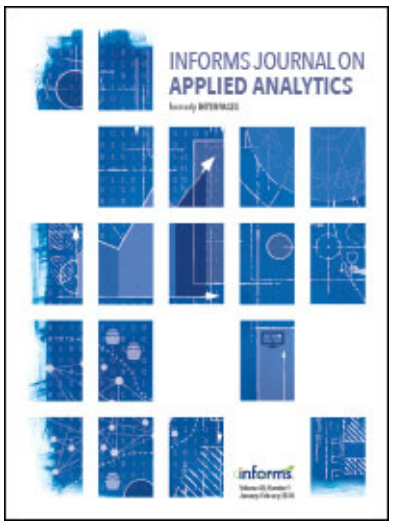

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IJAA: Past, Present, and Future

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Abstract. We review 50 years of research published in *INFORMS Journal on Applied Analytics* (*IJAA*), formerly named *Interfaces*. This historical review considers more than 3,000 publications and details the journal's coverage evolution over five decades. We identify topics, industries, companies, and organizations that have played a significant role in positioning the journal as INFORMS' premier outlet regarding the applications of operations research (OR) in practice. Our goal is to use historical observations to discuss the current state of the journal and reflect on the future, especially related to the increasingly popular area of analytics. We provide perspectives regarding how the fields of OR and analytics may continue to evolve as well as how researchers, practitioners, and *IJAA* can contribute to the continuing evolution of these two fields.

Keywords: analytics • operations research • industry analysis • review

Introduction

Over the last 50 years, the operations research (OR) discipline has seen many changes as well as several new names used to describe the changes, such as management science (MS) and, more recently, analytics. During this time, the journal *Interfaces*, which also recently underwent a name change to *INFORMS Journal on Applied Analytics* (*IJAA*), has served as a premier journal focusing on innovative applications of OR in practice and the impact of these applications on industry, education, and practice in general.

In this paper, we review the papers published in *Interfaces/IJAA* over its 50-year history. In the rest of the paper, we refer to the journal as *INT/IJAA*. The goal of our review is threefold. First, we aim to celebrate the journal's 50-year landmark by chronicling its evolution in content and scope. Along the way, we recognize industries, companies, and articles that have played a significant role in establishing the journal as a recognized source on OR practice. Second, we relate observations made in our review of the journal's evolution to the current state of our profession and the field of analytics, specifically focusing on how the journal has been and continues to be associated with this emerging field. The managerial relevance of analytics in the practice of OR/MS continues to fuel our current interests, research investigations, and emerging applications (Jaworski 2011). Finally, we provide perspectives on how the OR and analytics areas will continue to evolve in the future and the role that *INT/IJAA* can play in this evolution. Essentially, we aim to look at the historical evolution of the journal under a magnifying glass to understand where the journal has been, from the standpoint of coverage, and how it can best prepare for the future. A few other review papers discuss the big data and analytics evolution (see Franks 2014, Mortenson et al. 2015, Choi et al. 2018, Hazen et al. 2018, Sanders and Ganeshan 2018, Batistič and van der Laken 2019). However, this paper focuses explicitly on *INT/IJAA* papers, celebrating its contributions to this evolution over its 50-year history. This paper complements the two other papers in this special issue. First, Gorman et al. (2020) characterize the Edelman finalists. Because the finalist papers appear in *INT/IJAA*, there is an organic linkage between the influential companies/organizations listed in this paper and the impactful Edelman finalists. Second, Lilien et al. (2020) provide an overview of the journal's evolution from the editor's perspective, describing the unique challenges that have been faced and the solutions to these challenges that have shaped the journal's coverage and content. Although there is a relationship between trends in the OR discipline and the papers published in *INT/IJAA*, it would be misleading to ignore "selection bias." Specifically, some factors decouple broader trends in the discipline and the journal's coverage. First, the perspectives of editors in chief (EICs) may filter the coverage to some degree. Second, the practice-focused nature of the journal may deter some academics from submitting their manuscripts to *INT/IJAA*. Finally, some practitioners may not be aware of *INT/IJAA*

and not submit their qualified works to the journal as a result.

As a remark, because it is not possible for us to cite all of the more than 3,000 papers published in the journal over the last 50 years, we only cite the papers that emerge in different aspects of the analysis. The remainder of the paper is structured as follows. In the next section, we provide an overview of the approach we used to classify the articles published over the 50-year scope of the review. In Analysis of Topics, we discuss the selection of topics for classification purposes and provide basic statistics regarding the journal's thematic coverage. In Decades Analysis, we consider the evolution of OR and analytics by observing the changes in the topics and present a detailed analysis of topic linkages. The thematic analysis leads into a discussion of the top 30 impactful papers in Article Impact followed by impactful industries in Industry Analysis. In Company Impact, we provide a breakdown of company leaders in their respective industries. In Analytics and *INT/IJAA*, we discuss the emergence of analytics and the role that *INT/IJAA* has and is playing in the evolution of this field. In Future Trends, we provide a futuristic assessment of the analytical trends for our profession. Finally, in Conclusions, we summarize our key findings, discuss the limitations, and offer future research directions in light of this historical review.

Overview

This section provides an overview of the methodology. To properly review the past 50 years of publications, we collected information on all *INT/IJAA* publications using two data sources:

1. The INFORMS publication data available from https://pubsonline.informs.org/.
2. The CrossRef application programming interface, which is documented at https://github.com/CrossRef/rest-api-doc.

We used two sources to ensure that we obtain a comprehensive set of data regarding published articles. Using these two data sources, we harvested the metadata and abstracts for all articles published or accepted for publication in *INT/IJAA* through the year 2020. We use a unique digital object identifier (DOI) number to differentiate articles. For each unique DOI, we attempt to collect the following information: volume, issue, number of pages, authors, publication month, publication year, number of references, and number of citations. Although we did our best to collect data systematically, we cannot claim that our data are error-free. For instance, we observe that, for a given article, different citation numbers could be obtained depending on the information source, for example, Google Scholar versus CrossRef. For the sake of consistency, we only report data from the two stated sources, both of which rely on CrossRef information.

After the initial data processing, we obtained data for more than 3,200 documents. However, not all of these documents were refereed publications. Some of them were book reviews, opinion pieces, INFORMS meeting calendars, and other recurring articles of information published in the journal. We provide a breakdown of these recurring documents in Table 1. Before continuing, it is worth noting that the Rothkopf ranking, published regularly as an editorial, includes practice abstracts as *mini* papers. Specifically, the ranking considers these abstracts at one half the weight of a standard article. However, the data sources we use provide no meaningful abstracts for practice abstracts. Thus, including these abstracts would require an additional step of data processing that is not done for other articles. Instead of introducing "special cases," we elect only to utilize the abstract data obtained from the stated sources.

After removing these recurring titles, we have 2,367 articles over the 50 years. The remainder of our analysis focuses on this set of nonrecurring papers.

Analysis of Topics

This section uses the collected data to observe prominent topics that have been considered by the journal during its 50-year history. To conduct this analysis, we reviewed all of the abstracts, assigning topics to each abstract based on its content. After assigning topics, we then went through the list of topics, aggregating them into higher level categories. It is worth noting that we did not determine the topic or category names a priori. Instead, we generated topics and categories as needed to fit the collected abstract data best. Following these

Table 1. Uncategorized Articles

Nonpublication category	Number of observations
Book reviews	162
Contributors	88
INFORMS meeting calendar	90
Practice abstracts	31
Management science roundup	15
Franz Edelman Award for Management Science	15
Letters to the editor	21
The Daniel H. Wagner Prize	8
Seen elsewhere	8
Instructions to authors	16
Call for papers: Special issue	15
Editorial board	5
Interfaces Outstanding Reviewer Award	3
Commentary	12

Notes. We provide a breakdown of all of the uncategorized articles in this table. Book reviews represent the majority of the uncategorized articles.

steps, we obtained 46 categories. We list the exact keywords for these 46 categories in Tables A.1–A.3 in Appendix A. Note that each one of the topics can be seen as an application area of OR/analytics. Here is the list of the topics as a whole in alphabetical order: academic applications, advertising/marketing, advice, agriculture, air operations, armed forces, conferences, construction/project management, data analysis and analytics, delivery, distribution, emergency response, environmental, facility design, finance, forecasting/planning/scheduling, freight transportation, general, healthcare, human resources, human/life, information systems, inventory management, management, manufacturing, maritime operations, modeling/systems, operations research, pricing, productivity, public, queueing, rankings, research and development/technology, resource allocation, retail/food/nonprofit, reviews/surveys, risk management/conflict, security/safety, service, sports, strategy, suppliers/vendors, telecommunications, transportation/routing, and utilities/natural resources.

Note that in this categorization, some of the terms are somewhat generic. First of all, there are "fun" or "weird/offbeat" articles that we group under the general category. Next, although the application area–related terms do not require much of an explanation, let us explain what we refer to as operations research and data analysis and analytics. If a particular publication is based more on generic methodological developments, as opposed to applications, we used the operations research category. On the other hand, if a publication is based solely on data analysis and results based on the data analysis, we place it under the generic category of data analysis and analytics. However, the papers with a specific application focus, regardless of their OR methodology or data-based analysis, are put under more specific application categories. Figure 1 shows the proportion of DOIs that we associate with each of the categories. According to the proportion of DOIs, the top 10 categories are manufacturing, academic applications, operations research, finance, forecasting/planning/scheduling, utilities/natural resources, healthcare, armed forces, public, and data analysis and analytics. Note that these topics are across the 50 years. Looking into specific topics within the broader categories, we see a similar pattern. Specifically, Figure 2 provides the proportion of DOIs for the top 25 topics (regardless of their categorization). Similar to what we observe in the categories, we find that the manufacturing and operations research areas have the most significant number of publications. However, the next most prominent topics are education, healthcare, and military applications. It is also interesting to note that more than 2% of the DOIs consider applications related to sports.

Although counting the publications is one way to demonstrate the popularity of a particular topic or a category, another perspective is the number of citations within a topic. Figure 3 provides insight into the top 25 topics by interest. Specifically, the y-axis demonstrates the relative citations, that is, the number of citations associated with each topic divided by the

Figure 1. (Color online) The Proportion of DOIs Associated with Each of the 46 Categories

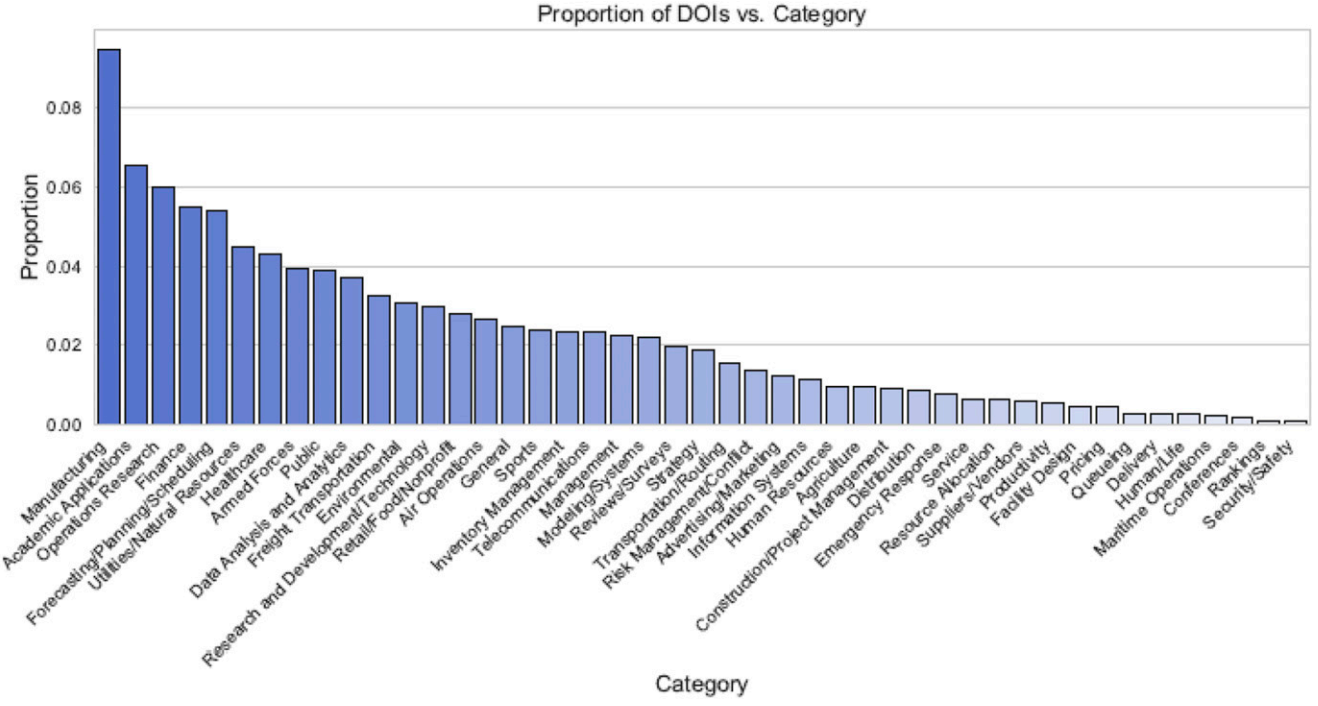
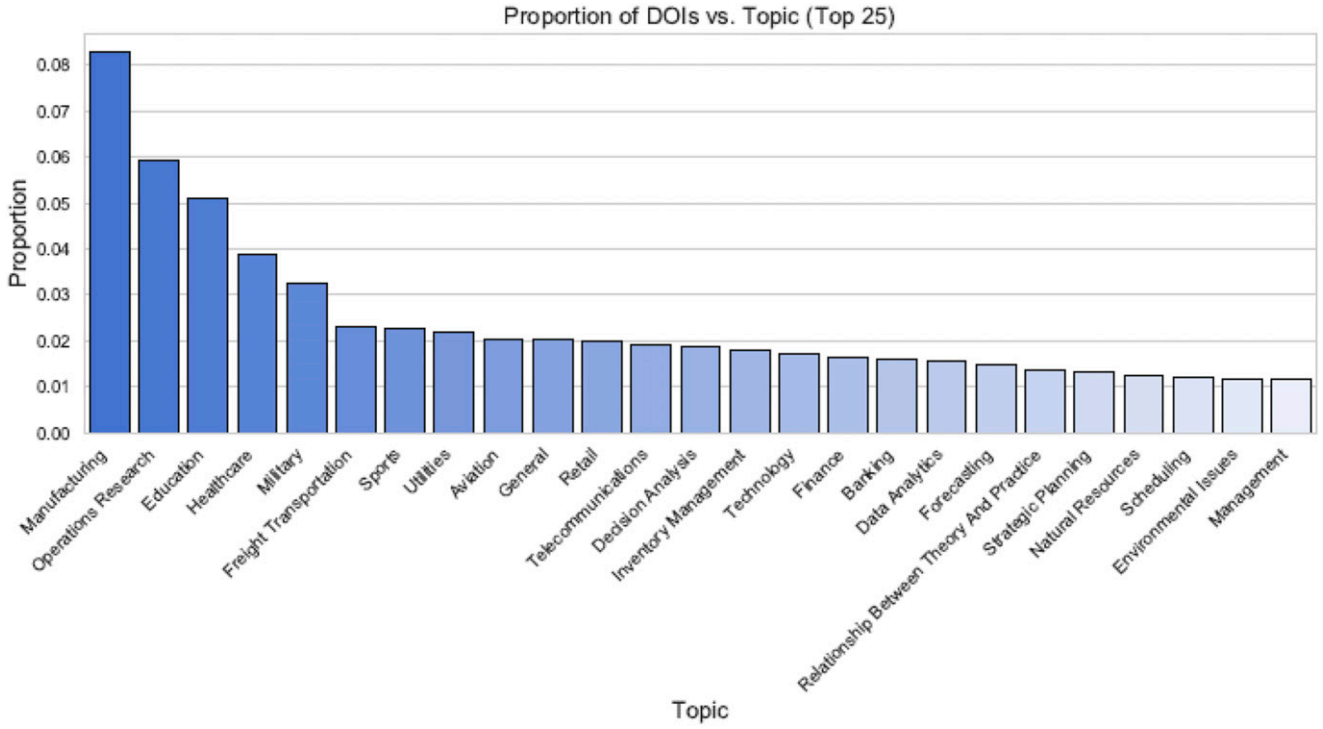


Figure 2. (Color online) The 25 Topics as a Proportion of the Total Number of DOIs



Notes. Over 50 years, manufacturing, operations research, education, healthcare, and military appear heavily represented. These topics continue their relevance today.

maximum number of citations associated with any topic. Then, we see the top 25 topics by relative citations. In terms of both publication counts and relative citations, the manufacturing and operations research topics come out on top. However, when we look into relative citations, aviation and retail move to the top five. Healthcare as a topic also moves up in the ranking by a spot to the third place.

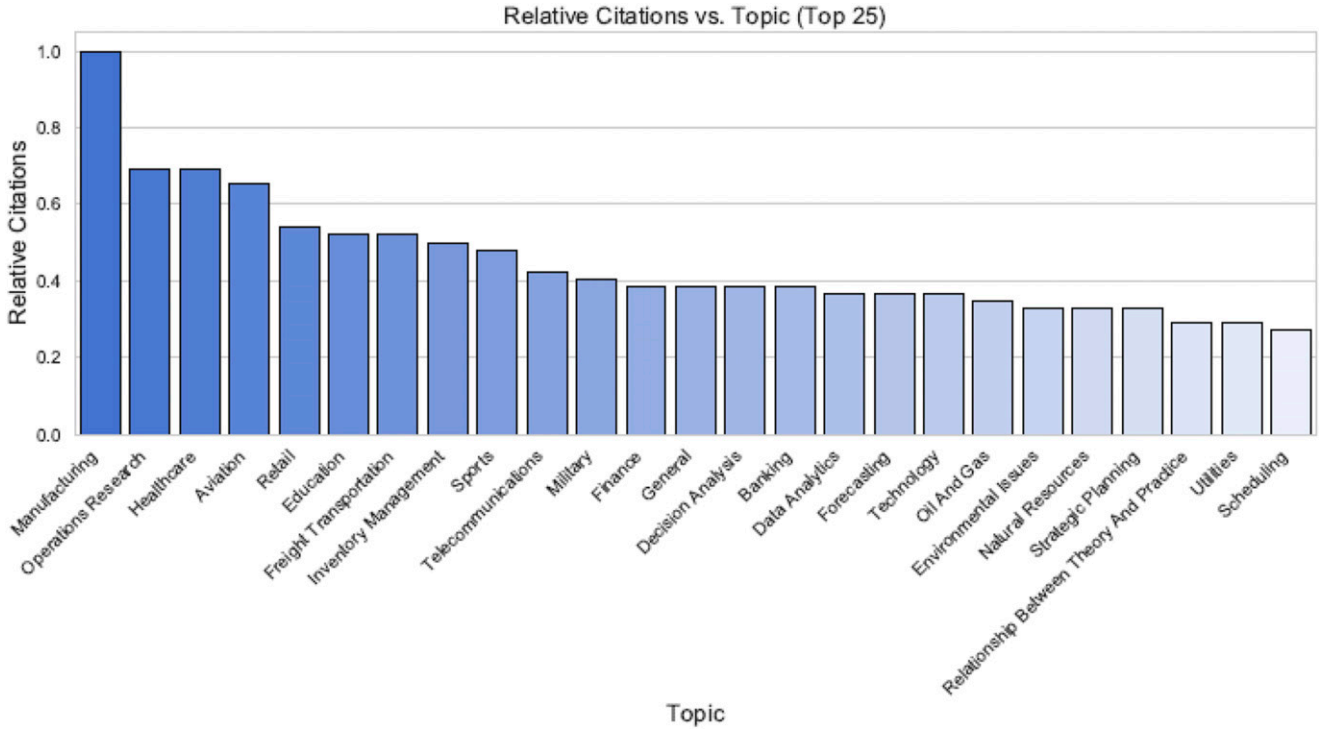
Decades Analysis

In this section, we expand our topic analysis by adding a time dimension. Specifically, we investigate the evolution of topics over the five decades and demonstrate some of the parallels between the evolution of discipline and the coverage of *INT/IJAA*. Although the selection bias we mention earlier is still valid, we see remarkable connections that allow us to understand the intertwined paths of *INT/IJAA* and our profession.

We first demonstrate the changes in overall topics over decades in terms of both relative publication counts (DOIs) and corresponding relative citations. We show these changes in the two heat maps provided in Figure 4. Specifically, the left subplot of the figure shows the evolution of topics based on the number of papers, and the right subplot shows the evolution based on the number of citations associated with each topic. In these subplots, we calculate the values associated with each cell as a proportion relative to the sum of values in the same column, that is, values for all topics in the same decade. For instance, manufacturing is the topic that is most covered over the whole tenure of the journal (as indicated by the overall column). At the same time, based on the darkness of the cells, manufacturing is the most popular topic by far during the 1990s and 2000s. We observe the same point in Figure 5.

Note that the topics associated with the highest number of unique DOIs (shown in the left subplot of Figure 4) do not necessarily correspond to those associated with the highest number of citations (shown in the right subplot of Figure 4). Two factors contribute to this discrepancy. First, in each decade, a subset of topics trends owing to high interest by the research and practitioner communities. Based on our data, the topics of management, modeling, and manufacturing are the dominant topics of interest in the 1970s, 1980s, and 1990s, respectively, when considering the number of citations. In the 2000s, we observe several topics vying for the top spot with respect to citations: manufacturing, data analysis and analytics, freight transportation, retail/food/nonprofit, and inventory management. It is interesting to note that this decade is also a period of growth in the field of supply chain management. In particular, it is during this decade that we observe a

Figure 3. (Color online) The Relative Citations for the Top 25 Topics



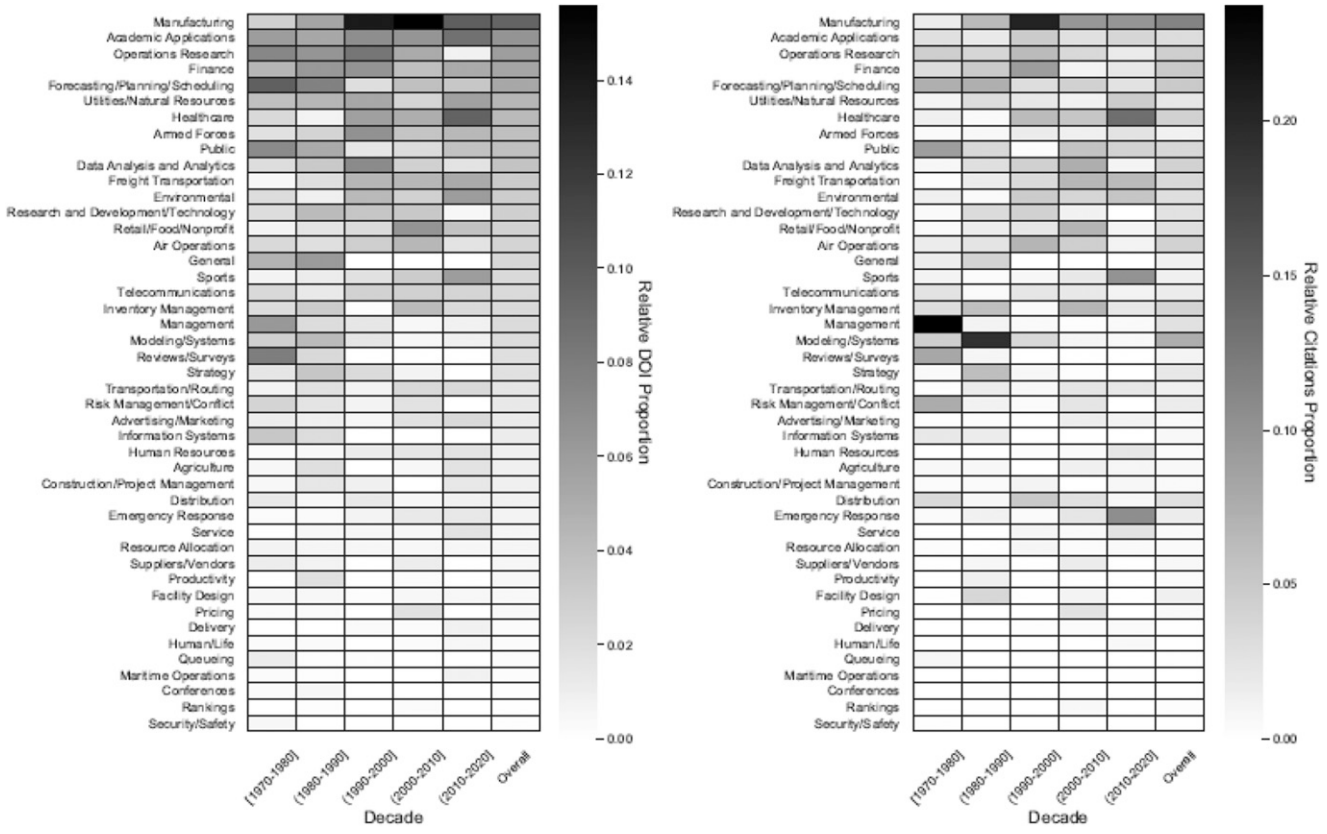
Notes. We define "relative citations" as the ratio of the number of citations associated with each topic to the maximum number of citations associated with any topic. Sorting by the relative citations metric serves as an approach to identify the most impactful topics.

sharp decline in the percentage of value-adding activity contributed by sellers of products, pointing at higher degrees of outsourcing, and China emerges as a global competitor in terms of manufacturing capability (Gilmore 2020). In the 2010s, we observe a shift in interest toward services, particularly healthcare. Specifically, although papers associated with manufacturing and freight transportation continue to garner a high number of citations, the two most popular topics are healthcare and emergency response. It is also within this decade that we see sports emerge as a popular topic, rivaling the interest obtained by manufacturing and freight transportation.

We now focus more closely on the 10 topics with the highest proportion of DOI values in each of the decades over the journal's 50-year history. We depict the results in Figure 5. Figure 5 suggests that the first decade of the journal primarily focuses on techniques related to forecasting/planning/scheduling techniques, reviews/surveys, and topics related to operations research. This observation is consistent with the findings of Mortenson et al. (2015) that associate the 1970s with the era of decision support systems. This is the decade in which several spreadsheet-based and computer technologies started to become available for forecasting and production planning. EIC Simon experiences a similar trend during his tenure (Lilien et al. 2020). Additionally, in the earliest decade, *INT/IJAA* is still trying to define its position in the OR landscape. Hence, although we observe reviews/surveys as a primary topic in this decade, it tends to decline in popularity in subsequent decades.

In the 1980s, two EICs serve the journal, Woolsey and Lilien, and establish the practice orientation of the journal. Although forecasting/planning/scheduling continues to appear as the topic with the largest number of papers, we see that operations research rises to the second spot. Recall that this is a category for generic methodological applications. This is not surprising because EIC Woolsey "was a champion of the common-sense practice of OR/MS" (Lilien et al. 2020, pp. 347–348). In this decade, we see increased importance in quantitative solution techniques. Likewise, in this decade, and only in this decade, modeling/systems appears as a top 10 category. In this decade, we also see that finance emerges as a prime application area. Although finance is in the top 10 in all decades, it achieves its highest relative importance in the 1980s. Another interesting observation from the 1970s and 1980s is that OR practice within the public domain (public and utilities/natural resources) is of high interest. As Kirby (2000) states, the 1980s is the decade in which "OR diffuses into manufacturing, the state-owned public utilities, an increasing range of government departments, and the discipline's incorporation

Figure 4. Two Heat Maps Representing the "Popularity" of the Topics over the Decades



Notes. The final column represents the cumulative data as in Figures 2 and 3. The left plot is for the number of papers on each topic, and the right plot is for the number of citations. The topics are sorted from largest to the least number of papers on the left. We kept the same order on the right for easier comparison. The values in each cell represent the ratio of the numbers for that topic to the total numbers in that decade.

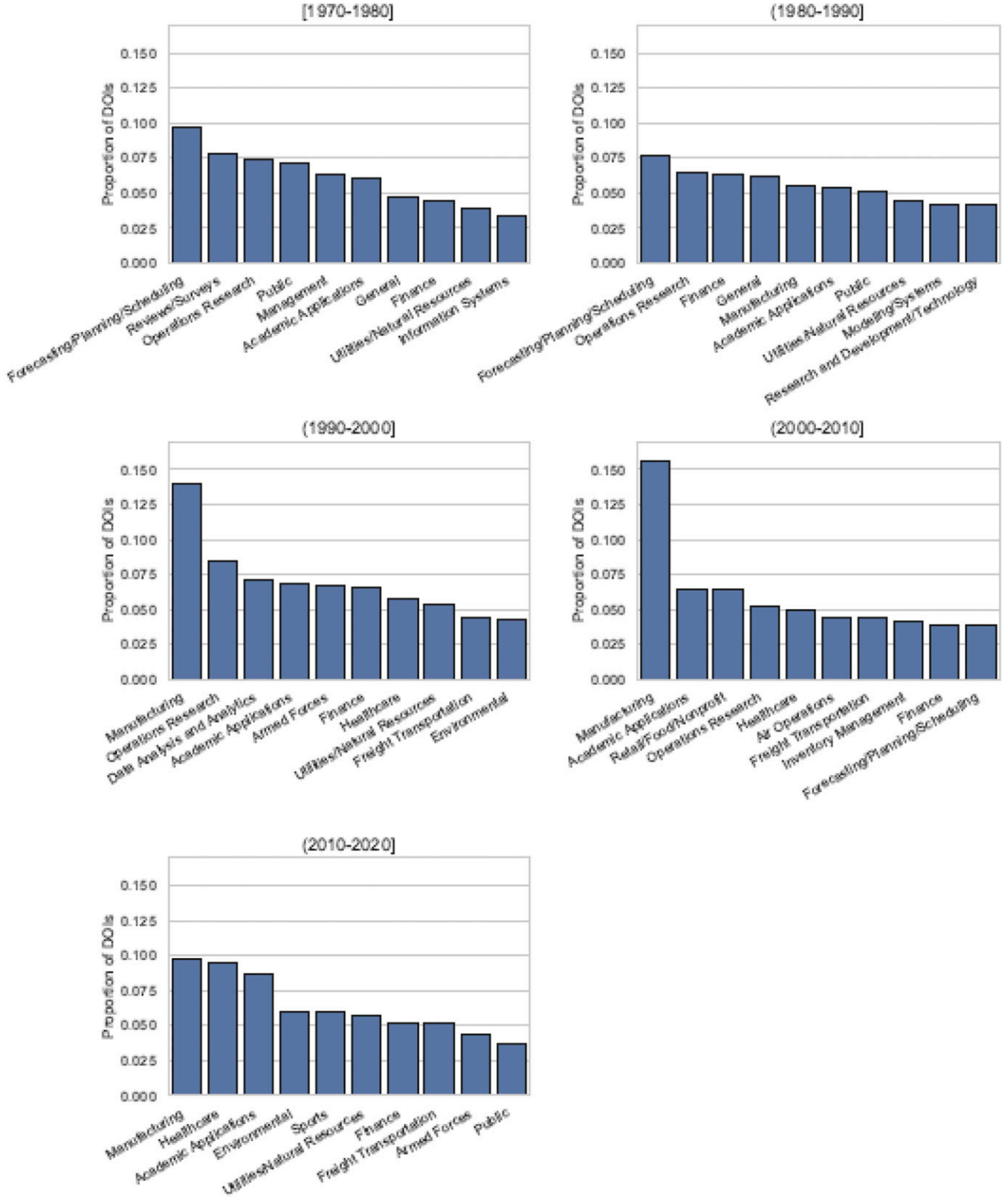
in university-level curricula." We observe this phenomenon within *INT/IJAA* publications from this decade.

In the 1990s, manufacturing rises to the top spot, nearly doubling the relative number of DOIs associated with the operations research category, which is ranked second. It is during this decade that we see increasing interest in material requirements planning (MRP) systems, just in time (JIT), the Toyota production system (TPS), and total quality management (Chopra et al. 2004). Also, in the 1990s, data analysis and analytics appears as a top 10 topic for the first (and last) time. This is related to our classification and a vast amount of transactional data being generated and used by systems such as MRP, JIT, and TPS. Note that this is more related to data handling and gives insight to the humble beginnings of *analytics* as we know it today. Several *INT/IJAA* papers focus on the best practices regarding the handling of data coming from these systems (Ulusoy and Uzsoy 1992, Flowers 1993, Schuster and Allen 1998, Roethlein and Mangiameli 1999, Klassen 2000).

In the 2000s, we see the continued interest in manufacturing, and we also see increasing interest in retail, food, and nonprofit-related topics as well as inventory management. Hence, the practice of OR starts looking into specific manufacturing and supply chain problems in detail. This is the decade that the notion of supply chain management emerges strongly in practice (Fisher 1997, Simchi-Levi et al. 2003, Harrison et al. 2006, Sanders and Ganeshan 2018). From the procurement of raw materials to manufacturing, distribution, inventory management, and customer demand fulfillment, a number of application papers appear under various categories. Additionally, the deregulation of transportation (especially the trucking and railroad industries) in the United States opens the door to more modeling-based improvements.

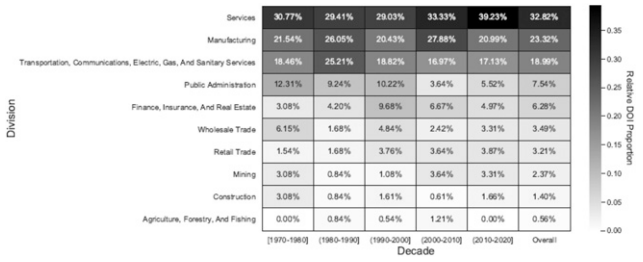
In the last decade, service operations nearly surpass manufacturing operations. Service organizations, from healthcare to finance to freight transportation, dominate the publications in this decade. Several healthcare applications continue to create value, including contributions related to healthcare practices, care (including home care and long-term care), emergency management systems, treatment optimization, operations research, and analytics.

Figure 5. (Color online) Five Subplots Displaying the Top 10 Topics with the Largest Number of Papers Each Decade



Note. These individual charts demonstrate the topics with the most sustained interest over the decades (e.g., manufacturing, operations research) and which ones popped in and out of view (e.g., human resources).

Figure 6. Heat Map Showing the Relative Number of Publications for Each SIC Division Each Decade



Notes. Accordingly, each cell represents the number of publications for the labeled SIC division during the associated decade as a percentage of the total number of publications in the same decade. The last column represents the cumulative percentage for each SIC division over five decades. The SIC divisions are sorted according to this last column.

Many related papers appear as Edelman finalists (e.g., American Red Cross) and winners (U.S. Centers for Disease Control and Prevention, Memorial Sloan Kettering Cancer Center) (Gorman et al. 2020). Despite the increased number of contributions related to services in this decade, there are still many opportunities for research on the design, deployment, and operation of systems offering new services—or old services via new technologies—more efficiently.

Industry Analysis

INT/IJAA is INFORMS' premier practice journal. Thus, we want to investigate the industries that are impacted by research published in the journal. For this purpose, we document any specific company names mentioned in the data and map the identified companies to industries via four-digit Standard Industrial Classification (SIC) codes. From Wikipedia (2020):

> The Standard Industrial Classification (SIC) is a system for classifying industries by a four-digit code. Established in the United States in 1937, it is used by government agencies to classify industry areas. Agencies in other countries also use the SIC system, e.g., the United Kingdom's Companies House, etc. SIC codes have a hierarchical, top-down structure that begins with general characteristics and narrows down to the specifics. The first two digits of the code represent the major industry sector to which a business belongs. The third and fourth digits describe the subclassification of the business group and specialization, respectively. For example, "36" refers to a business that deals in "Electronic and Other Equipment." Adding "7" as a third digit to get "367" indicates that the business operates in "Electronic, Component and Accessories." The fourth digit distinguishes the specific industry sector, so a code of "3672" indicates that the business is concerned with "Printed Circuit Boards."

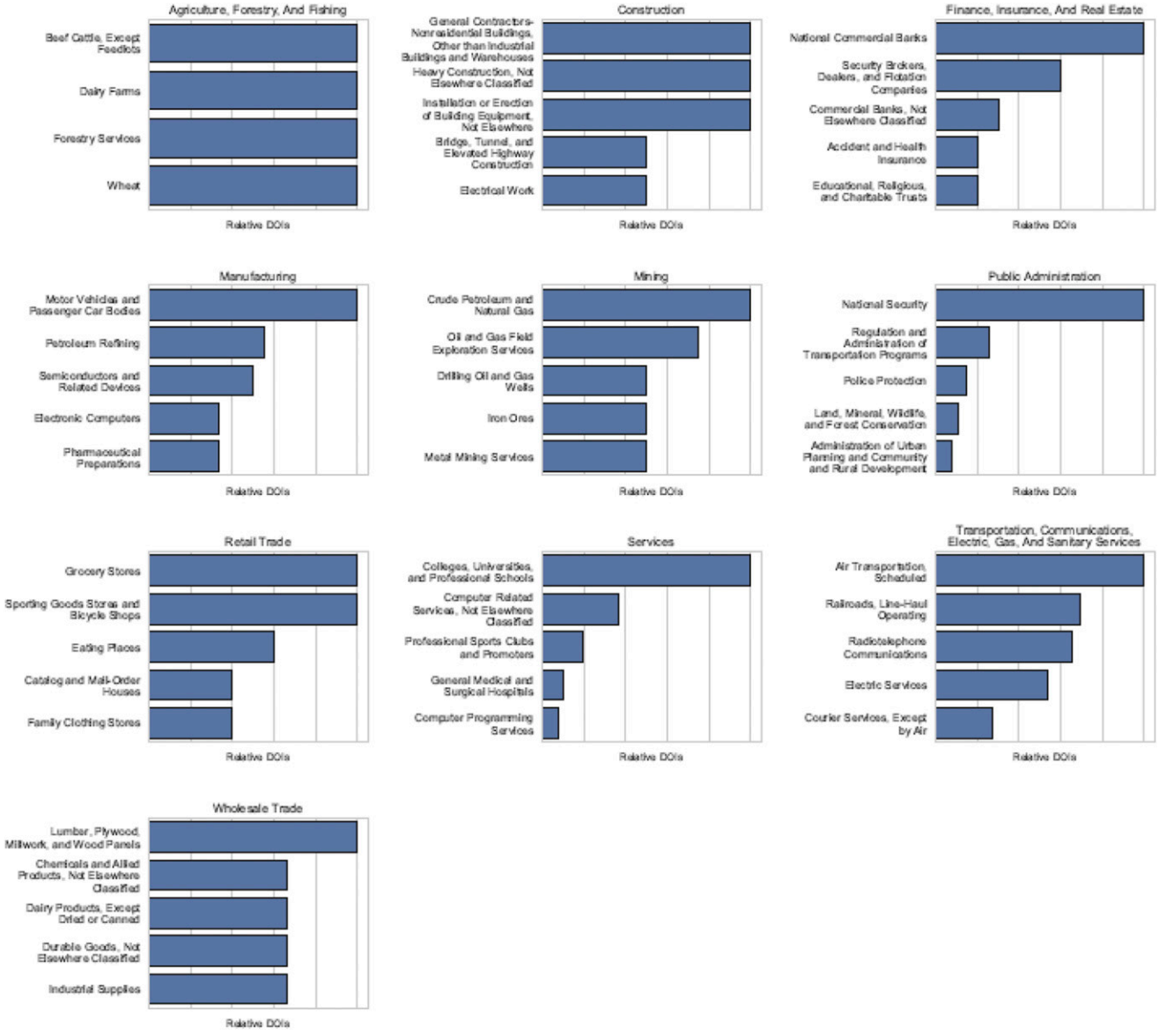
Figure 6 presents a heat map that is based on the labeled data and shows how the associated SIC divisions vary over time. The percentages included in each cell of the heat map indicate the percentage of publications that correspond to the associated division (row label) in the current decade (column label). Thus, the sum of the values in each column is 100%. Note that we are only considering publications for which we are able to identify an industry and map a company in this analysis. Figure 6 shows that research related to service and manufacturing is the predominant areas of focus throughout the journal's life, being associated with more than 50% of the publications that reference a company partner in each decade. The transportation industry is also well represented with more than 15% of the publications in each decade. Regarding other divisions, we observe a general decrease in the proportion of publications associated with public administration firms and an increase in firms associated with retail trade. Figure 7 expands on the categories shown in Figure 6 to industry sectors. Specifically, the figure shows the relative popularity of the five most popular industry sectors in each division.

Instead of discussing each subplot in Figure 7, we highlight several observations. First, *INT/IJAA* is a popular outlet for research regarding the oil and gas industry. Note that the SIC classification system that we employ classifies companies associated with this industry over two divisions: mining and manufacturing. In the former division, the three most popular sectors by the relative DOI measure are all related to oil and gas, primarily the extraction of oil and gas. In the latter division, research related to oil and gas refining claims the third most popular spot. This is not surprising as the oil and gas industry is an early adopter of OR in practice and major oil/gas companies make significant financial contributions to the early development of LP solvers, modeling languages, software, and so on. Second, the operations of commercial banks dominate the area of finance. Third, recall from Figure 6 that the service division appears as the most popular division across all decades. Figure 7 suggests that this popularity may be driven mainly by works engaging with or focusing on operations at academic institutions. A more interesting observation is that papers related to professional sports are historically more abundant than those focused on other popular services, such as healthcare.

Company/Organization Impact

In this section, we look at specific companies and organizations that have appeared in *INT/IJAA* papers. Figure 8 shows the companies and organizations that have appeared in two or more articles in the journal throughout its history. We calculate the values in each cell with respect to the associated decade column. Specifically, the value denotes the number of unique DOIs with which the company/organization is

Figure 7. (Color online) The Top Five Industries According to the Number of Publications for Each SIC Division

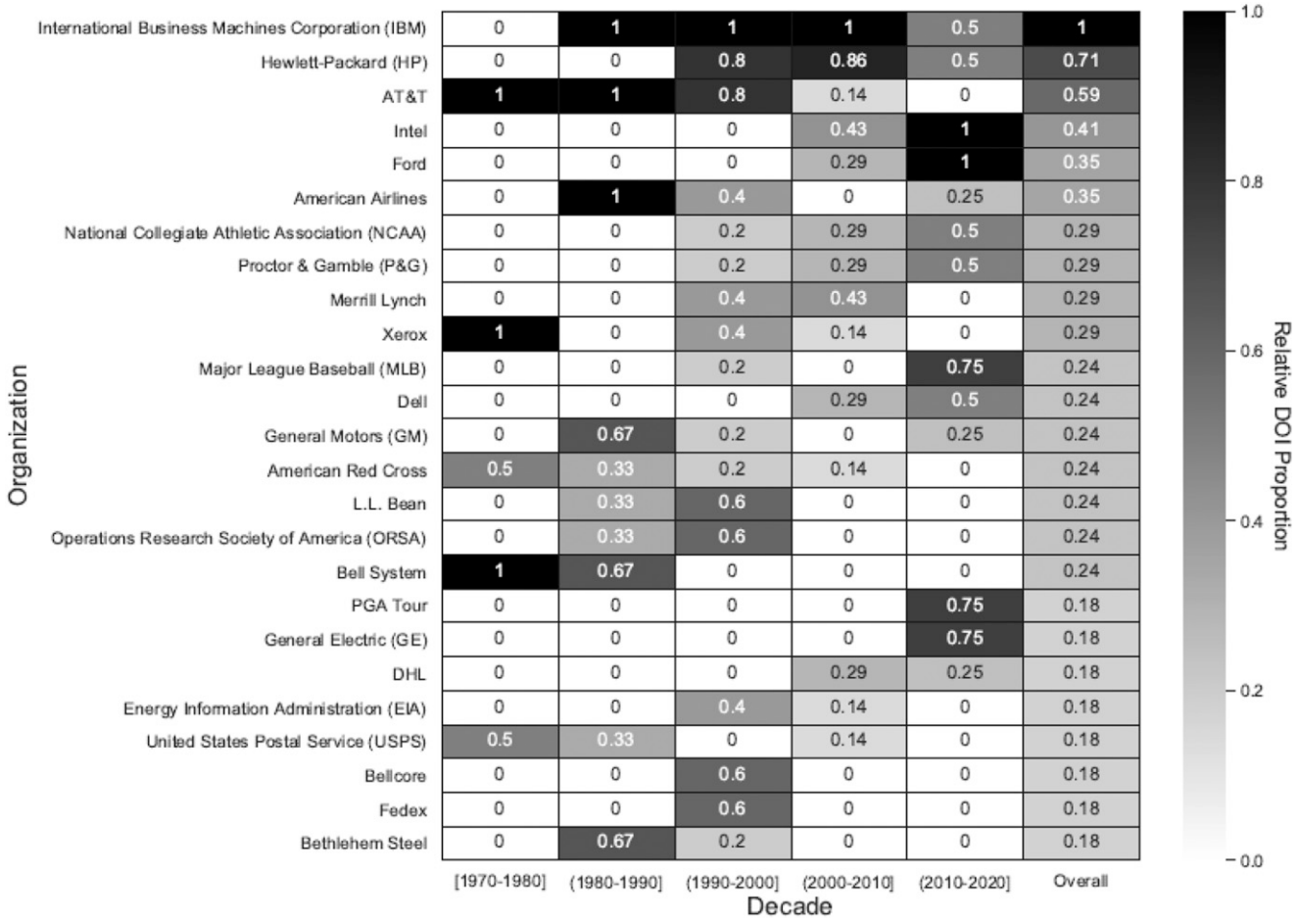


Note. In each SIC division, there are several industry sectors.

associated relative to the maximum number of DOIs associated with any company in the same decade. As an example, consider the column for 1970–1980. In this column, AT&T has a score of 1, which indicates that the number of unique DOIs that are associated with AT&T is as large as the number of unique DOIs associated with any other organization during the same period. On the other hand, a score of 0.5 for the American Red Cross indicates that some other organization(s) (e.g., AT&T, Xerox, and Bell System in this case) have more associated DOIs during the period.

Figure 8 shows that a small number of companies pave the way for other companies. These companies include AT&T, Xerox, the American Red Cross, USPS, and Bell System. It is not surprising that these companies have OR divisions or R&D divisions with OR PhDs. In the 1980s, General Motors, American Airlines, L.L. Bean, and Bethlehem Steel introduce the automotive, airline, retail, and steel manufacturing industries to the journal. The 1990s see a substantial increase in both the number and diversity of companies associated with the journal. It is in this decade that we see the National Collegiate Athletic Association (NCAA) and Major League Baseball (MLB) join the fold of companies interacting with the journal, serving as preliminary entrants for professional sports associations. Following their lead, we see the PGA Tour join during 2010–2020. In this latter decade, we see a diverse group of industries represented,

Figure 8. Heat Map Showing the Relative Involvement for Companies and Organizations that Have Been Associated with Two or More Articles in the Journal Throughout Its History



Note. The cell values denote the number of unique DOIs with which the company/organization is associated relative to the maximum number of DOIs associated with any company in the same decade.

including technology-related firms, professional sports organizations, transportation-focused firms, and manufacturers. Viewing the changes across the decades provides a good sense of the journal's breadth and the wide-ranging applicability of OR and analytics. Note that, although some of the companies listed in Figure 8 may no longer exist or be as prominent as they once were, they were once leading companies and organizations in their respective industries. As the discipline and journal become more welcoming of analytics, we should expect to see more involvement from leading companies in this space (e.g., Amazon, Google, Apple, Facebook, or Microsoft). To facilitate such a shift, we need to rethink the managerial relevance of OR/analytics in terms of the impact timing (present versus future) and the nature of the impact (action versus thinking) (Jaworski 2011).

Article Impact

This section highlights a subset of the most impactful articles that appear in the journal. It seems logical that such an assessment be based on the articles with the highest number of citations. However, this metric favors articles published early in the journal's life because they have been in circulation for a longer amount of time. It is also likely that papers associated with popular topics, such as manufacturing or forecasting, receive higher citations than papers focusing on more niche areas, such as natural resource– or utilities-related problems. Instead, we use an analytical method for calculating a citation score for each publication and compare the actual citations against this citation score.

Specifically, we use a simple linear regression model to control for the topic and the time of the publication. We use the following model to generate a prediction model for the number of citations received by each publication:

$$\ln(citations) \sim published\ decade + topic, \qquad (1)$$

where *published decade* is a categorical variable denoting the decade of publication and *topic* is a categorical

variable denoting the topic. The dependent variable is the natural logarithm of the number of citations, and we confirm that this model specification leads to residuals that are approximately normally distributed. Although the linear regression we use is straightforward, it does outperform more complex linear models, including interactions in terms of adjusted R^2. Moreover, it outperforms the predictions obtained by a mixed-effects model allowing each topic to have a different intercept. Our comparison with the mixed-effects model is based on comparing the mean sum-of-squares errors between the actual citations and the predicted citations. We provide additional details on the fitted regression model in Appendix B.

We use the regression model to predict the number of citations that each publication should have received. We use this predicted value to compute the ratio of actual citations to predicted citations. This ratio represents the number of citations each article has received as a multiple of the predicted citations. We use this value to identify the top 30 articles in Table 2. The A/P citations column in the table indicates the value of the computed ratio for each paper. As a result of our approach, the identified articles are not necessarily the most cited articles although most would be identified using a pure citation-based metric. Instead, the articles are those that have accumulated citations at an abnormally high rate in comparison with similar articles.

We elaborate slightly on the top 10 articles displayed in Table 2 to provide a better sense of the topical diversity represented by these articles. Galbraith (1974) is regarded as one of the first articles to outline an information processing view of organization design. Green et al. (2001) describe the use and evolution of conjoint analysis techniques over the 1970s, 1980s, and 1990s. Arntzen et al. (1995) describe a global supply chain model developed by Digital Equipment Corporation, a major company in the computer industry that was acquired by Compaq in 1998. Fylstra et al. (1998) is written by members of the team that developed the solver feature for Microsoft Excel. The paper discusses the project team's rationale between several design decisions that are implemented in the tool and identifies some common pitfalls that users may experience as well as workarounds. Zahedi (1986) presents a survey for the Analytic Hierarchy Process (AHP), a technique that blends mathematics with psychology to help decision makers determine objective rankings among alternatives. Smith et al. (1992) present details on the use and benefits of revenue management for a major early adopter, American Airlines. Bell et al. (1983) describe a decision support system developed for Air Products and Chemicals, Inc., in the early 1980s that integrates inventory management and vehicle scheduling decisions. Golabi et al. (1982) describe a pavement management system for the state of Arizona. The system produces optimal maintenance policies for the 7,400-mile highway network in the state and resulted in $14 million of savings during its first year of implementation. This is equivalent to approximately $37 million at the time of writing. A comparative site analysis that is based on data envelopment analysis () and funded by the Texas legislature for the location of a high-energy physics labs is described in Thompson et al. (1986). Guide et al. (2000) describe characteristics of recoverable manufacturing systems. Specifically, they compare them with the traditional manufacturing systems and present ways that recoverable manufacturers must adapt to manage the associated challenges.

Considering all 30 articles, it is interesting to note that many are tutorials or surveys for a particular concept or application area (Galbraith 1974, Teece 1988, Bertsekas 1990, Rosenhead 1996, Dowlatshahi 2000, Guide et al. 2000, Brown et al. 2006, Newman et al. 2010), methodology (Zahedi 1986, Bertsekas 1990, Glover 1990, Green et al. 2001), or technology (Fylstra et al. 1998). We also observe more opinion-oriented articles (Liebman 1976, Ackoff 1981, McKay et al. 1988, Ramdas and Spekman 2000). Thus, it seems that, historically, *INT/IJAA* is a popular outlet for works that define new application areas for OR, demonstrate how to apply OR techniques, and spur conversations on the practical utility of OR research. On the papers in Table 2 that are illustrating specific applications, it is interesting to note how the application areas evolve. In particular, earlier papers are mostly related to public entities, transportation systems, or logistics (Saaty 1977, Golabi et al. 1982, Bell et al. 1983, Thompson et al. 1986). In the 1990s, we see papers focus on service companies (Smith et al. 1992), banking/insurance companies (Carino et al. 1994, Sherman and Ladino 1995), and technology companies (Arntzen et al. 1995, Lee and Billington 1995). The most recent paper is on mitigation tactics for supply chain risks that arise in the automotive industry (Simchi-Levi et al. 2015). Ultimately, *IJAA* covers research spanning high-level models for information flows in organizations, reviews of emerging research areas, tutorials on popular techniques, and articles that showcase how leading companies are employing OR to improve operations. Moreover, the journal attracts submissions from this spectrum that turn out to be impactful contributions by the broader research and practitioner communities.

Table 2. Top 30 Articles Based on the Ratio of Actual Citations to the Number of Citations that the Regression Model Predicts Each Publication Should Have Received

Citation	Title	A/P citations
Galbraith (1974)	Organization Design: An Information Processing View	464.81
Green et al. (2001)	Thirty Years of Conjoint Analysis: Reflections and Prospects	194.10
Arntzen et al. (1995)	Global Supply Chain Management at Digital Equipment Corporation	176.50
Fylstra et al. (1998)	Design and Use of the Microsoft Excel Solver	142.90
Zahedi (1986)	The Analytic Hierarchy Process—A Survey of the Method and Its Applications	136.18
Smith et al. (1992)	Yield Management at American Airlines	120.83
Bell et al. (1983)	Improving the Distribution of Industrial Gases with an On-Line Computerized Routing and Scheduling Optimizer	106.78
Golabi et al. (1982)	A Statewide Pavement Management System	101.64
Thompson et al. (1986)	Comparative Site Evaluations for Locating a High-Energy Physics Laboratory in Texas	101.48
Guide et al. (2000)	Supply Chain Management for Recoverable Manufacturing Systems	100.66
Dowlatshahi (2000)	Developing a Theory of Reverse Logistics	98.93
Glover (1990)	Tabu Search: A Tutorial	96.87
An et al. (2013)	A Deployed Quantal Response-Based Patrol Planning System for the U.S. Coast Guard	92.51
Lee and Billington (1995)	The Evolution of Supply Chain-Management Models and Practice at Hewlett-Packard	87.36
Brown et al. (2006)	Defending Critical Infrastructure	87.28
Teece (1988)	Capturing Value from Technological Innovation: Integration, Strategic Partnering, and Licensing Decisions	83.89
McKay et al. (1988)	Job-Shop Scheduling Theory: What Is Relevant?	77.51
Carino et al. (1994)	The Russell-Yasuda Kasai Model: An Asset/Liability Model for a Japanese Insurance Company Using Multistage Stochastic Programming	74.37
Bertsekas (1990)	The Auction Algorithm for Assignment and Other Network Flow Problems: A Tutorial	74.36
Saaty (1977)	The Sudan Transport Study	68.85
Ackoff (1981)	The Art and Science of Mess Management	68.79
Liebman (1976)	Some Simple-Minded Observations on the Role of Optimization in Public Systems Decision-Making	66.63
Rosenhead (1996)	What's the Problem? An Introduction to Problem Structuring Methods	65.87
Fisher (1985)	An Applications Oriented Guide to Lagrangian Relaxation	65.51
Sherman and Ladino (1995)	Managing Bank Productivity Using Data Envelopment Analysis (DEA)	63.46
Lee et al. (1993)	Hewlett-Packard Gains Control of Inventory and Service Through Design for Localization	62.97
Simchi-Levi et al. (2015)	Identifying Risks and Mitigating Disruptions in the Automotive Supply Chain	61.39
Newman et al. (2010)	A Review of Operations Research in Mine Planning	61.14
Abara (1989)	Applying Integer Linear Programming to the Fleet Assignment Problem	60.84
Ramdas and Spekman (2000)	Chain or Shackles: Understanding What Drives Supply-Chain Performance	58.37

Notes. The "A/P citations" column in the table indicates the value of the computed ratio for each paper. The regression model we use considers both the decade and topical area when generating predictions.

Analytics and *INT/IJAA*

The recent name change from *Interfaces* to *INT/IJAA* may cause some to question whether the journal is simply trying to associate itself with the latest buzzword. Instead, our review of the journal's coverage suggests that the name change is very fitting and perhaps overdue. For example, many people associate the surging interest in *sports analytics* with the publication of *Moneyball* in 2003. However, our company/organization investigation reveals that the NCAA and MLB were both represented in the journal during the 1990s (see Figure 8). Instead of chasing the next popular catchphrase, it could be argued that the journal postponed the name change until the time at which an appropriate description emerged.

INFORMS defines analytics as "the scientific process of transforming data into insights to make better decisions" (INFORMS 2020). Davenport et al. (2010) offer another, very popular, definition of analytics: "the extensive use of data, statistical and quantitative analysis, explanatory and predictive models, and fact-based management to drive decisions and actions." A common aspect of both definitions is the suggestion that analytics seeks to *drive action*. On the other hand, INFORMS defines OR as a discipline focused on the application of advanced analytical methods for improved decision making. OR utilizes techniques from other mathematical sciences, such as statistics, simulation, queuing, and mathematical optimization. Because of the scale of problems faced in practice, the application of OR solutions often requires substantial computational infrastructure. Thus, the discipline also has strong ties to computer science.

The provided definitions for analytics and OR suggest that the two are closely related. Specifically, both definitions emphasize *applications* and *actions.*

In practice, it seems there is a perception that the OR discipline is focused on developing or identifying efficient methods for solving a wide range of problems under the assumption that data are "available" in a certain format. Note that we are not saying that OR assumes all inputs are known with certainty. A large amount of OR research focuses on models for situations in which certain inputs are unknown or stochastic. However, regardless of the assumed degree of certainty associated with the input parameters, models typically classified as OR models assume that input data satisfying some specified format are available. In contrast, the main focus of analytics is on data preparation, data transformation, and using appropriate models to generate insights that can support decision making. The area of analytics is typically subcategorized into three distinct types (Lustig et al. 2010):

Descriptive analytics: exploring historical data and converting data into information with a combination of information systems and basic statistics.

Predictive analytics: converting data into information and determining future trends with statistical methods and machine learning approaches.

Prescriptive analytics: determining business actions and insights using the information from descriptive analytics and trends from predictive analytics via traditional OR methods.

This segmentation provides insight into the aforementioned intertwining of the definitions for OR and analytics. It suggests that it is impossible to create mutually exclusive distinctions between the two fields. Since its inception, *INT/IJAA* has contributed to both OR and analytics, serving as a well-recognized outlet for methodological contributions and documenting success stories of world-renowned organizations with impactful solution approaches for challenging problems.

Future Trends

Big data and analytics are popular topics in both the regular press and academic publications (Davenport et al. 2010, Davenport and Patil 2012). However, the review paper by Mortenson et al. (2015) points out that references to analytics are limited in the OR literature despite strong connections. We suspect that the lack of references may be due to the view that the applied bent of analytics is somewhat inferior to the more theoretical work that is typically categorized as operations research. However, it is essential to recognize that the mindsets of companies and academics are changing. In particular, we are living in an age in which companies, organizations, and policymakers are aware of the impact that data and their analysis offer, influencing the culture, leadership, and organizational talent of companies. Thus, instead of striving to differentiate the field of OR from analytics, we should strive to increasingly associate our discipline and demonstrate its potential to contribute to business decision making. In the future, we hope that these nomenclatures will continue to merge as data-driven decision making continues to influence our profession.

As new opportunities for business analytics and OR talent emerge, there are implications for the educational programs. The new generation of OR analysts need to be data- and tech-savvy with proper soft skills. Modifying a somewhat comical definition used to define data scientists, the new generation of OR analysts need to be individuals who know statistics better than the software engineers, know software engineering principles better than the statisticians, understand the core concepts and quantitative methods of OR, and are able to explain their analyses to managers with little to no quantitative backgrounds. To facilitate the development of such individuals, OR educational curriculum should focus on appreciating the availability of different forms of data, the data-driven model formulation, analysis of results, and interpretation of the insights. We need to distinguish what quantitative analyses can offer as well as what the shortcomings are.

To this end, we see five future directions that will contribute to the practice of analytics: big data to big insights. Some of the most notable aspects of the current business environment are the availability of data, growth in data, real-time data analytics, and data visualization. With data becoming more abundant, it may be time to reexamine OR tools and quantitative techniques developed under less data-rich conditions. In particular, such reexamination can focus on validating the core assumptions of significant theoretical constructs, confirming and demonstrating the validity and use of theory, and linking behavioral decision making with the rational theory. Expanding our understanding in this realm will provide new and actionable insights for practitioners as well as interesting research directions for OR scientists. Regarding the implications to *INT/IJAA*, the journal encourages authors to discuss challenges encountered during the implementation of solution approaches specifically. These implementation details provide insights into situations in which modifications to the theory are sometimes warranted to fit reality. These insights help researchers understand the gaps between theory and practice and ways to replicate implementations in other contexts.

OR/MS/Analytics in a Wider Spectrum

Historically, outsiders tend to associate the OR discipline with a relatively narrow range of applications,

predominately in the manufacturing, service, and transportation industries. However, at its core, our discipline is designed for supporting decision making in general. In the past, we may have struggled to encourage the use of quantitative models with restrictive assumptions in practice. With increased appreciation for data-driven decision making, there are more opportunities for OR practitioners to be involved in a wider variety of business domains. We already see an increase in applications involving multiple areas, such as OR/finance, OR/supply chains, OR/marketing, and OR/human resources, to name a few. In the future, we believe that the popularity of techniques, such as machine learning and artificial intelligence, will carry OR/analytics to the front lines of other business (and nonprofit) domains. Our topic analysis has shown that *INT/IJAA* historically demonstrates the use of OR tools in a wide range of industries. We see no reason to believe this will change, moving forward.

Interdisciplinary Expertise

If OR/MS/analytics continues to increase its range of applications, it will no longer be sufficient to be an expert in a single domain. It is important to understand, respect, and apply constructs from more than one discipline. As many well-known results are designed for implementation in systems for automated decision making, the only way to act as an exception-handler is to expand the boundaries of knowledge with different perspectives from different disciplines. As a testament to this perspective, we have seen an increase in the number of interdisciplinary studies conducted in the last decade, and we believe this trend will continue.

Ethics, Security, and Privacy

As data grow, so do the issues surrounding how to ensure their security. However, data security is not the same as data privacy. Whereas data security focuses on the technology and tools to keep the data secure from cybercriminals, data privacy is related to proper handling of data, including their collection and maintaining compliance. There are still a number of open debates regarding data privacy, data security, and the ethics of data use. Looking forward, it is imperative that researchers stay informed of advances and policy changes stemming from these conversations to protect the integrity of their work and the data that are used.

Educational Innovations

Educational curricula need to evolve to address all three levels of analytics, that is, descriptive, predictive, and prescriptive. We expect OR applications of the future to move toward providing prescriptive analytics in real time and handling exceptions with human experts. We anticipate that *INT/IJAA* will facilitate this evolution by providing documented examples of successful applications. It is up to us, the current OR scientists, to stay current regarding how OR is being applied in practice so that we can adapt the curriculum as needed and prepare future generations appropriately.

Concluding Thoughts

This review summarizes 50 years of OR research published in *INT/IJAA*, showcasing the evolution of the discipline in practice. We observe that, through this evolution, the appreciation for applied problems is strongly pronounced, and the application areas shift as more suitable theory and technologies are developed. We demonstrate the shifts from manufacturing processes to the design and management of service industries. We also reflect on the boundaries and relevance of our discipline through an analysis of topics over time.

In his historical review of the OR discipline from the 1940s through the 1990s, Kirby (2000) writes,

> In a much broader context, applicable also to the United States, it is evident that the post 1950s diffusion of industrial OR was facilitated greatly by the ongoing process of economic growth. . . . As Pat Rivett remarked in a 1974 paper with respect to his own experience as an OR practitioner, "For many years, those of us in Operational Research had a rather easy and exciting life. Our life was easy because the national economies in which we worked were expanding, new job opportunities were constantly being created and the growth of the organizations which we served, which is one of the fundamental objectives of all organizations, was more or less assured by the continuing growth of the economies in which we worked. . . ."

As we demonstrate in this paper, many things have changed since 1974. Moreover, with the rapid increases in data, computational power, and interest surrounding analytics, we see no reason for things to slow down. Thus, the cited claim is as true today as it was in 1974. With the availability of data and new problem domains, we, OR researchers and practitioners, still have an exciting life ahead of us.

Appendix A. Topic Keywords

Specific keywords for the topic categories we use are given in Tables A.1–A.3.

Table A.1. Topics Used with Specific Keywords, Part 1

Topic	Keywords
Academic applications	Academic applications, class/room assignment, course scheduling, curriculum design, education, education systems, special education, pedagogy
Advertising/marketing	Advertising, advertising scheduling, customer channels, magazine/newspaper, market analysis, MS/advertising, MS/marketing, social media
Advice	Advise
Agriculture	Agriculture, fishing, food, forest operations, harvest planning, infestation prevention, land use, milk production, seed orchards
Air operations	Air traffic, aircraft, aircraft maintenance
Armed forces construction/project management	Coast guard, defense applications, military, military operations bid preparation, bridge construction, construction, labor contracts, project failure, project management
Data analysis and analytics	Analytics, data analysis, data analytics, data management, data principles, decision analysis, decision analytics, machine learning
Delivery	Delivery, delivery logistics
Distribution	Distribution, distribution centers, distribution design, logistics, logistics service, production transportation network, supply chain, warehouse operations
Emergency response	disaster, disaster management, emergency, emergency medical service planning, emergency response, fire management, fire response planning, natural disaster, search and rescue
Environmental	Environment, environmental issues, natural areas, natural resources, nature conservation, recycling, reservation systems, sustainability, waste collection, waste management, wastewater, water pollution control, water supply optimization, weather
Facility design	Facility layout, facility location, facility location and design, location allocation, location analysis, space allocation, terminal site location, space
Finance	Acquisitions, auditing, bank operations, bond market yields, compensation, cost analysis, cost minimization, cost effectiveness, credit, economic analysis, finance, funding, insurance, investment, investment planning, MS/finance, payment audits, revenue management, stock market, tax audits, tax, underwriting
Forecasting/planning/scheduling	Budgeting, capacity planning, capital budgeting, corporate planning, Delphi method, distribution planning, food planning and delivery, forecasting, formal planning methods, manpower planning, personnel scheduling, planning, production planning, production scheduling, sales forecasting, sales planning, scheduling, shift scheduling, shipment planning, timetabling, urban planning

Table A.2. Topics Used with Specific Keywords, Part 2

Topic	Keywords
Freight transportation	Fleet management, fleet sizing, freight transportation, rail, rail operations, rail transportation, ship routing
Healthcare	Blood bank operations, blood banks, blood testing, rail, dialysis services, disease, disease prevention and eradication, drugs, healthcare, heart valve production, medical payments, patient census, pharmaceutical, pharmacy, vaccinations
Human resources	Candidate screening (employment), ethical, ethics, human resources, interview, people skills, personnel management, recruiting, recruitment, retirement, staffing, training, workforce management
Human/life	Adoption, breeding, humor, religion, value of human life
Information Systems (IS)	Implementation, information systems, IS adoption, IS basics, IS implementation
Inventory management	Inventory, inventory control, inventory management, inventory planning, inventory risk management, newsvendor, order fulfillment, replenishment, supply and demand matching
Management	Business management, change management, conference management, management, management reporting system, psychological study of management
Manufacturing	Auto manufacturing, capacity management, flexible manufacturing systems, lean, lean enterprise, maintenance, manufacturing, manufacturing logistics, manufacturing performance, manufacturing strategy, PCB production, plywood manufacturing, production capacity, production control, publishing and publication process, quality, spare parts, wood product manufacturing
Maritime operations	Barge shipping, canal operations, port, port management
Modeling/systems	AHP, auction models, Bayesian modeling, case method, computer simulation, DEA, decision support systems, dynamic programming, expert systems, heuristics, Lagrangian relaxation, linear programming, Markov decision processes, modeling, multicriteria analysis, preference modeling, regression, simulation, spreadsheet modeling, systems analysis
Operations research (OR)	Conference notes, operations research, OR practice
Pricing	Auction, price controls, pricing, profit targeting, sales
Productivity	Productivity

Table A.2. (Continued)

Topic	Keywords
Public	Census, criminal justice and crime, districting, elections, electoral, government, inmate assignment, international, legal, patrol routing, police, population control, postal operations, public safety, public service, public transportation (school bus), regulations, society and policy, terrorism, unions, voting
Queueing	Queuing theory
Rankings research and development/technology	Awards, prizes, ranking, scoring action research, behavioral science, case studies, creativity, entrepreneurship, innovation, laboratory management, patents/trademarks, performance tracking, product development, progress and frontiers of MS, projective scaling, scientific research, technology
Resource allocation	Allocating resources, allocation, assignment, matching, product distribution, resource allocation, supply rationalization, worker productivity

Table A.3. Topic Details with Specific Keywords, Part 3

Topic	Keywords
Retail/food/nonprofit	Charity, commodity markets, e-commerce, food processing and distribution, housing, merchandising, newsprint industry, nonprofit, nutrition, real estate, rental operations, retail, volunteer
Reviews/surveys	Review, survey, journal impact
Risk management/conflict	Conflict management, disruption risk, economic issues, error, failure, modeling issues, risk analysis, risk management, risk mitigation, uncertainty, warranty
Security/safety	Piracy, rules, safety, security
Service	Customer satisfaction, customer service, hospitality, hotel industry, menu positioning, service, service/delivery, tourism
Sports	Dressage, gymnastics, horse racing, lineup selection, sports
Strategy	Corporate strategy, strategic planning, strategic decision, strategic planning, strategy
Suppliers/vendors	Collaboration, consulting, outsourcing, procurement, purchasing, sourcing, supplier relationships, suppliers, vendor selection
Telecommunications	Cellular, communication analysis, computer communications, computer interaction, network models, satellite communications, telecommunications, television, television programming
Transportation/routing	Route planning, routing, transportation, transportation logistics, vehicle routing
Utilities/natural resources	coal unloading, energy, energy audits, energy production, mining operations, oil & gas, solar, utilities

Appendix B. Regression Details

As described in Article Impact, we use a simple linear regression model to control for the topic and time of publication when assessing article impact. Specifically, we use the following model:

$$\ln(citations) \sim published\,decade + topic,$$

where *published decade* is a categorical variable denoting the decade of publication and *topic* is a categorical variable denoting the topic. The dependent variable is the natural logarithm of the number of citations. Figure B.1 shows a normal probability plot for the model residuals. Although we do observe some slight deviation from the diagonal line in the lower and extreme upper quantiles, the residuals largely display the linear relationship assumed to be present when using ordinary least-squares regression.

Table B.1 summarizes the results of the regression analysis, which was performed using the statsmodels library available with the Python programming language (Seabold and Perktold 2010). The adjusted R^2 value shows that our simple model is able to explain approximately

Figure B.1. (Color online) Probability Plot of Residuals for Article Impact Regression

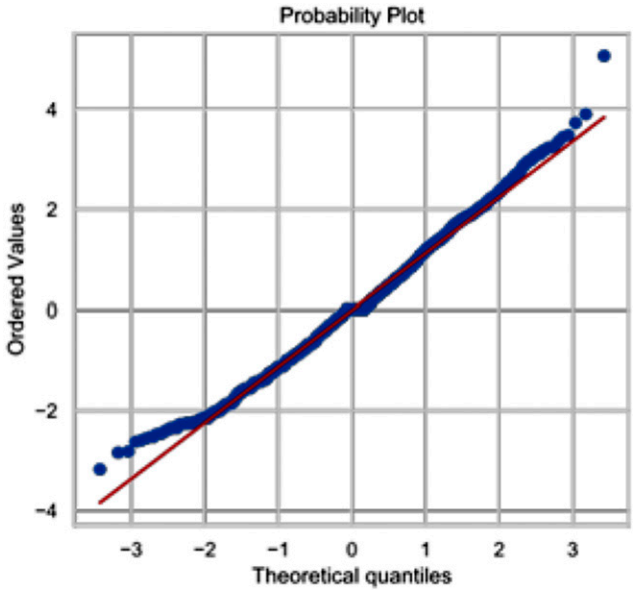


Table B.1. Regression Results

Dependent variable	ln(*citations*)
Model	OLS
Method	Least squares
R^2	0.336
Adjusted R^2	0.221
F statistic	2.919
AIC	8,148
BIC	1.013e+04

22% of the variation observed in the transformed citations values.

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