POM Forum

Evolution of Operations Management Research: from Managing Flows to Building Capabilities

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Abstract: This forum paper examines the past and the future of Operations Management (OM) research. First, we investigate the evolution of OM research from 1997 to 2018 by using machine learning tools to analyze all OM papers published in five journals (JOM, MS, M&SOM, POM, and OR), and find that the number of information/financial flow-focused OM research papers has increased steadily over the years. Second, we present three research topics motivated by the US-China trade war and the Covid-19 pandemic, and postulate that future OM research is likely to involve all three flows: material, information, and financial flows. Finally, we argue that, to achieve operational efficiency, resilience, and sustainability in the Industry 4.0 era, firms should build (or strengthen) three new capabilities: *Connectivity, Clarity, and Continuity.* As firms develop new ways to build these new capabilities, more innovative OM research ideas will ensue.

Keywords: Operations management, Supply chain management, Research trends, Flow, Ecosystem.

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1 Introduction

In the last two decades, three types of disruptions have spawned various exciting Operations Management (OM) research topics. The first type is *supply chain disruption risk* caused by man-made and natural disasters such as the September 11 attacks, Hurricane Katrina, Tohuku earthquake, and the ongoing Covid-19 pandemic. The second type is *business model disruptions* brought about by rapid advances in information technologies: internet, mobile phones, and Industry 4.0 technologies (Internet of Things, artificial intelligence, robotics, 3D printing, drones, cloud computing, blockchain, etc.). The third type is the *expanded goals* resulting from public pressure over environmental sustainability and social responsibility. These three types of disruptions have motivated firms in different industries to develop: (1) supply chain risk management programs, (2) new business models such as online platforms, and (3) new initiatives to address environmental and social issues. Over the last three years, there have been heated debates over deglobalization caused by nationalism, Brexit, the U.S.-China trade war, and the current Covid-19 pandemic. These new disruptions have motivated us to reflect upon the past and postulate about the future of OM research.

In this paper, we aim to investigate the evolution of OM research over the last two decades and propose some future research topics. We examine the past from the perspective of three fundamental elements: material flows, information flows, and financial flows. These three flows are essential for managing any operations in the manufacturing and service sectors. To propose future research directions, we take the three aforementioned types of disruptions into consideration. Our intent is to stimulate discussions among OM researchers for identifying novel and relevant OM research topics.

This paper is organized as follows. In §2, we examine OM research papers published in five major journals and identify the trend of **three flows** (material, information, and financial) between 1997 and 2018.[1] We find that there is an increasing trend in the number of published papers focusing on information and financial flows (with material flow in the backdrop), and this trend is driven by economic forces, technological forces, and political and societal forces. Upon reflecting on this increasing trend, we propose **three topics** for future OM research that involve three flows in §3. These three topics are: socially and environmentally responsible supply chains motivated by public concerns, global supply chain redesign triggered by the U.S.-China trade war and the Covid-19 pandemic, and innovative supply chain financing prompted by the emerging needs for suppliers to get access to credit in order to restart the world economy amid the Covid-19 pandemic. By examining these three topics in the presence of Industry 4.0 technologies, we argue in §4 that, to achieve sustainability, operational efficiency, and resilience, firms should leverage these new technologies to build **three capabilities**: Connectivity, Clarity, and Continuity. We conclude in §5.

[1] We choose 1997 because it was the year when the "Bullwhip" supply chain paper by Lee et al. (1997) was published.

2 Analyzing Articles Published in Five OM Research Journals

To understand the evolution of OM research, we begin by analyzing papers published in five major journals; namely (in alphabetical order), Journal of Operations Management (JOM), Management Science (MS), Manufacturing and Service Operations Management (M&SOM), Operations Research (OR), and Production and Operations Management (POM) between 1997 and 2018.[2] Except for the M&SOM journal launched in 1999, we include all OM-focused papers published in the other four journals from 1997 to 2018. Additionally, because JOM, M&SOM and POM are OM-focused journals, all published research articles are included in our study. However, because MS and OR are multidisciplinary, we exclude those papers that are not OM-focused by using a "filtering process" as presented in Appendix 1. Once we compiled all OM-focused papers from these journals, we collected relevant information associated with each paper (i.e., title, abstract, authors and affiliations, keywords, and publication information) from the corresponding journal website. We highlight our key findings below, and the reader is referred to Zhang et al. (2020) for details.

2.1 OM Research Emphasis: Topics

Between 1997 and 2018, the aforementioned five journals published a total of 4,188 OM-focused papers. On average, POM published 62 papers per year, accounting for 37% of all OM research papers published during 1997-2018. In terms of countries associated with the authorship affiliations of those papers published between 1997 and 2018, we find that U.S.-affiliated authorship accounted for 69.83%. To examine the emphasis in terms of research topics, we use 18,729 keywords listed on those 4,188 OM-focused papers to create a tag cloud as depicted in Figure 1.

Keywords	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Supply Chain Management	5	3	6	11	12	15	9	24	15	11	28	12	20	20	13	10	20	12	11	8	12	9	286
Pricing	2	4	2	3	5	3	4	8	9	12	10	15	12	13	12	8	12	8	14	9	15	8	188
Empirical Research	8	11	13	8	20	6	6	11	4	13	4	3	7	4	3	5	6	4	4	4	1	1	146
Service Operations		3	3	5	2	5	6	11	1	8	11	6	6	8	8	8	7	7	3	6	4	9	127
Inventory/Production	13	13	11	2	2	3	1	14		7	13	13	8	10	4	5	1	2	3				125
Dynamic Programming	5	4	2	1	4	5	1	4	1	3	5	7	3	9	9	6	7	8	11	7	7	6	115
Operations Strategy	2	5	5	11	10	7	7	6	5	6	9	4	6	5	4	2	2	6	2	2	2	2	110
Revenue Management						1	2	3	3	4	7	16	7	8	6	5	8	11	7	6	3	11	108
Supply Chain	2	2	5	5	3	5	3	4	6	5	6	4	6	2	6	7	3	6	6	9	3	7	105
Game Theory			3	1	4		1	4	4	3	4	2	6	3	7	2	8	9	12	8	5	12	98
Inventory Management	3			1	3	6	1	7	3	3	3	4	3	7	6	1	13	5	10	5	9	3	96
Inventory	4	1	4	2	2	5	1		2	5	12	8	5	5	5	1	6	3	6	9	4	2	92
Competition		2	1	1	2	1		2	2	2	4	6	1	8	7	6	4	9	8	8	4	4	82
Behavioral Operations												3	1	2	3		13	7	7	10	5	20	71
Dynamic Pricing			1				2	1		5	3	5	8	5	4	6	4	7	6	1	4	7	69
Stochastic	3	8	6		1		1	8		4	5	6	5	7	4	1	2	1	3	2			67
Quality Management	2	2			4	1	3	4	3	6	6	6	3	4	2	2	3	2	6	2	1		62
Applications	8	7	3	1	1		1	3		5	4	9	4	3	4	1	1	1	1		2		59
Outsourcing	1		1	2		2		1		2	4	10	4	2	3	6	6	2	3	3	4	1	57
Simulation	3	4		5		1	4	6	1		2	5	1	2	5	4	1	3	3	2	2	2	56

Table 1: Frequency of top-20 keywords of OM research articles published in five journals during 1997-2018.

[2]For each journal, we exclude certain articles from our study, including errata, award announcements, calls for papers, etc.

Figure 1: A tag cloud of keywords of OM articles published in five journals during 1997-2018.

We have also ranked the frequency of the keywords (plural and singular forms are combined, e.g., "service operation" and "service operations" are combined as "service operations"). Among the top-20 keywords during 1997-2018, "supply chain management" has the highest frequency, as shown in Table 1. The frequency of this keyword increased until 2007 and then decreased to a certain extent. The keyword "inventory/production" is the fifth most frequent keyword; however, the frequency has decreased drastically since 2011. The keyword "revenue management" first appears in 2002, and then it fluctuates to a certain extent across the years. The keyword "behavioral operations" first appears in 2008, and then increases steadily. The keyword "application" almost disappears after 2012. However, we actually have advocated application-oriented research in recent years. It is possible that some other keywords have replaced the keyword "application" but refer to similar topics. We find that "big data" has become a common keyword in POM and that "data-driven optimization", "data-driven research", "data-driven models", "data-driven newsvendor", and "data-driven algorithm" have begun to appear in M&SOM, MS, and OR in recent years.

2.2 OM Research Trends: From Material Flow to Information and Financial Flow

Recognizing that material, information, and financial flows are three fundamental elements for managing operations within a firm or across firms along a supply chain, we examine whether or not a trend exists among those 4,188 OM papers published in all five journals during 1997-2018. To begin, we need to classify each of those 4,188 OM papers according to its focus: material flow-focused, information flow-focused or

financial flow-focused.[3] Because the bulk of all published OM research papers is material flow-focused, we shall focus primarily on research developments in information flow and financial flow. Specifically, we exclude those material flow-focused papers to avoid diluting the trend of the other two flows (i.e., being overshadowed by the sheer number of material flow-focused papers).

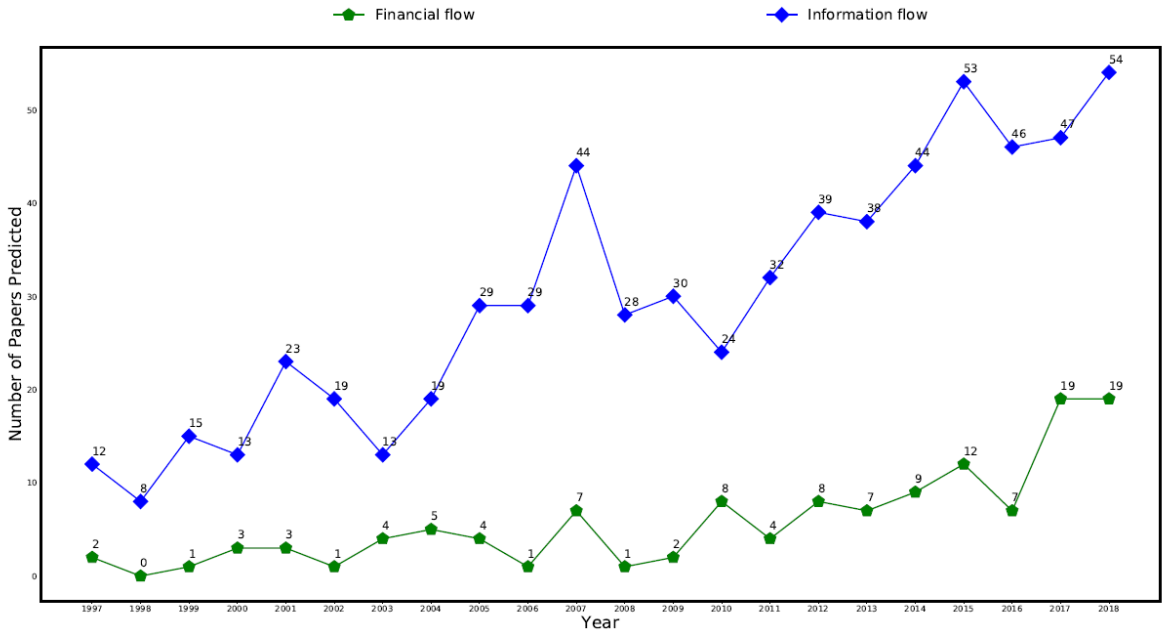

Figure 2: Trend of information and financial flow-focused papers published from 1997 to 2018.

Figure 2 reports the total number of OM papers in five journals (MS, OR, M&SOM, POM, and JOM) during 1997-2018 that is information flow- and/or financial flow-focused (as predicted by our machine learning tool as explained in Appendix 2). While the majority of OM papers are material flow-focused (data omitted), there is an increase in the number of OM papers that are information/financial flow-focused with material-flow in the backdrop. Specifically, between 1997 and 2018, the number of OM papers focusing on information/financial flows has increased sixfold. Comparatively, there are more information flow-focused OM papers than financial flow-focused papers published in these five journals. Finally, Figure 3 reports the trend of information/financial flow-focused papers in each of these five journals during 1997-2018. As shown, relative to JOM and OR, POM, MS, and M&SOM published more OM papers that are information flow-focused. In addition, the increasing trend of information flow-focused OM papers is most pronounced

[3]To do so, we adopt the machine learning approach presented in Angrist et al. (2017) because of the vast number of articles. To begin, we manually review and classify the article type for each of the 655 M&SOM papers published from 1999 to 2018. Specifically, we first extract certain "features" from the titles, keywords and abstracts from those 655 M&SOM articles based on natural language processing techniques. Then, we take these features as inputs to "train" a multilabel classification model to assign the types of flow associated with each OM paper published in JOM, MS, OR, and POM. We provide the details of all procedures used in this study in Appendix 2.

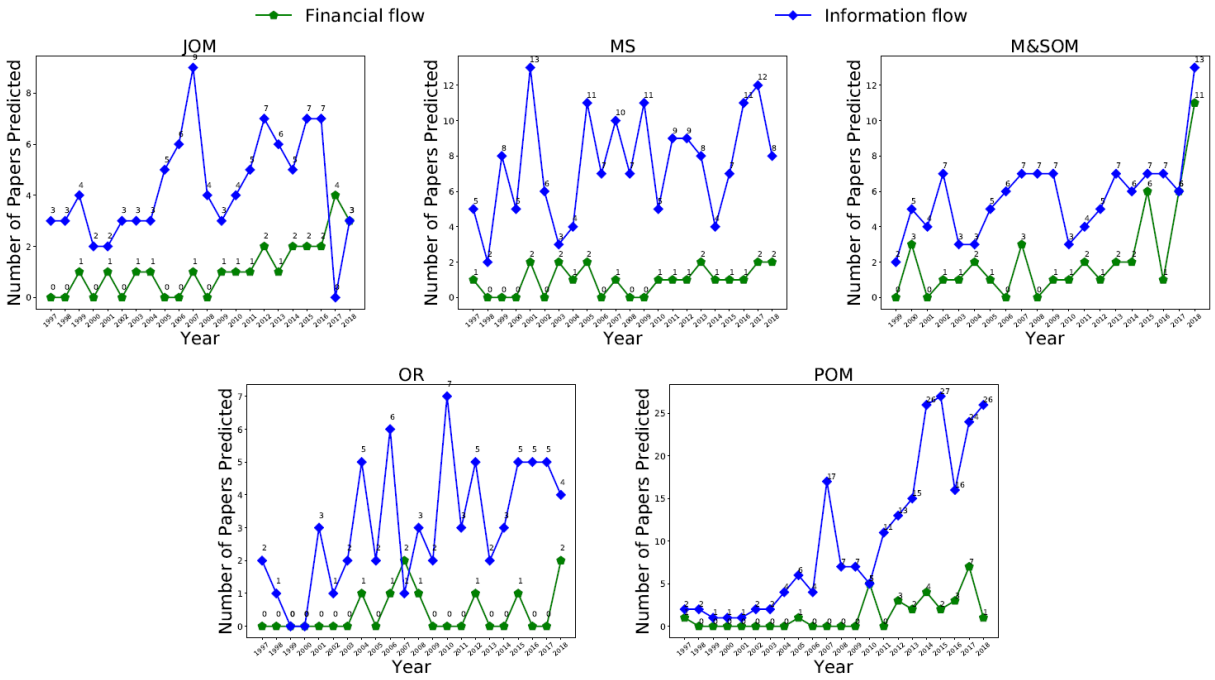

Figure 3: Trend of information and financial flows in each journal

in POM and M&SOM. Moreover, M&SOM published the highest number of OM papers that focused on financial flows, especially between 2016 and 2018 (partly due to a special issue co-edited by Babich and Kouvelis (2018)).

2.3 OM Research Trends: Driving Forces

From Figures 2 and 3, we observe a trend in which OM research has shifted (or expanded) from material flow-focused to information/financial flow-focused. This observation motivates us to postulate three key drivers for this recent OM research trend. We argue that the **economic force** of offshoring and outsourcing is the first driver that motivates OM researchers to go beyond material flow-focused research. As a result of outsourcing and offshoring since the late 1980s, many companies in developed economies focused on product design and marketing, while outsourcing operational activities (e.g., production, procurement, logistics, etc.) to overseas suppliers located in developing countries (Dai et al. 2020). Although this form of "division of labor" can help lower operations cost, it creates additional challenges as well. First, different firms in the decentralized global supply chain are self-interested and reluctant to share their true information with others. This creates an opportunity for OM researchers to examine the role of information flow in global operations to mitigate the negative effects caused by information distortion and information asymmetry. Second, as increasingly more firms delegate their operations to overseas manufacturing and service providers,

a number of financial issues arise (e.g., contract payments, tariffs, custom duties, currency exchange rates, etc.). Therefore, this motivates OM scholars to study how financial flow can affect supply chain operations.

Next, we argue that **technological force** is the second driver for motivating OM researchers to go beyond material flow-focused research. Since the early 1990s, we have observed several waves of technological innovations, such as internet and mobile devices, Internet of Things (IoT), big data, artificial intelligence (AI), 3D printing, and blockchain technology, etc. For example, the emergence of the internet and smartphones helps build e-commerce and online platforms (e.g., Amazon, eBay, Uber, Airbnb, Alibaba, etc.). Online platforms usually have better capability to connect the supply and demand sides, and thus increase the efficiency of integrating material flow and information flow. Mobile payment systems (e.g., Alipay, Wechatpay) and blockchain technology also resolve trust issues in transactions between sellers and buyers and enhance the efficiency and security of financial flows. Therefore, technological force is the second main driver that shapes the ecosystem of three flows in OM research.

Finally, the **political and societal force** is the third driving force for OM researchers to go beyond material flow-focused research. For example, how to survive the unprecedented challenges brought by the Covid-19 pandemic is now a question faced by all companies across the globe. The worldwide shortage of personal protection equipment (PPE) amid the Covid-19 pandemic is a wake-up call for responsive operations and supply chains (Tang, 2020). Strategies such as supply chain mapping, digital supply networks, and blockchains are applied to improve the visibility of the supply chain (Choi et al. 2020). To restart the world economy, all parties in the financial supply chain (lenders, stakeholders, and insurance agents) should find proactive ways to deal with the collapse of receivables financing and purchase order financing and to provide immediate liquidity and keep supply chain partners afloat (Tang and Yang, 2020).

3 New Forces and Future OM Research Topics

In §2, we identified an increasing trend in which OM research has expanded its emphasis from material flow to information and/or financial flow. We also discussed how recent economic, technological, and political and societal forces have motivated OM researchers to expand their research scope. Now we shift from the evolution of OM research during 1997-2018 to examining the current forces observed between 2019 and 2020 in order to propose some future OM research opportunities. To begin, we use Google Trends to track search activities between April 26, 2019 and April 26, 2020 using four terms: "sustainability", "social responsibility", "reshoring", and "supply chain financing" (Figure 4).

Observe from Figure 4 that sustainability and social responsibility continue to be popular search keywords; however, there has been a surge in searches about reshoring and supply chain financing amid the Covid-

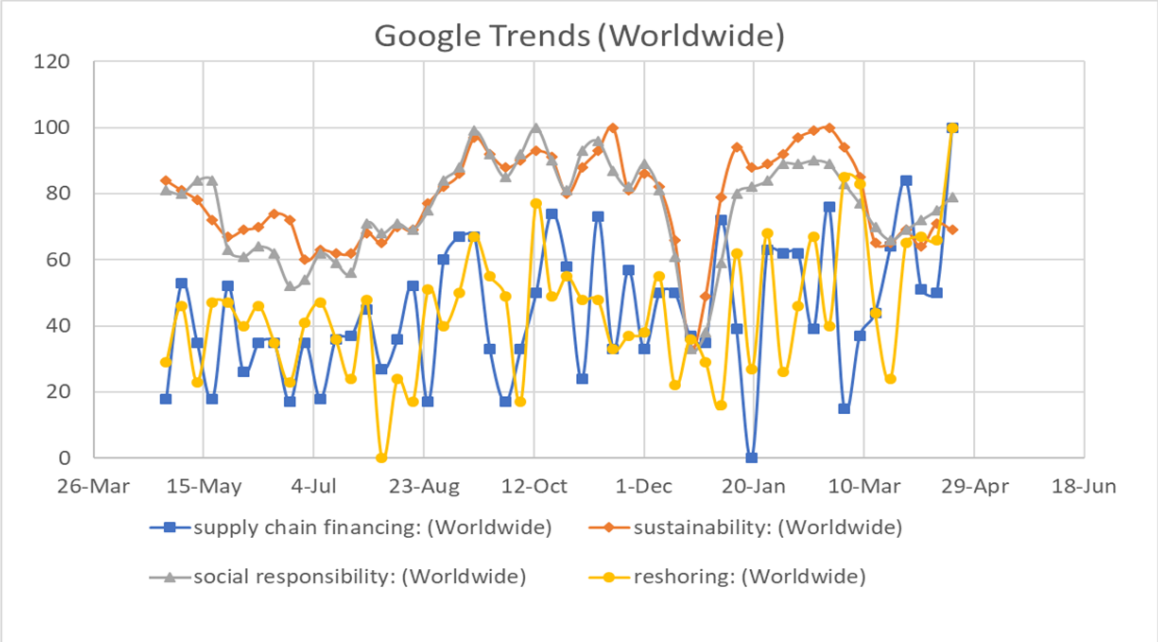

Figure 4: Trend of Google searches (worldwide) using four terms.

19 pandemic since mid-March 2020. This surge is probably triggered by the worldwide shortages of PPE resulting from global supply chain breakdowns and retailers' default payments to their suppliers. These new trends represent new forces, creating the following new OM research topics.

3.1 Topic 1: Socially and Environmentally Responsible Operations

Traditionally, operations and supply chain management focuses on efficient material flows from sourcing raw materials to distributing end products to consumers. The interactions among supply chain partners are primarily through material and financial flows. However, as firms sourced their products from emerging and developing countries with inconsistent enforcement of environmental regulations and labor laws, consumers, NGOs, and governments have exerted pressure on western companies to expand their goals from profits alone to people, planet, and profits (PPP). To achieve the PPP goals in a global supply chain with operations in developing countries, companies face different contextual constraints, objective functions, and stakeholders that are not prevalent in developing countries (Lee and Tang 2018).

To ensure that its global supply chain operates in an environmentally sustainable and socially responsible manner, the focal firm needs to change the way they manage all three (material, information, and financial) flows. Consider a company that sells coffee at a premium price and claims that its coffee beans are sourced from coffee farms that adopted certain sustainable farming techniques such as drip irrigation systems, cover

crops[4], and integrated pest management[5] and certain socially responsible practices such as fair wages, worker safety programs, and health benefits. However, to prove these claims, a company needs to develop track-and-trace capabilities to monitor and verify that all three flows are compliant with the said practice. As more firms are managing all three flows to achieve the PPP goals, there is a new research opportunity for OM researchers to develop ways to manage all three flows efficiently. For example, how should a firm evaluate the trade-off between the cost of track-and-trace of all three flows (using high-tech solutions or NGOs) and the cost of non-complying suppliers? How should a firm establish a reward and penalty system to entice their suppliers to comply with the said practice willingly?

3.2 Topic 2: Global Supply Chain Redesign

To source from and sell to developing countries, a firm should take different costs (production, transportation, and inventory), trade agreements that affect customs and duties rates, regulations, and local (content and labor) requirements of different countries into consideration when designing its global supply chain (Cohen and Lee, 1989). While global trade has exploded over the years, barriers to trade and protectionism measures have skyrocketed in recent years. Many trade agreements involve special rules and regulations for specific products with specific trading partners, but these agreements face an uncertain future given that President Trump withdrew from the Trans-Pacific Partnership negotiation in 2017,[6] and considering the Brexit saga and the ongoing trade war between the United States and China. Because import tax and customs duty can range from zero to 25%,[7] and these charges are uncertain, many firms are redesigning their global supply chains to reduce their total supply chain costs. To avoid the import tax from China, Apple shifted some production of Airpods to Vietnam, Google has shifted its Nest smart home product production to Malaysia, and GE reshored some of its electric appliance production to Louisville, Kentucky.

The current economic and political climate pressures companies to take the aforementioned PPP goals into consideration when redesigning their global operations networks. Besides the total supply chain cost (production, transportation, import tax, customs duty), carbon emissions and job creation should be included in the PPP goals. Also, as we experience the shortage of PPE amid the Covid-19 pandemic, one needs to take supply chain resilience into consideration to ensure that supply chain operations can be restored within a

[4]Crops such as clover or hairy vetch are planted during off-season when soils might otherwise be left bare to prevent erosion, replenish soil nutrients, and reduce the need for herbicides.

[5]This program involves mechanical and biological pest control methods for keeping pest populations under control while minimizing use of chemical pesticides.

[6]Trans-Pacific Partnership was an attempt to create a single market for the U.S. and 11 countries (Canada, Mexico, Vietnam, etc.) to trade more freely as a way to ward off China's growing economic influence.

[7]In 2018, President Trump ordered 25% tariffs on about $50 billion of Chinese imports, and China imposed tariffs of up to 25% on 128 U.S. products, including airplanes and soybeans.

reasonable time frame. To incorporate all these factors with uncertain trade agreements and uncertain (and unanticipated) disruptions, many companies need to take all relevant costs and the lead time associated with the material flow, the cost and time associated with the financial flow (loans, payment terms, trade-credits, transfer pricing, currency exchange rates), and the requisite information flow (for measuring and monitoring the environmental and social impact) into consideration when redesigning a responsive global supply chain to meet their PPP goals. This is a big challenge for firms, and a great opportunity for OM researchers to help companies to redesign their global supply chains by considering all three flows.

3.3 Topic 3: Innovative Supply Chain Financing

Supply chain research has traditionally focused on material flows by assuming that each supply chain partner has adequate funds to support its operations. However, because there is a significant "time gap" between the time at which an upstream seller (e.g., a supplier) needs funds to start its operations and the time at which it receives its payment from its downstream buyer (e.g., a manufacturer), different financing schemes are needed to facilitate financial flow for the supplier. Such financing schemes include: "receivables financing" (e.g., factoring, reverse factoring) where suppliers borrow against the invoice by leveraging on a buyer's stronger credit profile, and "purchase order financing" where suppliers borrow against the purchase order from financial institutions or directly from buyers. By noting that the buyer is likely to possess more accurate and timely information (than a bank) about the financial health of its supplier due to past transactions, industrial knowledge, and implicit control of payments, Tang et al. (2018) show that buyer direct financing (i.e., a buyer lends to its supplier) is more efficient than the traditional purchase order financing when the supplier is financially constrained.[8] However, purchase order financing turns out to be very risky in the midst of the Covid-19 pandemic because many buyers (e.g., Neiman Marcus and JC Penney) are filing for bankruptcy.[9] Hence, there is a need to develop innovative supply chain financing schemes to restart the world economy.

While traditional lenders (e.g., banks) usually do not have access to information about physical transactions among supply chain partners, they can form partnerships with one of the key supply chain players to gain information access in order to evaluate the financial health of the borrower. For example, HSBC has linked up with Alibaba in March 2020 to gain visibility about the background, historical transactions, and projected future transactions of its merchants in Hong Kong who sell on Alibaba's platform Tmall. With access to accurate and timely data about these merchants, HSBC can afford to offer loans (up to $500,000)

[8] During the financial crisis in 2008, firms such as Rolls-Royce (UK) and Mercedes Benz (Germany) offered buyer direct financing to their suppliers to keep them afloat so that the production operations will continue.

[9] Clearly, one can insure against non-payments via trade-finance insurance. However, besides a high insurance premium, this insurance service is limited in developing countries and non-existent in many developing countries.

to these merchants quickly without the need for collateral or financial documents (Tang and Yang, 2020). Hence, having access to information flow within a supply chain can enable banks to facilitate financing more swiftly to ensure smooth material flows in the supply chain. This innovative partnership offers a new opportunity for OM researchers to examine the underlying value of different flows. Specifically, observe that the buyer knows about information flows of the supplier's transactions, the bank controls the financial flows of the supplier, and the supplier manages the material flows in the supply chain. Given that different parties control different flows, how should one divide the value created among these three parties to ensure voluntary participation (i.e., Pareto improving)? Which financing scheme (receivables financing or purchase order financing) is more efficient? To answer these research questions, one needs to examine the strategic interactions among all three flows.

4 New Capabilities: Connectivity, Clarity, and Continuity

We have suggested three emerging research topics driven by three new forces observed from Google Trends between 2019 and 2020. We now argue that, to succeed in a dynamic and yet uncertain world, a firm should consider leveraging Industry 4.0 associated technologies to build three capabilities (i.e., Connectivity, Clarity, and Continuity) in order to achieve efficiency, resilience, and sustainability. For each capability, we first provide a definition, and then illustrate ways to build such capability in managing the three flows by using the three new OM research topics described in §3. As an overview, Table 2 provides a summary about what these capabilities are, why they are important, and how they can be strengthened.

4.1 Connectivity

Recognizing that global supply chains involve partners spreading across the globe, it is essential for each firm to develop "connectivity" as a capability to connect resources (e.g., technology, raw materials, and human capital) and entities (e.g., supply chain partners and customers) for better communication, coordination, and collaboration. As more businesses move beyond traditional industry silos and weave themselves into networked ecosystems, connectivity will become a vital tool for firms to maintain a competitive edge and expand into new markets. In the following section, we elaborate on the notion of "connectivity" as a capability in several contexts, including those research topics presented in §3.

Connecting business partners within a supply chain. Industry 4.0 technologies IoT sensors and blockchain can facilitate connectivity among dispersed resources and decentralized entities to achieve on-time, transparent, and reliable information flow. In the context of sustainable coffee farming as described in §3.1, the firm's socially responsible practices rely on its connectivity capability to track and trace all

	Connectivity	**Clarity**	**Continuity**
What	The capability to connect resources and entities for synergistic value enhancement.	The capability of using data to clearly understand and predict customer needs so that a firm can make precise operational decisions.	The capability to sustain business operations and improve environmental sustainability and social responsibility.
Why	Connecting partners within a supply chain (or supply chain partners in a different sector) can facilitate information sharing so that firms can improve communication, coordination and collaboration (including resource sharing).	In the big data era with high volume, variety, velocity, and veracity, firms should leverage data analytics to establish clarity to sense and respond swiftly with targeted and customized solutions.	Operating in a dynamic and uncertain world (e.g., the Covid-19 pandemic), firms need to improve business continuity capability and organizations need to ensure environmental sustainability by leveraging technologies as well as natural and social resources.
How	Using Industry 4.0 technologies such as IoT sensors and blockchain to enhance connectivity among dispersed resources and decentralized entities to facilitate the three flows in an on-time, transparent, and reliable way.	Leveraging new technologies to gain visibility within the ecosystem, business analytics tools to understand market and predict demand, and prescribe data-driven solutions.	Using new technologies like drones, 3D printing, blockchain, and AI tools to reduce risks, carbon emission, and animal extinction.

Table 2: Triple-C capabilities for improving efficiency, resilience, and sustainability.

three flows to ensure the compliance of sustainable farming practices. For example, Denver's Coda Coffee partnered with a startup, bext360, to develop a blockchain that integrates machine vision, blockchain, cloud computing, and AI to trace coffee in every step: collecting, washing, drying, milling, export, and roasting of beans through retail operations (Philips, 2018). For instance, smallholder farmers in Uganda can deposit their produce into a "bextmachine" that uses 3D scanners, machine vision, and AI (machine learning) to determine the quantity and quality of the coffee beans. Then the machine issues a receipt to farmers to collect fair payments (Sodhi and Tang, 2020). These examples illustrate how IoT sensors and blockchain can enable a firm to "connect" all involved parties. In a similar vein, a blockchain platform can enable all partners to connect by sharing, authenticating, and verifying relevant information automatically. For

example, IBM and Maersk formed a partnership in 2017 to develop a blockchain platform to automate the updating process of information and documentation provided by different supply chain partners (exporter, logistics providers, banks, insurance companies, customs, shippers, etc.). In doing so, all information can be verified and reconciled by all involved parties without duplication errors, and without delay so that the shipping process can become more efficient (Tang and Veelenturf, 2019).

Connecting business partners across different supply chains. In addition to partners within a supply chain, establishing connectivity with partners offering complementing resources in a different supply chain (or industry) can create synergistic value that can enhance each firm's value. Consider the HSBC-Alibaba supply chain financing example as described in §3.3. Through the partnership connection between HSBC and Alibaba, HSBC can utilize Alibaba's data about its merchants' background and historical transactions, and Alibaba shares a portion of the gain from successful supply chain financing. This form of connections can be very valuable in the midst of the Covid-19 pandemic (Tang and Yang, 2020). Besides financing, connectivity can enable different firms in different sectors to share employees during a crisis. For example, during the Covid-19 lockdown, Amazon, CVS, and Albertsons faced demand surges and yet Hilton hotels were in lockdown. By collaborating with Hilton, these retailers were able to hire those furloughed Hilton workers for short-term assignments (Rivera 2020). Similarly, when Hema (Alibaba's retail grocery chain) faced demand surges and labor shortages during the Covid-19 pandemic, it connected with restaurant chains such as Xibei and Yunhaiyao (with excessive workers during lockdown) to develop an employee-sharing plan so that over 3,000 restaurant workers could help Hema temporarily without losing their jobs permanently (Wang 2020).

Connecting people: providers and users. In addition to connecting with business partners, connectivity with customers is equally important, especially for firms that operate as on-demand service platforms. Essentially, all platform business models connect service providers and users (Chen et al. 2020). For example, eHarmony (an online dating platform) uses data analytics and AI to develop matching algorithms to improve the success rate for men and women to find their soulmates for marriage. Also, social network platforms such as WeChat can connect unknown shoppers to make purchases in order to obtain a "group discount" on Pinduoduo.com – China's fastest-growing e-commerce platform (Zhu et al. 2019).

4.2 Clarity

In this data-rich era, descriptive, predictive and prescriptive analytics are essential for firms to improve efficiency, resilience, and sustainability. In this context, we define "clarity" as the capability to analyze data and process information in a timely and accurate way. With such a capability, a firm will be able to clearly understand supply conditions and market needs and therefore make precise operational decisions.

Clarity in gaining visibility. Supply chain operations are often opaque and firms rarely have clear visibility about their supply chain operations. For example, immediately following the Covid-19 outbreak in China, many company executives in the U.S. were still trying to identify which of their suppliers had a site in the specific locked-down regions of China (Choi et al. 2020). Therefore, to reduce supply chain risk, clear visibility of supply chain operations is critical. To elaborate, consider the supply chain financing issue as described in §3.3. We argue that it is vital for lenders to gain visibility not only about a buyer's direct supplier, but also its indirect suppliers. Industry 4.0 technologies can bring clarity to firms. For instance, Chinese fintech startup JDH leverages mobile technology and blockchain to allow lenders to finance suppliers several tiers deep into various complicated electronics manufacturing supply chains based on the buyer's creditworthiness. This approach alleviates potential supply disruption caused by suppliers hidden further upstream in the global supply chain. Further, technologies such as IoT and smart contracts can help better link loan amount and timing to physical supply chain transactions; e.g., releasing funds in purchase order finance can be directly linked to the amount of raw material procured.

Clarity in understanding and predicting demand. A firm can build its clarity by leveraging different industry 4.0 technologies. For example, retailers can use smart shelves with sensors and webcams to gather data on shopper behavior and demographics. AWM (a leading smart shelf company) uses various Artificial Intelligence and machine learning tools to analyze different customers' shopping behavior data and to predict the interest of a customer when she is located within the proximity of a smart shelf. Based on the predicted interest, this smart shelf can present personalized promotional videos to entice this customer to make purchases. In the event this customer picks certain items off the shelf, the smart shelf has weight sensors to monitor the existing quantity of items on the shelves and notify stock room staff to refill inventory before the item gets depleted from the shelf. Hence, this form of clarity can improve operational efficiency.

Besides smart shelves, the clarity is also a new capability to improve sustainability by reducing food waste. Anticipating savvy customers will purchase the freshest item that has the longest expiration date, wasteless.com has developed electronic price tags and smart algorithms for retailers to predict the underlying demand and set different prices according to the expiration date: Items with a short expiration date are sold at a discount price.[10] Based on various pilot runs conducted in Italy, this form of clarity enabled by wasteless tags with smart pricing has shown a reduction of 89% in food waste (Pieters, 2019).

Clarity in prescribing data-driven solutions. Analyzing customer-centric data enables firms to improve the customer experience and operational efficiency by prescribing solutions to delight customers. For example, by using AI to analyze each customer's preference, JD.com, a leading e-commerce company in

[10]The discount is determined by a smart algorithm that takes multiple factors such as weather, day of the week, location, and time into consideration.

China, is able to select six personalized products to display on the customer's mobile phone to maximize its projected profit based on the purchase likelihood and the profit margin. In the same vein, Alibaba's online marketplaces (Tmall and Taobao) use machine learning tools to make product assortment decisions to better meet each user's preference (Feldman et al. 2018). Leveraging artificial intelligence, fintech lenders such as Ant Financial (formerly known as Alipay, affiliated with Alibaba) and Kabbage (a U.S.-based online financial technology company) can make data-driven business loan decisions within minutes.

4.3 Continuity

Firms operating in a dynamic and uncertain environment need to have the resilience and tenacity to survive for the long term. Meanwhile, the existence of businesses has been increasingly associated with the well-being of nature (which offers resources) and society (which offers labor and market). Therefore, "continuity" is a critical capability for firms to sustain business operations and improve environmental sustainability and social responsibility.

Continuity in reducing risk. Industry 4.0 technologies can enable firms to mitigate the risk of disruption so that they can continue their operations. First, to enable farmers to improve their productivity and reduce waste (water and fertilizer), smart phones, drones, and big data analytics can be beneficial. In Chile, researchers are developing drones with special cameras that can allow farmers to monitor the condition of their crops from their smartphones. By analyzing the data captured on camera using big data analytics, farmers can monitor moisture content, ground water, plant health, and pest infestation. This way, they can localize water and pest control, saving water and improving yield (Tang, 2016). Second, due to PPE shortages, the Food and Drug Administration approved the 3D-printed mask created by the Veterans Health Administration and the 3D-printed shield developed by Nissan (USA). This 3D-printed PPE can serve as a stopgap solution (a liquid barrier) to protect health care professionals against Covid-19 so they can continue to save lives (Ryan, 2020). Third, to reduce the risk of product adulteration, blockchain technology can help companies to reduce the disruption so that they can continue their operations. For example, Walmart and nine other firms – Nestlé, Dole, Tyson Foods, Unilever, and others – partnered with IBM to use blockchain to track and trace provenance so that they can improve food safety and be more responsive to food recalls. Luxury-brand conglomerate LVMH launched a blockchain platform in 2019 to track the origins of products to authenticate its luxury goods (Sodhi and Tang, 2020).

Continuity in reducing carbon emission. Besides electric vehicles, firms can leverage online platforms to improve sustainability by reducing carbon emission due to unnecessary driving. Consider a crowd shipping platform that assigns drivers (ordinary persons who registered with the platform) to parcels for them to deliver to their neighbors on their way back home from the office or from a shop. Therefore, by piggybacking

on rides the drivers would have taken anyway, this crowd-shipping platform reduces the number of deliveries via traditional delivery vans and thereby reduces emissions. Other than crowd shipping, "trunk delivery service" is a new initiative being developed in which a Logistics Service Provider (LSP) such as DHL can gain temporary access to the trunk of the customer's car (Volvo, GM, Ford, or Lincoln) by having the customer unlock the car remotely via a smart phone. This can reduce emissions because it reduces the need for the LSP to visit the customer again or for the customer to pick up the goods at a designated collection point (Liu et al. 2019).

Continuity in reducing extinction. Many species are facing extinction, and drones and AI can help. Across Africa and Asia, $10 billion in annual illegal trades of endangered species are threatening the survival of elephants, rhinoceroses, tigers, etc. Many organizations such as the World Wildlife Fund (WWF) and Save the Rhino collected donations and contributed funds to recruit more rangers to safeguard these Rhinos, but this preservation effort is inefficient. Currently, scientists are developing innovative methods to save these animals. First, through direct observations obtained from drones, IBM scientists learned that Zebras move along-side Rhinos, but move in opposite direction when encountering a poacher with a gun. Anticipating this behavior, these scientists put sensors on zebras to monitor their movement. This way, scientists can alert the rangers when the zebras move in the opposite direction to reduce poaching. Second, by using machine learning tools to analyze historical data on poaching incidents, computer scientists can predict when and where Rhinos are likely to be poached so that rangers and drones can patrol these target areas to prevent poaching (Tang, 2018).

In summary, we have argued that, to achieve efficiency, resilience, and sustainability, firms should leverage Industry 4.0 technologies to build three capabilities (i.e., Connectivity, Clarity, and Continuity). As firms explore these capabilities, they will develop more innovative business models that can spark novel research ideas for OM researchers to consider.

5 Conclusion

Recent economic, technological, political and societal changes have posed significant challenges yet created abundant opportunities for OM researchers. In this paper, we examine the evolution of operations management research from a three-flow perspective, and propose future research directions for OM scholars and future operations capabilities for OM practitioners to explore.

Through our investigation of all 4,188 OM papers published in five journals from 1997 to 2018, our literature analysis has revealed that the number of published papers focusing on information and financial flow (with material flow in the backdrop) has increased steadily. Reflecting on this trend along with three

key drivers (economic forces, technological forces, and political and societal forces), we argue that future OM research should take all three flows into consideration.

To postulate future OM research opportunities, we have used Google Trends to examine the search volume during 2019-2020 and found that reshoring, supply chain financing, sustainability and social responsibility appear to be popular searches. This observation has motivated us to suggest three OM research topics, including socially and environmentally responsible supply chains, global supply chain redesign, and innovative supply chain financing, where each topic involves all three flows. Finally, upon closer examination of these three topics along with the ongoing adoption of various Industry 4.0 technologies, we have argued that firms should build (or strengthen) three capabilities (Connectivity, Clarity, and Continuity) to achieve efficiency, resilience, and sustainability. As firms find new ways to develop these new capabilities, more novel OM research ideas will emerge.

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Appendix

1. A Filtering Process for Classifying MS and OR Articles

We examine the department (or review) area that was involved in processing each paper published in MS and OR. For MS, the processing department of a paper is identified in "History Information", whereas in OR, it is clearly presented as "Area of Review". There are some extra steps involved. First, before 2005, MS provided the department editor instead of the processing department for each published paper. By using the editorial board membership listed in the "Front Matter" in each issue, we can trace the corresponding department for each research article published in MS before 2005.[11] Next, because the corresponding area of review is provided for each paper published in OR, we include areas of review related to "operations" or "supply chain".[12] In addition to these areas, we also include (1) a special issue on operations research in healthcare, and (2) "OR practice" and "technical notes" articles that are closely related to operations management.

2. A Machine Learning Procedure for Classifying Articles According to Different Flows

Since only a small portion of the papers published in M&SOM are (manually) classified as information and financial flow-focused papers,[13] we know that they are not sufficient to capture the features of these

[11]For MS, we include the papers processed by the following departments: call center management; design and operations management; incentives and coordination in operations management; inventory management; manufacturing, distribution, and service operations; marketing and operations management interfaces and coordination; operations and supply chain management; operations management; and supply chain management.

[12]For OR, we include the papers under the following areas of review: logistics and supply chain operations; manufacturing; manufacturing, operations, and scheduling; manufacturing, production and scheduling; manufacturing, service and supply chain operations; manufacturing, service, and operations management; operations and supply chain; operations management; revenue management; and supply chain and operations management.

[13]The 655 M&SOM papers contain 111 information flow labels and 44 financial flow labels.

two flows. For this reason, we collected 400 articles from JOM, OR, MS and POM,[14] and develop our "vocabulary" in order to capture certain salient features arising from information and financial flow focused OM research articles. Our approach for developing our vocabulary can be described as follows. First, titles, keywords and abstracts are preprocessed (including tokenization, stop-words removal, lemmatization, and stemming).[15] Next, bag-of-words (BOW) based methods are adopted to extract features of titles, keywords, and abstracts, and 2-gram is used to model sequences of words. For abstracts, we identify the words with a frequency of 1-30% among all abstract texts and then calculate each word's term-frequency minus inverse-document-frequency (TF-IDF). For titles and keywords (short text and contain only 5-20 words drawn from a large vocabulary), the extracted TF-IDF features are very sparse and many informative words will never appear in the training data set. Thus, instead of using TF-IDF for words in titles and keywords, we adopt the Latent Dirichlet Allocation (LDA) algorithm (Blei et al. 2003) to extract the distribution of topics for titles and keywords data, as LDA is a popular dimension-reduction technique to better capture the features of text in this scenario. We set the number of topics to be 100, which performs well in our grid-search and 10-fold cross-validation experiments. We combine the extracted features of titles and keywords with the features of abstracts in classification. Finally, based on these features, articles are judged if they belong to a certain article type using XGBoost (Chen and Guestrin 2016), whose optimal settings are decided by performing grid-search and 10-fold cross-validation as well. Then, the classifier chains method (Read et al. 2011) is used to transform the binary classification problem to a multilabel classification problem due to the consideration of dependencies between labels.

We also compare the performances of various classification algorithms using the grid-search and 5-fold cross-validation techniques. The best result of our experiments is obtained by performing oversampling to alleviate the data imbalance problem and using LightGBM wrapped with classifier chains to predict the possible topics for each article.[16] Once the training process is complete, we make predictions for out-of-sample data (samples) from JOM, OR, MS, and POM journals.

In addition, we choose an additional 66 papers at random and manually label these papers to validate the algorithm's outputs, and the micro-average of precision, recall, and F1-score are 93%, 65%, and 76%, respectively. Notice that the recall performance is low, causing a considerable amount of relevant papers not to be retrieved. So we perform a trade-off analysis between recall and precision by changing the classification thresholds θ. In our experiments, we choose 0.5 and 0.3 as classification thresholds for financial and information flows, respectively, and the obtained micro-average of precision, recall, and F1-score are 84%, 80%, and 82%, respectively.

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[14] These 400 articles contain 115 information flow labels and 35 financial flow labels.

[15] Tokenization is the process of dividing a large quantity of text into smaller parts; stop-words removal is the process of deleting the most common words in a language, such as "is", "we", etc.; lemmatization is the process of grouping together the inflected forms of a word so they can be analyzed as a single item; stemming is the process of reducing inflected words to their word stem, base or root form. Preprocessing uses the standard procedures in the Python Natural Language Toolkit.

[16] Comparisons include logistic regression, support vector machines, random forests, XGBoost and LightGBM algorithms for the binary classification problem, and binary relevance, label powerset and classifer chains methods for the multilabel classification problem.