a counterfeit-resistant pharmaceutical supply chain (e.g., [10, 32, 52]).

Figure 4: The Number of Papers by Research Areas



4. A SUMMARY OF THE RESEARCH FINDINGS, TRENDS, AND FUTURE RESEARCH IMPLICATIONS

Based on our analysis of the past HSCM literature, the following points are noteworthy:

1) As evidenced by the number and diversity of journal outlets which published at least one HSCM paper, the HSCM field is viewed as the multi-disciplinary research domain. In fact, more than 90 different journals have published HSCM papers. These journals represent diverse fields of study including emergency medicine, pharmacy, public administration, public health, chemical engineering, operations research, industrial engineering, health care marketing, global/international business, service operations, electronic business, and general management, not to mention supply chain management. Although the main stream supply chain oriented journals (e.g., International Journal of Logistics Systems and Management, Supply Chain Management: An International Journal, International Journal of Services and Operations Management, International Journal of Physical Distribution and Logistics Management) still play a prominent role as a viable forum or as a popular publication outlet for the HSCM research, specialty journals (e.g., Annals of Emergency Medicine, Air Medical Journal, Resuscitation) exclusively dedicated to health care/medical issues have become the frequent publication outlets for the HSCM research. Also, it is noted that a journal covering public sector decision issues (i.e., Socio-Economic Planning Sciences) often publish HSCM papers (especially papers dealing with emergency

planning and health care facility location issues). On the other hand, four main stream SCM journals mentioned above rarely published HSCM articles dealing with emergency planning. This finding indicates that main stream SCM journals seem to shy away from the subject that has been heavily covered by the specialty journals. Thus, in selecting the proper publication outlet, academicians should be aware of the fact that a certain journal tends to have its own specific focus or preference for a particular subject or research theme.

2) In contrast with the Sachan and Datta [50]’s finding that direct observation research methods such as case studies were less popular for conducting generic (or non-HSCM) supply chain research in mainstream supply chain journal outlets, case study methods turned out to be more popular among the HSCM research published in four main stream SCM journals. On the other hand, it is intriguing to note that, in congruent with the pattern of generic SCM research, empirical research methods based on hypothesis testing are minimal in the HSCM research.

3) The HSCM research activities dealing with IT, purchasing, and security in the health care sector are scant relative to those studies focusing on emergency planning, process improvement, and network design. This pattern reflects the fact that studies dealing with emergency planning have a long history of research streams dating back to 1960s and thus established clear research agenda and well-defined problems to solve. On the other hand, HSCM studies addressing IT, purchasing, and security issues are still in infancy and thus are lacking the clearly established research agenda. As

Table 4 shows, more than half (55%) of the published papers for these application areas are still conceptual and descriptive, illustrating a lack of confirmed theory. The dearth of this line of research presents ample research opportunities. For instance, future research efforts should be directed toward the impact analyses of IT (e.g., enterprise resource planning, web technology, RFID) as well as sourcing practices (e.g., medical supply sourcing, pharmaceutical supplier selection, health care outsourcing, and group purchasing through health care alliances) which encouraged many tiers of suppliers to comply with a set of new health care regulations and rules. In addition, given the increasing incidences of tainted or counterfeit drugs, research tackling drug safety or bio-terrorism problems is greatly needed.

4) Despite the unique inventory situation in the health care industry where hospitals and pharmacies have to deal with more challenging inventory problems associated with many perishable pharmaceutical items and medical supplies with a short shelf life, the HSCM studies that are mainly concerned with inventory control and planning issues are sparse and dwindling (a total of only nine published articles for the last three decades).

5) Emergency planning still remains as the dominant subject of research interest for many scholars as evidenced by the prevalence and longevity of HSCM papers concerning emergency planning (one third of total HSCM publications; at least one article per year over the last 30 years and 35 articles between 2005 and 2012). The popularity of this particular subject led to the birth of some specialty journals (e.g., *Annals of Emergency Medicine*, *BMC Emergency Medicine*, *Journal of Emergency Medicine*, and *Air Medical Journal*) almost exclusively dedicated to emergency medical care and emergency vehicle deployment. It is also noted that a subject of emergency planning was approached by diverse research methodologies (see Table 4). However, the analysis of the past HSCM literature on emergency planning reveals the absence of an empirical study. From a methodological standpoint, another intriguing pattern that we found is a gradual transformation of popular research tools. For instance, an analytic method was most popular for the HSCM papers on emergency planning during the 80's, whereas the popularity of conceptual papers gained steam during the 90's and then exploratory studies have been increasingly used for the last decade (early 21st century). A change in the popularity of research methodology may have reflected a gradual change in the popular research theme (from emergency vehicle deployment to quick disaster response).

6) It is apparent that both the analytic method and the conceptual study are still the most popular research methodology for HSCM (66% of the total

HSCM publications) due in part to the growing difficulty in collecting empirical or secondary data. In particular, the prevalent use of an analytic method has something to do with the nature of specific applications such as network design (e.g., health care facility location) and emergency vehicle deployment for emergency planning. For example, there exist well-defined, structured mathematical problems (i.e., a p-median problem for health care facility location; a set covering problem for emergency vehicle deployment) for these applications. Thus, it is easier for the model builder to develop systematic decision-aid tools such as mathematical models and solution algorithms. This rationale explains why 36 (92%) out of 39 network design HSCM papers are analytical. However, as health care issues cut across different functional areas of the supply chain and encompasses the different level of decision-making hierarchy (from operational to strategic), there is a growing need for a more fluid, open research methodology such as soft operations research (O.R.) tools that can effectively deal with ill-defined, less structured health care supply chain issues facing practicing managers and policy makers. In addition, there is a growing need for the use of hybrid research methodologies (e.g., a mixture of both the case study and the analytic method) which combine the merits of different research tools and address interdependent health care supply chain issues (e.g., the impact of IT implementation on process improvement, the use of IT for increased drug safety) encompassing the entire spectrum (from the upstream to downstream) of supply chain issues.

7) The empirical methodology, despite being recognized as a hallmark of rigorous supply chain research, constitutes a mere 4.4 percent (eleven out of 246 papers). This indicates that much of the HSCM research methodologies are largely expository, exploratory, analytic, and descriptive in their approaches. In particular, it should be noted that the use of the empirical research methodology for emergency planning, inventory control, purchasing, and security is nearly non-existent. Although a lack of empirical studies indicates the youth of HSCM research without much of the developed or confirmed theory, additional empirical research is in great need to establish HSCM as the serious research field. For example, empirical studies investigating the impact of the Obama Care on health care supply chains and/or the financial performance or the competitiveness of the firm complying with the Affordable Care Act may be worth pursuing.

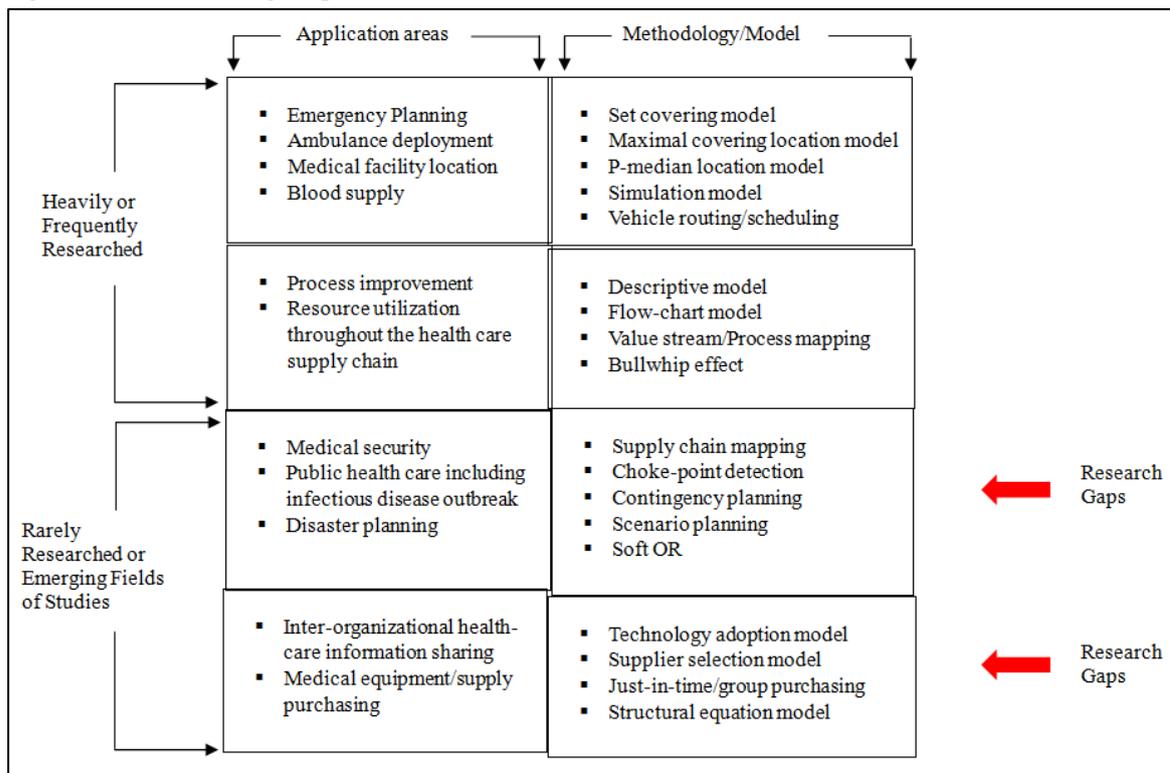
8) For the last several years, there is a rapid increase of HSCM papers (especially between 2009 and early 2013) which attempted to address public health issues related to infectious diseases (e.g., avian influenza, malaria) and public drug distribution. This line of research dates back to Min

[39] and Min and Maltz [41] who proposed ways to increase the accessibility of essential anti-malarial drugs for controlling Malaria outbreaks in Sub-Saharan countries by developing a drug supply chain map. More recently, Arifoglu et al. [1], Chick et al. [12], and Hessel [25] initiated SCM research dealing with the vaccination plan for preventing the influenza pandemic.

9) Based on aforementioned analyses and findings, various research gaps are identified as shown in the study positioning map of Figure 5. Examples of the noticeable research gaps include:

(a) a lack of HSCM studies which facilitate medical information sharing across the all kinds of health-care organizations (e.g., primary care, urgent care, first respondent treatment facilities, and special care medical clinics) at the different phases of supply chain activities; (b) a growing need for developing a disaster response plan model which improves the coordination and synchronization of various inventory planning and quick response logistics activities involving the deliveries of needed medical supplies, pharmaceuticals, and food items to the disaster hit areas.

Figure 5. The Positioning Map of the HSCM Studies



5. CONCLUDING REMARKS AND FUTURE RESEARCH DIRECTIONS

Over the last century, the human life expectancy has continued to climb thanks to a series of medical breakthroughs and improved living conditions. For example, the today's American life expectancy has increased to nearly 80 years from 47 years at the turn of the last century [70]. To enjoy the sustained acceleration of human life expectancy and high quality of living, a greater access to high quality health care is imperative. Unfortunately, there is a growing concern over such access due to fast rising health care costs and further strained health care resources. Without finding systematic ways to control health care costs and utilize limited health care resources, the quality of our lives will deteriorate rapidly and may reach the point of no

return. One of such ways includes leveraging supply chain management (SCM) principles for the continuous improvement of health care services. The field of studies which focus on the SCM disciples of health care is dubbed HSCM. For the last ten years, we have seen a wealth of articles addressing HSCM related issues. In an effort to gain valuable insights into the evolution of HSCM research and grow this line of research further, this paper describes the past development and current status of HSCM research, synthesizes the focused areas of HSCM research, and captures the emerging perspectives of HSCM research. As the HSCM research is beginning to take off as a subfield of main-stream supply chain studies, we should not lose sight of major drivers of HSCM: the incorporation of lean and agile principles into health care value chains, links among sourcing,

making, and delivering activities, and externalities (e.g., laws and regulations) influencing those activities. Thus, the continued investigation of these drivers is worth pursuing as the future research agenda, since it would help the HSCM research field mature and refresh. In particular, we would like to suggest the following lines of research for the subjects of further scientific investigation.

- According to the Congressional Budget Office [14], prices of prescription drugs are approximately 35% to 55% higher in the U.S. than they are in other countries. For example, prices for the 30 most-commonly prescribed drugs are one-third higher in the U.S. than in Canada and Germany, and more than double the prices in Australia, France, Netherlands, New Zealand, and the U.K. [56]. Likewise, pharmaceutical prices vary considerably from one country to another. Considering this price variation, there is a need to study the impact of grey drug market diversion on drug distribution channels (e.g., direct-to-end user vs. direct-to-wholesaler) and subsequent drug pricing.
- Medical supplies are the second largest expense to hospitals after labor in providing patient care [31]. As such, studies developing more cost-efficient inventory planning or JIT delivery strategies of medical supplies are worth pursuing. Also, with a growing prospect of disintermediation, distributing medical supplies directly from medical supply producers to hospitals, studies examining how significantly disintermediation improves health care supply chain efficiency and subsequently saves health care expenses may be in great need.
- As pharmaceuticals and medical supplies move through the complex array of health care supply chains, some of them can be contaminated, damaged, mishandled, mislabeled, and misplaced while going through numerous supply chain players. To ensure the supply chain integrity, a growing number of hospitals explore the use of new technology, such as radio frequency identification (RFID), to keep track of those items throughout the health care supply chain [8]. The growing adaptation of such technological advance often requires changes in supply chain planning (e.g., demand planning, inventory planning, and distribution planning) and subsequently necessitates new management imperatives. With that in mind, for example, further studies investigating how RFID implementation can facilitate collaboration, information sharing, and data transfer among the health care supply chain constituents may be needed.
- In an effort to push health care to less expensive settings, today's health care systems tend to drive health care services from the traditional health care institution such as hospitals to the community. This trend means the greater prevalence of outpatient care than ever before. Since outpatient procedures are being performed in offsite medical clinics, while more patient care is being shifted to the home, the conventional model that was designed to locate hospitals and medical clinics as a single-echelon health care facility no longer makes sense. Thus, a new network design model that reflects the aforementioned shift in health care needs to be developed. Going one step further, the network design model that can help create health care or medical intelligence within the business analytics framework will be needed in the future.
- With the fast rising health care cost in the fragmented health care industry, a growing number of hospitals have tried to take advantage of a group purchasing organization (GPO) such as Novation, Amerinet, Premier, and HealthTrust Purchasing Group which can pool the purchasing volume of its members for various medical equipment, supplies and services and develop more favorable purchasing terms (e.g., lower price through the volume discount). However, with hundreds of health care GPOs to choose from, its selection and joining its membership can be a daunting task. Thus, more systematic decision-aid tools are needed to choose the most appropriate GPO and then maximize its membership benefits, while avoiding any overpayments to the selected GPO.
- As the world gets closer with improved transportation means, infectious diseases can spread out more quickly and widely all across the world [40]. Especially, developing countries with a rapid population growth but limited medical resources are highly susceptible to deadly disease outbreaks. Although some ground works have been established by a few pioneering researchers, more research from a supply chain angle is needed to tackle public health care issues associated with infectious disease outbreaks including avian influenza which is still rampant in Far-Eastern Asian countries. The example of such research includes the development of a pharmaceutical supply chain that can increase the access and affordability of essential drugs and vaccinations.
- Considering the controversies surrounding some of the landmark healthcare laws such as the Affordable Care Act in the U.S., HSCM studies assessing the impact of such laws or policies on the health care supply chain would be another fruitful area of future HSCM research. In particular, reversing the past

research pattern of SCM areas (including HSCM research field) which seldom utilized the secondary data sources, the use of secondary data sources would be rewarding for studying the HSCM impact of government-induced health care laws, regulations, and policies.

- Given the limited research tackling inter-organizational issues in the supply chain network, HSCM research investigating the inter-dynamics or organizational learning among healthcare supply chain partners such as healthcare insurance companies, healthcare logistics providers, and healthcare service providers would be in great need.

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