Journal of Operations Management 27 (2009) 185–202

Contents lists available at ScienceDirect

Journal of Operations Management

journal homepage: www.elsevier.com/locate/jom

# The evolution of the intellectual structure of operations management—1980–2006: A citation/co-citation analysis

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ARTICLE INFO

*Article history:*
Received 23 November 2007
Received in revised form 4 August 2008
Accepted 8 August 2008
Available online 20 August 2008

*Keywords:*
Operations management
Bibliometric techniques
Co-citation
Citation analysis
Social network analysis

ABSTRACT

Citation analysis combined with a network analysis of co-citation data from three major operations management (OM) journals is used to reveal the evolution of the intellectual structure of the OM field between 1980 and 2006. This spans the entire time since the beginning of research journals specific to the field. Employing a bibliometric citation/co-citation analysis to investigate the foundations of the discipline enables a robust, quantitative approach to uncovering the evolution of research in OM. The study finds that the intellectual structure of the field made statistically significant changes between the 1980s, the 1990s, and the 2000s and evolved from a pre-occupation with narrow, tactical topics toward more strategic, macrotopics, including new research methods and techniques. A factor analysis identifies the 12 top knowledge groups in the field and how they change over the decades. Illustrations of the structure of the co-citations representing the field are generated from a spring-embedded algorithm that is an improvement over the standard multi-dimensional scaling (MDS) approach to illustrating the knowledge groups.



## 1. Introduction

On the opening page of the first issue of the *Journal of Operations Management* (*JOM*), Buffa (1980, p. 1) declared that "The field of Operations Management has evolved from a purely descriptive origin through the Management Science/Operations Research phase, and is now in the process of finding itself as a functional field of management." Later in the article, Buffa estimated the death of the descriptive phase as being 1961, and the end of the MS/OR phase as 20 years later, saying (1980, p. 2) "MS/OR methodology does not define the OM field nor point the way of the future." and that now "we are emerging from the MS/OR phase into a clear recognition of OM as a functional field of management."

OM finally appears to be gaining momentum as a respected academic discipline (Ketokivi and Schroeder, 2004; Pagell and Krause, 2004), largely through the availability of strong and respected OM-specific publication outlets. Thus, this may be a good time to re-evaluate the evolution of the field and its intellectual structure since Buffa's (1980) evaluation almost three decades ago. To achieve this, we set three goals for our research:

1. To identify the major publications/citations in our field and their evolving research utility over the decades. As other fields have found, we expect the citations to include books as well as articles from journals outside the field.
2. To identify and illustrate the major knowledge groups in the field and the general relationships between them.
3. To determine and illustrate the evolution of these knowledge groups over the decades in terms of their

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doi:10.1016/j.jom.2008.08.001

research popularity and the general relationships between them.

The data source for the study is the set of approximately 75,000 citations listed in the three oldest primary journals in operations management: *JOM*, the *International Journal of Operations and Production Management* (*IJOPM*), and *Production and Operations Management* (*POM*). To determine the underlying intellectual structure of OM and its evolution, we apply quantitative citation and network co-citation analysis to this data set.

The paper starts with a brief review of the bibliometric methodology employed here, using earlier bibliometric studies, primarily in other fields, to exemplify the approach and its results. We then describe and justify our data source for the study. Next, we present the results of our analysis and describe the evolution of the intellectual structure of the field. Last, we offer our conclusions, discuss the limitations of the study, identify implications for research and practice, and recommend avenues for future research.

## 2. Literature review

Over the decades, there have been many qualitative studies that attempted to identify the major knowledge groups in OM (Meredith, 1979; Buffa, 1980; Chase, 1980; Miller et al., 1981; Mabert, 1982; Hill et al., 1988–1989; Amoako-Gyampah and Meredith, 1989; Meredith and Amoako-Gyampah, 1990; Neely, 1993; Voss, 1984; Scudder and Hill, 1998; Pannirselvan et al., 1999; Gupta et al., 2006). Most of them, however, were focused on a particular journal, setting (manufacturing, services, practice), research method, or type of outlet (e.g., dissertations). The usual method of determining these knowledge groups was to examine the selected outlets and manually categorize the citations into groups, often pre-selected. More relevant to revealing OM's intellectual structure might be studies that identified the most influential and important publications in the field and their relationship to each other. Sower et al. (1997) in their survey of OM professionals attempted to get at one aspect of this by identifying the "classics" in the OM field. First, they identified the factors that would indicate what works would be considered "classics" and then they identified authors and publications (books and journal articles) for respondents to consider and rate. Although the results are interesting, the authors describe the many problems with their findings resulting from the nature of the study methodology (e.g., classics that few have ever read, or are out of print, or recent articles or books on "hot" subjects). And while an identification of these classics may give us some historical insight into how OM is perceived and thus communicated to students, it does not provide us with those works that are *directly* influencing current research, nor does it give us a contemporary view of the subject or its theoretical structure.

Another, more objective, way to get at the intellectual structure of the field is through bibliographic studies, such as citation and co-citation analyses. That is, what articles are *actually cited* in research studies? And to reveal the structure of the interrelationships among articles, what works are commonly cited together (co-cited)? Using citation analysis, we can examine the growth in citations over the time period of interest to get a sense of when the major articles in the field were written, how their popularity fared over the time period, and if an article is still useful today for current researchers. If it continues to be cited, that indicates its historic value over time as well as its role in spawning follow-on studies. We can also use the citation rates to determine when the field made major changes in direction.

In contrast to citation analysis, Leydesdorff and Vaughan (2006) discuss the information we can obtain through co-citation analysis, where they speak of publications as "texts:" "Co-citation data can be considered as such linkage data *among* texts, while cited references are variables attributed *to* texts. ... one should realize that network data are different from attributes as data. From a network perspective, for example, one may wish to focus on how the network develops structurally over time." Identifying co-citations can tell us, through factor analysis for example, what the major factors and groups are within the field and how they vary across journals and over time. We can also graphically illustrate what the most influential citations are for each of the factors, how they are related, how strong their relationships are, and how far removed from, or central to, the factor groups they are—in other words, the relationships inherent in the intellectual structure of the field. And the co-citation studies can show us what topics, authors, journals, and research methods were central, and peripheral, to the field, and how they may have changed over time.

A variety of bibliometric analyses have been performed on the literatures of fields adjacent to OM. For example, Culnan (1986) used co-citation analysis to investigate the founding pillars of management information systems and found the subject to have more affinity with information science than organization studies. Similarly, Karki (1996) examined the sociology of science literature and found that information scientists and sociologists exchange ideas only when they are discussing "scholarly communication" as a subject. Cottrill et al. (1989) investigated the traditions of innovation research and the links between its sub-fields of "diffusion theory" and "technology transfer." Somewhat surprisingly, they found the use of distinct approaches within each sub-field that rarely interacted with each other. And Nerur et al. (2008) used an author co-citation analysis to reveal the intellectual structure of the strategic management field by author, updating an earlier citation/co-citation study (Ramos-Rodriguez and Ruiz-Navarro, 2004) that identified changes in the intellectual structure of the strategic management field. Similarly, Hoffman and Holbrook (1993) conducted a co-citation study of authors to identify the intellectual structure of consumer research based on the first 15 years of publication of the *Journal of Consumer Research*.

There appear to be only two co-citation studies of the field of OM. In an early study covering 1994–1997, Pilkington and Liston-Heyes (1999) explored *IJOPM* citations to plot OM's sub-fields and found five main categories which they termed: Manufacturing Strategy Proposers, Manufacturing Strategy Developers, Japanese Manufacturing, Performance Measures, and Best Practice. They also concluded that North American and European researchers place significantly different emphasis on each of these categories, at least in terms of research citations. Pilkington and Fitzgerald's recent *IJOPM* update (2006) identified changes in the discipline's categories over 10 years—primarily the two additions of Resource-Based View and Theory Building, and the deletion of Japanese Manufacturing. There were also some "emerging" topics: lean, qualitative methods, supply chain, and sustainable resources. In general, it appeared that the more recently published research studies focused on a more subtle understanding of OM by consideration of its practice relative to strategy, context, and resources. In our case, we are looking at the field more inclusively using three journals and for the full 27-year duration of OM publications. Next, we describe this methodology in more detail and reference some important studies that illustrate it. We also describe our data and discuss important issues in constructing and using the data set.

## 3. Methodology and data

Our methodology for ascertaining the intellectual structure of the OM field is bibliographic citation and co-citation analyses. Citation analysis is based on the premise that heavily cited articles are likely to have exerted a greater influence on the subject than those less frequently referenced (Sharplin and Mabry, 1985; Culnan, 1986) and thus are indicators of activity or importance to the field. Although this assumption may have weaknesses, with adequate screening and a sufficiently large sample, citation analysis can provide useful insight into which journals, papers, and authors are considered influential. As such, according to White and Griffith (1981), citation analysis represents "the field's view of itself." For example, Vokurka (1996) used citation analysis to determine what journals are the "most important" to the field of OM, a topic of great interest to academics, especially department heads and deans, for promotion and tenure decisions.

However, there are some dangers in using citations to make inferences also. As Garfield (1977) points out, we typically are basing our inferences on the first author, rather than all authors, and hence may miss important contributions and collateral citations by secondary and later authors—a potential weakness of this research, although our unit of analysis here was not the identification of *people* who had contributed to the field but rather the *publications* themselves. And there is the perennial problem of identifying the correct person (or journal or book) among sets of such with the same name. In our case of working in a specific, relatively narrow field, we have been able to largely bypass this problem by paying careful attention to names and topics and years. For instance, due to different journal citation policies, the same journal may be called or abbreviated quite differently; authors may be cited by full name, one initial, or multiple initials; books may be published in multiple editions; and other types of such confusions—these problems were carefully screened for in this study.

There is also the problem of including negative citations (citing a reference as a *bad* example of practice), and self-citations. In our case, we thought the negative citation problem was too slight to worry about and the self-citations probably about equally distributed among authors. Garfield also notes that this process treats methodological papers as equally important as findings papers, but in our case we were equally interested in such papers so this was not seen as a problem. Finally there is the issue of what importance to attach to such citations, both in terms of relative advancement of the field (all papers are equally important as potential contributors) and whether such citations are truly "significant" or simply provide "utility" for follow-on researchers. But in our study, we believe that equal potential is indeed what we want, and utility may be as "significant" a measure as we are ever going to find to describe the evolution of the field.

Yet, according to Leong (1989), citation analysis fails to illustrate the *structure* of influence within a field. Co-citation analysis is thus a handy adjunct to citation analysis for identifying *relationships* among authors, topics, journals, keywords, or even research methods, thereby illustrating structural groupings of these relationships. It also helps illustrate how such groups relate to each other (Small, 1973). As White notes (1990, p. 84), co-citation analysis helps reveal "the intellectual structure of scholarly fields" and (1990, p. 88) there is "nothing better for reconnoitering 'macro-level' intellectual structure as it evolves. The maps are essentially a new kind of graphic for revealing inter-textual relationships." Normally, the common interests in the body of citations are extracted using factor analysis or multi-dimensional scaling (MDS) of the correlations in a co-citation frequency matrix to identify the implicit dimensions.

There is some variation in the use of similarity, dissimilarity, and correlation measures in performing multidimensional analysis of co-citation data (Bensman, 2004). However, in a lengthy discussion, Leydesdorff and Vaughan (2006) show that while these have a significant impact on lower dimension MDS representations of the relationships, "by rotating the matrix, factor analysis enables us to retrieve the underlying structure despite the assumptions made about normality in the distribution" and obtains "a higher-dimensional and quantitative understanding of the structures underlying these geometrical representations."

To analyze the structure of interactions between the co-citations representing the various factors we can diagram the citations that constitute the various factors. As noted, there are a variety of different methods to diagram these publications (the nodes) and the co-citation linkages between them so as to represent the various structural knowledge groups. Some authors, such as Ramos-Rodriguez and Ruiz-Navarro (2004) and Hoffman and Holbrook (1993), have used MDS to represent the structural knowledge of their discipline. For our data we obtained satisfactory MDS results using PROXSCAL® in SPSS—specifically stress values of 0.174 for the proximity data (Euclidean distances calculated using Gower's classical metric ordination procedure in Ucinet 6) for the 197 by 197 co-citation matrix, down to 0.084 for a 23 citation matrix.

However, the graphical outputs gave poor visual results due to the difficulty of representing the underlying 12 factors (knowledge groups) in only a two-dimensional space, as was also the case in several other studies such as Culnan (1986); this problem is also described by Leydesdorff and Vaughan (2006).

Since our purpose here was to display the results graphically, we looked for another approach. Recently, many techniques have been developed based on graph theory in social network analysis (Scott, 1991; Wasserman and Faust, 1994) to visualize relationships such as the linkages among publications present in our co-citation data (Leydesdorff, 1987). The resulting graphs were produced using the NETDRAW® software which comes with the UCINET SNA® package (Borgatti et al., 2002). NETDRAW® (along with another package, PAJEK®) is a standard tool for graph mapping. The graphs are representations of the links in the co-citation matrix and are produced by first reducing all the co-citation values to binary zeros and ones, with the strength of the links added later in the form of line thicknesses. The position of the nodes on the graph results from the spring-based algorithm of Kamada and Kawai (1989), which seeks to iteratively reduce the stress in the graph by altering the position of the nodes (publications here)—co-locating nodes with strong linkages between them and dispersing nodes without links between them. The resulting graphs are less sensitive to the issues of high multidimensionality and implied data normality inherent in MDS visualization techniques when applied to co-citation data.

Turning now to the issue of the source data used for the citation and co-citation analyses, there are various ways to obtain the source publications whose items are co-cited, but it is critically important to be sure that only *appropriate* articles have been selected to represent the area of investigation. The standard approach is to use a panel of experts to identify a sample of prominent authors in a given field and then identify and retrieve papers that cite any of their articles. This source population of papers is then the subject of the bibliometric analysis, which occurs at the cited author level. As such, authors act as a proxy for the ideas and contributions of their papers and books. In this study, the standard approach just described has been improved by using three "OM-only" journals – *JOM*, *POM,* and *IJOPM* – as the source population. As a result, we can perform the analysis at the individual publication level, giving a more detailed representation of topics discussed, particularly given that prominent authors in a field are likely to have made contributions in a number of areas.

The data used in the study reported on here included the full contents of *JOM*, *POM*, and *IJOPM* between 1980 (the beginning of *JOM* and *IJOPM*; *POM* initiated publication in 1992) and 2006. These journals were selected because of their sole relationship to OM and their long history. Although this may be a somewhat imperfect record of the OM literature as a whole, since OM articles have certainly been published in journals such as *Management Science*, *Decision Sciences*, *IEEE Transactions on Engineering Management*, and so on, these other journals typically have a different publication purpose, philosophy, aim, and scope whereas the three journals used here represent the range of perspectives and intellectual structure in the field of OM, and *only* OM. That is, although other journals frequently publish OM research, these three journals were created to publish *only* OM research and, as such, best represent the pure intellectual historical structure of the field since the 1980s.

The normal source of information for bibliometric studies is the ISI social science citations index which contains index information and citation lists. This data was used for this study where available, but as the ISI social science citations index does not cover all volumes of the selected journals, the missing data had to be obtained and processed from other sources. In addition to ISI data, the *IJOPM* data from Vol. 1 No. 1 (1980) to Vol. 14, No.7 (1994) and *JOM* from Vol. 1 No. 1 (1980) to Vol. 17, No.6 (1999) were collected as pdf files from the EBSCO® business source premier system. ABBYY Fine Reader 8.0® was used to convert the pdf format into text which was subsequently manipulated using a combination of RAZZMATAG® and MATLAB® scripts to tag and extract the desired information. The *POM* data from Vol. 1 No. 1 (1992) to Vol. 7, No.4 (1998) were obtained as html from the EXTENZA® system and several MATLAB® scripts were used to extract the information.

As well as converting the raw data obtained above into a standard format, there is a major issue of data inconsistency in using ISI. Both these issues were addressed through a laborious process of manually checking and re-checking terms in indexes generated from the data and using complex search and replace routines. The result was a collection of datasheets which index the source article information such as publication information, authors, titles, and keywords; and the citations they make. The citation information analyzed was the first author (without initials), publication (journal or book title), and publication year. Particular care was taken to check that no information was amalgamated when removing author initials and publication issue information. Another major area of standardization was in combining book editions, which was accomplished using a manual checking and editing of indexes generated from the data.

## 4. Results

Fig. 1 shows the publication-year distribution of cited papers in our database going back to 1950. Although the study includes references prior to this point, the growth in cited works primarily begins with the frequently cited paper in 1951 by Cronbach. As seen, most of the cited papers were published from 1980 onwards, the time period encompassed by our study. The sharp falloff in citations since 1994 does not mean that no good works have been published since then, but rather that it takes about a dozen years for works to be recognized and become widely cited. In addition, recent publications will be too new for most OM papers to cite, especially since they have probably been "in process" at one of the journals for at least a few years before publication and the authors often do not update their references after submitting their work to a journal.

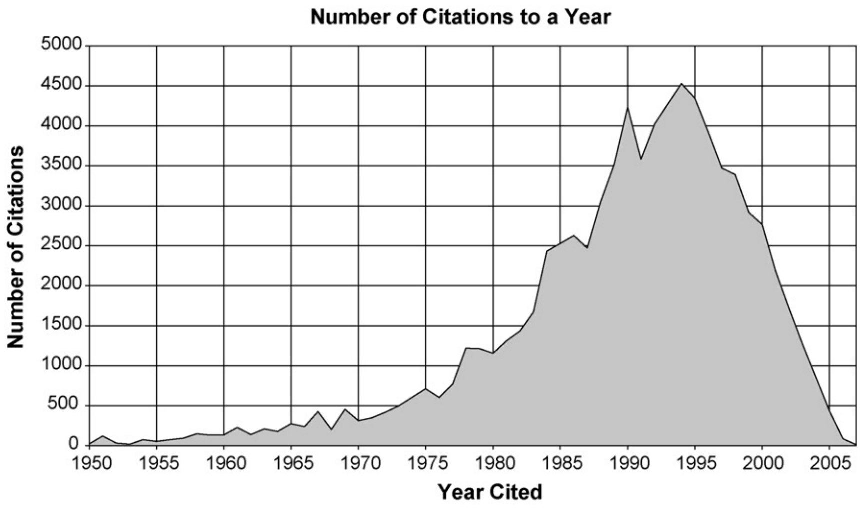


**Fig. 1.** Time distribution of cited papers.

In general, the shape of the distribution in Fig. 1 is relatively invariant with time, as well as field, and 10 years from now will probably look much the same, though the scales and slopes may be different. This shape and 12-year peak is also seen in strategic management (Fig. 4 in Ramos-Rodriguez and Ruiz-Navarro, 2004, p. 988) and marketing where Stremersch et al. (2007, p. 177, Fig. 2) show a 12-year peak, a growth of about 2.3 citations/journal/year up to an average of 28 after 12 years, and a variation in citation rates reaching a maximum of four times the average for popular articles.

### *4.1. Citation analysis*

We use the citation analysis to address our first goal of this study: To identify the major publications in the OM field and their evolution over time. Table 1 lists the 50 most-frequently cited publications among the three journals over the 27 years of this study (‘‘Overall’’ column) and their resulting ranks. The citation frequencies are also broken down by decade. Since the different journals publish a different number of papers each year – *IJOPM* is monthly for example whereas *JOM* is bi-monthly and *POM* is quarterly – the citation frequencies are normalized by the number of citations made by each journal in each decade. As well, the values given are ‘‘basis points;’’ that is, reference citations per 10,000 total normalized citations. Hence, the most frequently cited reference is Hayes and Wheelwright (1984), which is cited 31.4 times, on average across the three journals, for every 10,000 total citations.

In spite of the growth of research and journals in the field, many of the most popular citations are nevertheless of books rather than research articles. Ramos-Rodriguez and Ruiz-Navarro (2004, p. 999) also found this to be the case in strategic management: ‘‘The compilation of citations . . . reveals works written in book form as exerting the strongest influence: of the 20 most frequently cited works, 18 are books and two are articles published in journals.’’ Often a new book in the field that captures the interest of industry (e.g., Orlicky’s MRP book, Crosby’s Quality is Free, or Schonberger’s Japanese Manufacturing Techniques), also starts a wave of academic research related to the topic. It is not clear if these books are following or leading industry, probably a bit of each, but they do clearly generate a lot of research interest in the topic.

For ease of comparison, the ranks are also displayed for each column. Note that some publications are not referenced in the 1980s decade (denoted by N/A), usually because they appeared too late for that decade. In other cases (e.g., Yin’s Case Study Research), the publication had not yet gained popularity. As well, there are some cases (the 2000s) where the publication simply lost popularity. By using the ranks it is possible to see how the most popular publications stand the test of advancing decades, fade away, or perhaps become even more popular. Later, in the co-citation subsection, we will examine the knowledge groups across the decades to find the statistically significant differences between them.

Fig. 2 depicts the changing popularity of the top 50 publications across all three journals between the 1980s and the 1990s (in solid shading) and then from the 1990s to the 2000s (in lighter shading). The publications are not ordered in terms of overall popularity like in Table 2 but instead in order of increasing popularity between the 1980s and the 1990s. Thus, Hayes and Wheelwright (1984) increased the most in popularity, followed by Womack et al. (1990); the publication that lost the most popularity across the two decades was Orlicky (1975). But for many publications, popularity was short-lived, with Hayes and Wheelwright (1984) also decreasing the most in popularity between the 1990s and the 2000s. However, not all continued to lose popularity, as shown by Yin (1984) increasing the most in popularity between the 1990s and 2000s, and even Nunnally (1978) adding substantially to its earlier growth in popularity. Loss of popularity was not confined to those who became more popular in the 1990s either, since many lost popularity in both decades, such as Orlicky (1975) and Berry (1972). And finally, Porter (1985) lost popularity between the 1980s and 1990s, but then

**Table 1**
Publication citation frequencies (per 10,000 citations) and ranks overall and by decade

| Citation | Overall | | By decade | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Frequency | Rank | 1980s | | 1990s | | 2000s | |
| HAYES;RESTOR_COMP;1984 | 31.409 | 1 | 20.54 | 6 | 43.88 | 1 | 26.18 | 2 |
| HILL;MANUF_STRAT;1985 | 25.319 | 2 | 15.41 | 15 | 34.28 | 2 | 22.97 | 3 |
| SCHONBERGER;JAP_MANF_TCH;1982 | 19.389 | 3 | 40.55 | 2 | 18.32 | 12 | 6.35 | 62 |
| SKINNER;HBR;1969 | 18.442 | 4 | 14.28 | 19 | 23.19 | 3 | 16.47 | 6 |
| NUNNALLY;PSY_THY;1978 | 18.091 | 5 | 1.71 | 47 | 18.44 | 11 | 28.66 | 1 |
| ORLICKY;MRP;1975 | 14.997 | 6 | 52.66 | 1 | 4.40 | 111 | 0.49 | 200 |
| PORT ER;COMP_STGY;1980 | 14.960 | 7 | 11.75 | 25 | 19.34 | 10 | 12.72 | 13 |
| SWAMIDASS;MAN_SCI;1987 | 14.047 | 8 | 5.43 | 43 | 21.06 | 6 | 12.78 | 12 |
| W OMACK;MACH_CHNG_W LD;1990 | 13.711 | 9 | N/A | N/A | 21.92 | 5 | 14.64 | 8 |
| SCHONBERGER;W LD_CLSS_MANF;1986 | 13.705 | 10 | 5.14 | 44 | 22.33 | 4 | 10.79 | 19 |
| SKINNER;HBR;1974 | 12.823 | 11 | 12.87 | 23 | 16.37 | 15 | 9.24 | 24 |
| FLYNN;JOM;1990 | 12.065 | 12 | N/A | N/A | 19.98 | 7 | 12.19 | 15 |
| DEMING;OUT_CRISIS;1986 | 11.766 | 13 | 2.01 | 46 | 19.61 | 9 | 10.43 | 21 |
| HAYES;HBR;1979 | 11.430 | 14 | 3.42 | 45 | 17.24 | 13 | 10.96 | 18 |
| HAYES;DYN_MAN;1988 | 11.051 | 15 | 1.71 | 47 | 19.76 | 8 | 8.57 | 35 |
| FERDOW S;JOM;1990 | 10.786 | 16 | N/A | N/A | 15.90 | 19 | 12.86 | 11 |
| HAIR;MULT_DATA_ANAL;1992 | 10.697 | 17 | N/A | N/A | 8.14 | 44 | 20.38 | 4 |
| MONDEN;TOYOTA_P_SYS;1983 | 10.346 | 18 | 8.85 | 35 | 15.92 | 18 | 5.77 | 70 |
| YIN;CASE_STUDY_RES;1984 | 10.253 | 19 | N/A | N/A | 7.34 | 51 | 20.01 | 5 |
| MILLER;MAN_SCI;1994 | 9.651 | 20 | N/A | N/A | 11.81 | 22 | 13.93 | 9 |
| VOLLMANN;MANUF_PLANNI;1988 | 9.583 | 21 | 9.15 | 34 | 13.03 | 21 | 6.42 | 59 |
| FLYNN;JOM;1994 | 9.178 | 22 | N/A | N/A | 11.60 | 23 | 12.88 | 10 |
| EISENHARDT;AMR;1989 | 8.769 | 23 | N/A | N/A | 8.53 | 38 | 14.85 | 7 |
| BAKER;INT_SEQ_SCHED;1974 | 8.621 | 24 | 19.48 | 9 | 9.51 | 30 | 0.49 | 200 |
| W AGNER;MAN_SCI;1958 | 8.535 | 25 | 22.31 | 4 | 6.44 | 69 | 1.44 | 180 |
| HALL;ZERO_INV;1983 | 8.379 | 26 | 14.88 | 17 | 10.49 | 26 | 1.94 | 168 |
| CROSBY;QUAL_FREE;1979 | 8.293 | 27 | N/A | N/A | 17.11 | 14 | 5.00 | 91 |
| ANDERSON;JOM;1989 | 8.230 | 28 | 2.01 | 46 | 16.37 | 16 | 4.24 | 107 |
| THOMPSON;ORG_ACTION;1967 | 8.227 | 29 | 10.86 | 28 | 7.31 | 52 | 7.38 | 43 |
| ADAM;J_MANAGE;1989 | 8.017 | 30 | 2.01 | 46 | 16.31 | 17 | 3.73 | 126 |
| CONW AY;THEO_SCHED;1967 | 7.959 | 31 | 18.07 | 10 | 8.45 | 41 | 0.73 | 194 |
| PORT ER;COMP_ADV_CREA;1985 | 7.904 | 32 | 7.73 | 38 | 7.07 | 58 | 8.85 | 31 |
| GERW IN;MAN_SCI;1993 | 7.885 | 33 | N/A | N/A | 10.59 | 25 | 10.44 | 20 |
| SKINNER;MANUF_CORP_STRAT;1978 | 7.628 | 34 | 12.87 | 23 | 8.47 | 40 | 3.29 | 139 |
| BERRY;PIMJ;1972 | 7.222 | 35 | 26.92 | 3 | 1.31 | 176 | N/A | N/A |
| MONDEN;IND_ENG;1981 | 6.942 | 36 | 16.29 | 12 | 6.50 | 67 | 1.15 | 183 |
| VICKERY;DEC_SCI;1993 | 6.926 | 37 | N/A | N/A | 9.52 | 29 | 8.95 | 29 |
| DEMEYER;SMJ;1989 | 6.922 | 38 | N/A | N/A | 13.60 | 20 | 4.86 | 95 |
| CLARK;MAN_NP_PROC_DEV;1991 | 6.846 | 39 | N/A | N/A | 8.49 | 39 | 9.77 | 23 |
| CHASE;HBR;1978 | 6.829 | 40 | 11.16 | 27 | 7.10 | 57 | 3.67 | 127 |
| LAWRENCE;ORG_ENV;1967 | 6.547 | 41 | 8.85 | 35 | 7.04 | 59 | 4.51 | 101 |
| BUFFA;MEET_COMPET_CHAL;1984 | 6.477 | 42 | 13.46 | 22 | 7.93 | 46 | 0.37 | 203 |
| SASSER;MAN_SERV_OP;1978 | 6.212 | 43 | 10.57 | 29 | 6.68 | 63 | 2.84 | 144 |
| CLEVELAND;DEC_SCI;1989 | 6.032 | 44 | 2.01 | 46 | 9.05 | 33 | 5.70 | 73 |
| BURBIDGE;INT_GROUP_TECH;1975 | 6.012 | 45 | 15.76 | 14 | 5.52 | 89 | N/A | N/A |
| BUFFA;JOM;1980 | 6.002 | 46 | 14.05 | 20 | 4.60 | 105 | 2.03 | 164 |
| HAYES;HBR;1981 | 5.888 | 47 | 16.00 | 13 | 4.25 | 116 | 0.79 | 192 |
| FEIGENBAUM;TQC;1961 | 5.887 | 48 | 9.15 | 34 | 6.41 | 70 | 3.19 | 140 |
| POW ELL;SMJ;1995 | 5.883 | 49 | N/A | N/A | 6.50 | 68 | 9.19 | 26 |
| CONW AY;J_IND_ENG;1965 | 5.834 | 50 | 19.78 | 8 | 2.01 | 160 | 0.37 | 203 |

gained popularity (in OM, that is) as the field moved in his direction between the 1990s and 2000s.

These citation popularity changes give some insight into the changing intellectual structure of the field. As the field moved from the 1980s to the 1990s, the articles that lost favor (bottom 40% of Fig. 2) tended to be the more tactical or technical topics such as those aligned with industrial engineering and operations research. Those that gained popularity between these two decades seemed to be more strategic, managerial, or organizational, or related to newer research methods. However, between the 1990s and 2000s, most of these lost favor also, with only a few gaining favor. We will analyze the dynamics of the intellectual structure of the field more directly in the next sub-section.

### 4.2. Co-citation analysis

The co-citation analysis will allow us to address our second and third goals: To identify and illustrate the knowledge groups in OM, the general relationships between them, and their evolution over the decades. By analyzing the references of published articles, we can determine if any two references are commonly referenced together, or "co-cited." If a set of such references tend to be frequently co-cited, then this constitutes what we term a "structural knowledge

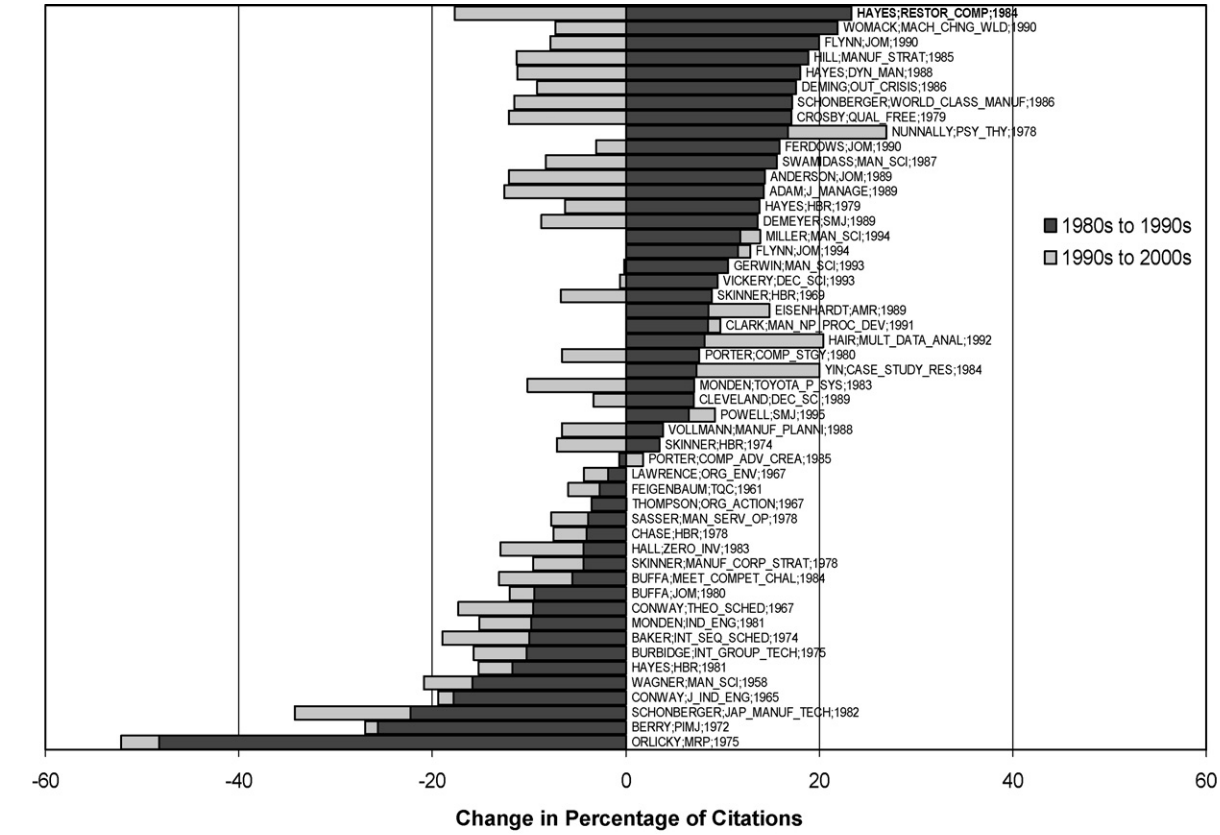


**Fig. 2.** Change in citation rate over the decades.

group." It is the set of these groups, and the relationships between and among them, that constitute the intellectual structure of a field (Leydesdorff and Vaughan, 2006). Table 2 lists again the 50 top-cited publications among the three journals and, for comparison, their maximum co-citation frequencies (again in basis points). As we see, Hayes is not only the most frequently cited reference but is also one of the most frequently *co-cited* with other references, the most commonly cited co-reference being Hill, with an average of 15.3 co-citations per 10,000 total citations.

But now consider the third listed reference of Schonberger (1982), which has a citation frequency of 19.4. The reference it is most commonly cited with is his more recent book Schonberger (1986) (which is also listed as the 10th top-cited work). But here the co-citation frequency is only 3.6 which is much less than many of the other co-citations on the top-50 list. The interpretation of this difference is that Schonberger (1982) is a major and important contribution to the literature (as is Schonberger, 1986) but since it is not consistently cited with any other particular publication, it may not be a major part of OM's intellectual structure, or knowledge groups. In general then, a reference that is co-cited a lot, such as Cleveland co-cited with Vickery toward the bottom of the top citations list, may be a major contributor to a knowledge group even if it is not all that frequently cited. So, a reference item may contribute to the field on its own, or through its participation in an important knowledge group.

To determine the major structural knowledge groups, we ran a principal component factor analysis of the co-citation matrix as is common practice in bibliometrics (White and McCain, 1998). The principal component analysis was conducted in SPSS® and involved the analysis of the correlation matrix calculated from the co-citations of the top 197 citations overall. We chose to use a varimax rotation as this tries to fit (or load) the maximum number of documents on the minimum number of factors. We note in passing that the publications that are most popular typically do not drive the factors since popular publications also load on other factors too; thus, the factors are extracted based on the "tightness" of the groups of publications that are commonly co-cited. The Kaiser–Meyer–Olin measure of sampling adequacy for the matrix was acceptable at 0.5499 and Bartlett's test was significant at a *p*-value of less than 0.001, which indicated that principal components analysis was applicable. Based on a scree test, 19 factors were extracted which together explained over 79% of the variance in the correlation matrix. By examining the topics of the citations included within the factors (which score greater than 0.4 loadings), the knowledge groups being captured by each of the first 12 factors were clear from the publications that loaded on them; hence the factors were named accordingly. Table 3 lists the first 12 factors which explain 73% of the variance, along with their proportions and ranks similar to Table 1.

**Table 2**
Most frequent reference citations (per 10,000 citations) and associated highest co-citations

| Publication | Citation frequency | Maximum co-citation value | Publication most co-cited with |
|---|---|---|---|
| HAYES;RESTOR_COMP;1984 | 31.4 | 15.3 | HILL;MANUF_STRAT;1985 |
| HILL;MANUF_STRAT;1985 | 25.3 | 15.3 | HAYES;RESTOR_COMP;1984 |
| SCHONBERGER;JAP_MANUF_TECH;1982 | 19.4 | 3.6 | SCHONBERGER;WORLD_CLASS_MAN;1986 |
| SKINNER;HBR;1969 | 18.4 | 12.2 | HAYES;RESTOR_COMP;1984 |
| NUNNALLY;PSY_THY;1978 | 18.1 | 7.1 | HAIR;MULT_DATA_ANAL;1992 |
| ORLICKY;MRP;1975 | 15.0 | 2.2 | CRONBACH;PSYCHOMETRIKA;1951 |
| PORTER;COMP_STGY;1980 | 15.0 | 8.1 | HAYES;RESTOR_COMP;1984 |
| SWAMIDASS;MAN_SCI;1987 | 14.0 | 9.5 | HAYES;RESTOR_COMP;1984 |
| WOMACK;MACH_CHNG_WLD;1990 | 13.7 | 5.0 | HAYES;RESTOR_COMP;1984 |
| SCHONBERGER;WORLD_CLASS_MANUF;1986 | 13.7 | 5.4 | HAYES;RESTOR_COMP;1984 |
| SKINNER;HBR;1974 | 12.8 | 7.5 | HAYES;RESTOR_COMP;1984 |
| FLYNN;JOM;1990 | 12.1 | 4.6 | NUNNALLY;PSY_THY;1978 |
| DEMING;OUT_CRISIS;1986 | 11.8 | 6.0 | CROSBY;QUAL_FREE;1979 |
| HAYES;HBR;1979 | 11.4 | 5.3 | HAYES;RESTOR_COMP;1984 |
| HAYES;DYN_MAN;1988 | 11.1 | 5.9 | HAYES;RESTOR_COMP;1984 |
| FERDOWS;JOM;1990 | 10.8 | 6.9 | HAYES;RESTOR_COMP;1984 |
| HAIR;MULT_DATA_ANAL;1992 | 10.7 | 7.1 | NUNNALLY;PSY_THY;1978 |
| MONDEN;TOYOTA_P_SYS;1983 | 10.3 | 3.5 | SCHONBERGER;JAP_MANUF_TECH;1982 |
| YIN;CASE_STUDY_RES;1984 | 10.3 | 5.4 | EISENHARDT;AMR;1989 |
| MILLER;MAN_SCI;1994 | 9.7 | 6.7 | HAYES;RESTOR_COMP;1984 |
| VOLLMANN;MANUF_PLANNI;1988 | 9.6 | 1.5 | HILL;MANUF_STRAT;1985 |
| FLYNN;JOM;1994 | 9.2 | 4.9 | NUNNALLY;PSY_THY;1978 |
| EISENHARDT;AMR;1989 | 8.8 | 5.4 | YIN;CASE_STUDY_RES;1984 |
| BAKER;INT_SEQ_SCHED;1974 | 8.6 | 1.1 | BAKER;JOM;1981 |
| WAGNER;MAN_SCI;1958 | 8.5 | 2.1 | OLEARYKELLY;JOM;1998 |
| HALL;ZERO_INV;1983 | 8.4 | 2.1 | SCHONBERGER;JAP_MANUF_TECH;1982 |
| CROSBY;QUAL_FREE;1979 | 8.3 | 6.0 | DEMING;OUT_CRISIS;1986 |
| ANDERSON;JOM;1989 | 8.2 | 5.2 | HAYES;RESTOR_COMP;1984 |
| THOMPSON;ORG_ACTION;1967 | 8.2 | 2.5 | HAYES;RESTOR_COMP;1984 |
| ADAM;J_MANAGE;1989 | 8.0 | 4.8 | HAYES;RESTOR_COMP;1984 |
| CONWAY;THEO_SCHED;1967 | 8.0 | 1.9 | SKINNER;HBR;1969 |
| PORTER;COMP_ADV_CREA;1985 | 7.9 | 2.7 | HAYES;RESTOR_COMP;1984 |
| GERWIN;MAN_SCI;1993 | 7.9 | 5.3 | SWAMIDASS;MAN_SCI;1987 |
| SKINNER;MANUF_CORP_STRAT;1978 | 7.6 | 3.5 | HAYES;RESTOR_COMP;1984 |
| BERRY;PIMJ;1972 | 7.2 | 2.3 | BERRY;MPS;1979 |
| MONDEN;IND_ENG;1981 | 6.9 | 1.0 | SCHONBERGER;JAP_MANUF_TECH;1982 |
| VICKERY;DEC_SCI;1993 | 6.9 | 4.7 | HAYES;RESTOR_COMP;1984 |
| DEMEYER;SMJ;1989 | 6.9 | 4.3 | HAYES;RESTOR_COMP;1984 |
| CLARK;MAN_NP_PROC_DEV;1991 | 6.8 | 2.3 | HAYES;RESTOR_COMP;1984 |
| CHASE;HBR;1978 | 6.8 | 2.9 | CHASE;OPER_RES;1981 |
| LAWRENCE;ORG_ENV;1967 | 6.5 | 2.5 | HAYES;RESTOR_COMP;1984 |
| BUFFA;MEET_COMPET_CHAL;1984 | 6.5 | 2.3 | HAYES;RESTOR_COMP;1984 |
| SASSER;MAN_SERV_OP;1978 | 6.2 | 2.3 | CHASE;OPER_RES;1981 |
| CLEVELAND;DEC_SCI;1989 | 6.0 | 4.1 | VICKERY;DEC_SCI;1993 |
| BURBIDGE;INT_GROUP_TECH;1975 | 6.0 | 1.7 | CHAIKEN;MAN_SCI;1978 |
| BUFFA;JOM;1980 | 6.0 | 1.6 | MILLER;DEC_SCI;1981 |
| HAYES;HBR;1981 | 5.9 | 2.0 | HAYES;RESTOR_COMP;1984 |
| FEIGENBAUM;TQC;1961 | 5.9 | 2.9 | DEMING;OUT_CRISIS;1986 |
| POWELL;SMJ;1995 | 5.9 | 3.3 | FLYNN;JOM;1994 |
| CONWAY;J_IND_ENG;1965 | 5.8 | 1.7 | NELLEMANN;PIMJ;1982 |

Manufacturing Strategy (Factor 1) was the most important, explaining 25% of the variance by itself and always being the top-ranked factor in terms of percentage of loading citations for all decades. During the 1990s, it represented over half of all the co-citations by itself. This factor had 69 citations, including such works as Porter's book *Competitive Strategy* in 1980 and Hill's *Manufacturing Strategy* in 1985, as well as dozens of well-known operations strategy publications. Interest increased during the 1990s, but then fell back to the 1980s level in the 2000s.

The second factor was clearly quality-related and was thus named Quality and its Metrics, explaining 10% of the variance and representing 11% of the overall citations in the co-citation matrix. This quality knowledge group increased in popularity over the decades from the 1990s to the 2000s. The factor had 26 co-citations and included the works of such well-known authors as Deming, Crosby, Feigenbaum, Garvin, and many others.

The third factor, with 22 co-citations, was named Statistical Methods because it captured a wide variety of co-citations that related to statistical methodology, data analysis, and psychometric theory. Included here were authors such as Cronbach, mentioned earlier, and others equally well known, plus many academic papers, even from the marketing research literature. This factor was virtually absent in the 1980s, but became increasingly popular in the 1990s and 2000s.

**Table 3**
Loading of co-citations onto factor/knowledge groups (%) and popularity % and ranks, overall and by decade

| Factor name (cum var expl. %) | Overall | | By decade* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total (%) | Rank | 1980–1989 | | 1990–1999 | | 2000–2006 | |
| 1. Manufacturing Strategy (25) | 44.2 | 1 | 39.1 | 1 | 52.2 | 1 | 40.3 | 1 |
| 2. Quality and its Metrics (35) | 11.0 | 3 | 4.7 | 5 | 9.7 | 3 | 11.9 | 3 |
| 3. Statistical Methods (43) | 11.2 | 2 | 0.4 | 10 | 4.1 | 4 | 15.5 | 2 |
| 4. Process Design (49) | 9.5 | 4 | 25.0 | 2 | 14.9 | 2 | 6.1 | 5 |
| 5. Services (54) | 3.8 | 6 | 6.3 | 4 | 3.8 | 5 | 3.7 | 8 |
| 6. Flexibility (59) | 3.3 | 8 | 0.8 | 9 | 3.3 | 6 | 3.5 | 9 |
| 7. Qualitative Methods (62) | 4.9 | 5 | 0.0 | 11 | 2.9 | 8 | 6.1 | 4 |
| 8. Supply Chains (65) | 3.0 | 9 | 1.2 | 8 | 1.4 | 11 | 3.9 | 7 |
| 9. Product/Service Innovation (67) | 1.9 | 11 | 2.3 | 7 | 1.3 | 12 | 2.2 | 10 |
| 10. RBV (70) | 3.4 | 7 | 0.0 | 12 | 1.7 | 10 | 4.4 | 6 |
| 11. Measures/Balanced Scorecard (71) | 2.4 | 10 | 3.5 | 6 | 3.0 | 7 | 2.0 | 11 |
| 12. Inventory Control (73) | 1.3 | 12 | 16.8 | 3 | 1.9 | 9 | 0.3 | 12 |

Factor table: KMO measure of sampling adequacy = 0.202; Bartlett's test of sphericity: approximate $\chi^2$-square = 27592, d.f. = 9730, sig = 0.000.
* $\chi^2$-square significant at 0.000.

The fourth factor was termed Process Design which originally focused on works about Japanese manufacturing techniques by authors such as Schonberger and Monden, but then broadened into more general interest in process improvement as advocated by Womack, Goldratt, Stalk, and others. This factor was particularly prominent in the 1980s when it was the second most important knowledge group. Interest generally fell off during the 1990s, and even more so in the 2000s.

The fifth factor, with less than 4% of the total co-citations but explaining 5% of the variance, is Services. Although of substantial interest in the 1980s, it has slipped somewhat in the 1990s and 2000s to about 4%. Most of the works here are those of well-known OM scholars such as Sasser, Heskett, Chase, Fitzsimmons, and Schmenner, but also some marketing researchers.

The remaining factors, in order, are Flexibility, Qualitative Methods, Supply Chains, Product/Service Innovation, Resource-Based View (RBV), Measures/Balanced Scorecard, and Inventory Control. Their popularity across the decades can be seen in Table 3 but a few observations will be made here. Qualitative methods (case studies, ethnographic research, grounded theory, and so on) has experienced increasing interest over the decades. Supply Chains has also experienced growing interest over the decades, as has Flexibility and the Resource-Based View. Finally, Inventory Control has had the biggest drop in interest, falling to almost nothing in the 2000s; Measures/Balanced Scorecard has also received less research interest. The only knowledge group to drop in popularity and then regain it was Product/Service Innovation, accounting for 2% of both the articles and the explained variance.

These changes are depicted graphically in Fig. 3 where the factors are ordered by greatest increase in co-citation rates between the 1980s and 1990s. As can be seen, and alluded to earlier, Manufacturing Strategy had the greatest increase (13%) between the 1980s and 1990s, followed by Quality and its Metrics (5%), and so on. However,

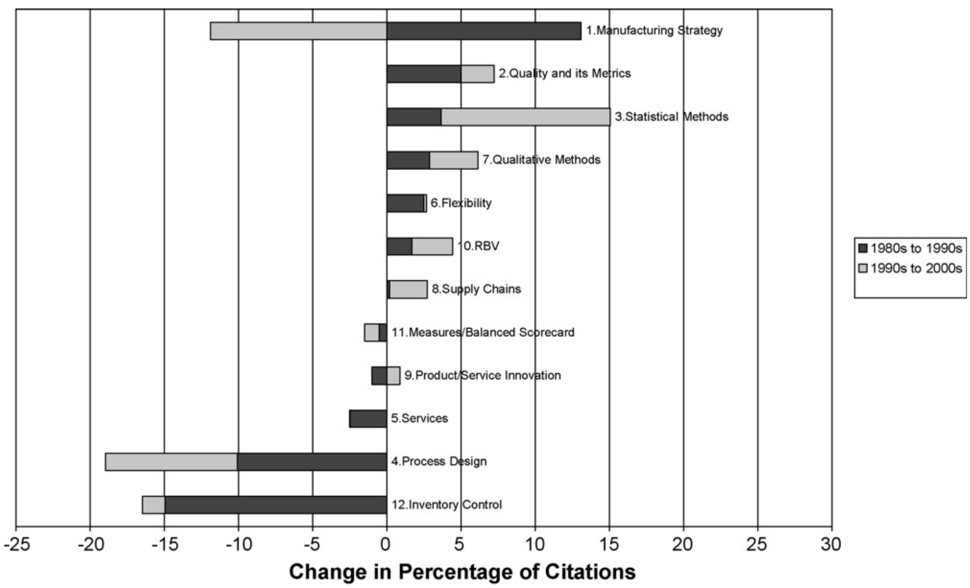


**Fig. 3.** Change in factor co-citation rates over the decades.

Manufacturing Strategy also had the greatest decrease (12%) between the 1990s and 2000s, followed by Process Design (9%). Moreover, Process Design also had a 10% *decrease* between the 1980s and 1990s, exceeded only by Inventory Control with a 15% decrease. In contrast to these decreases in popularity, many of the factors had continuing increases such as Statistical Methods (3.7% from 1980s to 1990s, followed by 11.4% from 1990s to 2000s), Quality and its Metrics (about 7% in total), and Qualitative Methods (about 6% in total).

What we see from this graph is, like Fig. 2, a major evolution of interest not only across topics but also across research methodologies and theories over the decades. Where Fig. 2 gave some indication of popularity in particular publications, from which we inferred changes in topical interests, we see here the changing interests directly. In terms of topics, the hot topic of the 1990s – Manufacturing Strategy – lost the most interest in the 2000s, while all the other topics that gained interest between the 1980s and 1990s continued to gain interest, especially Supply Chains and Quality. And interestingly, where Product/Service Innovation lost interest between the 1980s and the 1990s, it gained between the 1990s and 2000s. The greatest gain in interest between the 1990s and 2000s however was in research methodology, both Statistical Methods and Qualitative Methods, as well as a substantial gain in interest in the Resource-Based View theory. This seems to be a positive development for the field in that it shows the increasing interest in conducting more rigorous and also more empirical research, as well as borrowing theories from other areas beyond Industrial Engineering and Operations Research.

To see the general relationships between the knowledge groups we can also graphically depict the co-citation data, as illustrated in Fig. 4. Through special graphing techniques these relationships can be depicted on a diagram to show each publication in relation to all other co-cited publications. Space does not allow for listing the reference for each node in this diagram for the overall data (we will consider each decade separately later), but the various knowledge groups can be separated out and their interrelationships identified. In such a diagram, the resulting groups may be independent, with no ties between them, or perhaps loosely linked, or even tightly linked. The citations in a grouping may be relatively evenly linked across the grouping, or perhaps all tied to one or two central citations. Papers that are cited a lot will appear as larger nodes than papers that are co-cited less frequently, and papers that are often co-cited with each other will appear close together with a heavy line between them. As well, papers that are co-cited with many other papers will tend to be centrally located while those that are co-cited with fewer other papers will lie toward the outskirts of the diagram.

However, there can be substantial differences in the distribution frequency of particular co-citations, depending on the data set being analyzed (such as by decade) and this will alter the look of the diagram of citations. Moreover, in graphing the resulting data set, some limit on the number of co-citations needs to be stated or there may not be enough space on the graph to show all the co-citations, or they may overlap so extensively they cannot be distinguished. Thus a limit of, say, at least 10 co-citations may be set and a diagram produced. It is important to remember that the values represent co-citation rates per 10,000 citations in the relevant database and so if a limit of at least 9 were to be used, the same diagram may result since with this data set there may not have been any publications co-cited 9 times per 10,000 citations. Similarly, the diagrams for one data set may look substantially different from those for another data set, even though the same limit was used in each. For example, one diagram might have 35 nodes in it and the other perhaps only 10 even though the

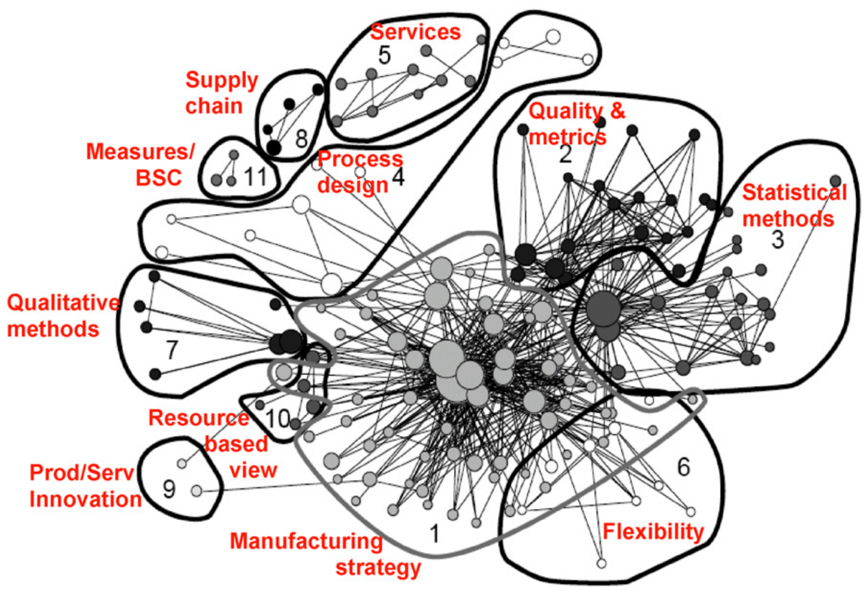


**Fig. 4.** Overall factor structure of the OM field.

same limit was used for both, making comparisons across data sets more difficult.

Using this method for the factors identified in Table 3 with the "Overall" data set resulted in the knowledge structure shown in Fig. 4 (based on a co-citation limit "greater than 5"), where Factors 1–11 are indicated by separate envelopes. Factor 12 did not show up at this level of co-citations—that is, all of its co-citations were 5 or less. As seen, Manufacturing Strategy, as Factor 1, is the central and largest factor, and interacts strongly among itself (as do all the factors, except 9) as well as with many of the other factors. Factors 2 (Quality and its Metrics) and 3 (Statistical Methods) are also centrally located and quite large, but interact primarily with Factor 1 (besides themselves) and each other, but much less with the other factors and hence are shunted off to the right side. It might be noted that some of the citations in Factor 3 are as heavily cited as those in Factor 1. Factor 4 (Process Design), when showing only co-citations greater than 5, separates into two distinct groups, one of which (process improvement) is removed from all the other groups and is at the upper outskirts of the diagram, and the other (Japanese manufacturing) which is more centrally located but interacts only with Factor 1.

Factor 5 (Services) is also removed from the other groups and sits on the outskirts of the diagram, interacting only with itself at this co-citation limit, as is true of Factors 8 (Supply Chain) and 11 (Measurement/Balanced Scorecard). Factor 6 (Flexibility) and Factor 10 (Resource-Based View) are more central, and interact primarily with Factor 1, with which their envelopes overlap at the edges. In spite of their centrality, neither factor has a heavily cited primary reference (equally sized nodes). Their overlap with Factor 1 indicates their close integration with strategy, and this makes sense, given the nature of the factors. Factor 7 (Qualitative Methods) has some highly cited references which lie close to and interact with Factor 1. Factor 9 (Product/Service Innovation) also interacts with Factor 1 but is much further removed than many of the other interacting factors.

The layout of the 11 factors and their logical interactions (or lack thereof) with other factors lends face validity to the factor analysis of Table 3 by illustrating the detailed positioning, roles, and interactions among the factors. For instance, we see some factors with major, central references (large nodes) and other factors with no major reference but rather a network of publications of relatively equal importance. The interactions within the factors, and between them, also reflects our expectations, such as RBV theory, quality, and flexibility being closely tied to manufacturing strategy but innovation, services, and supply chains being less so.

We now want to determine the evolution of this structure over the three decades. First, we must determine if the three decades were statistically significantly different from each other, and then we can repeat the above process to see what the decade diagrams look like and how they differ from each other. Hence, a statistical analysis was conducted on the 9215 co-citations in Table 3 to investigate whether the decades were statistically significantly different from each other. A set of $\chi^2$-square tests were conducted on the actual numbers of citations for

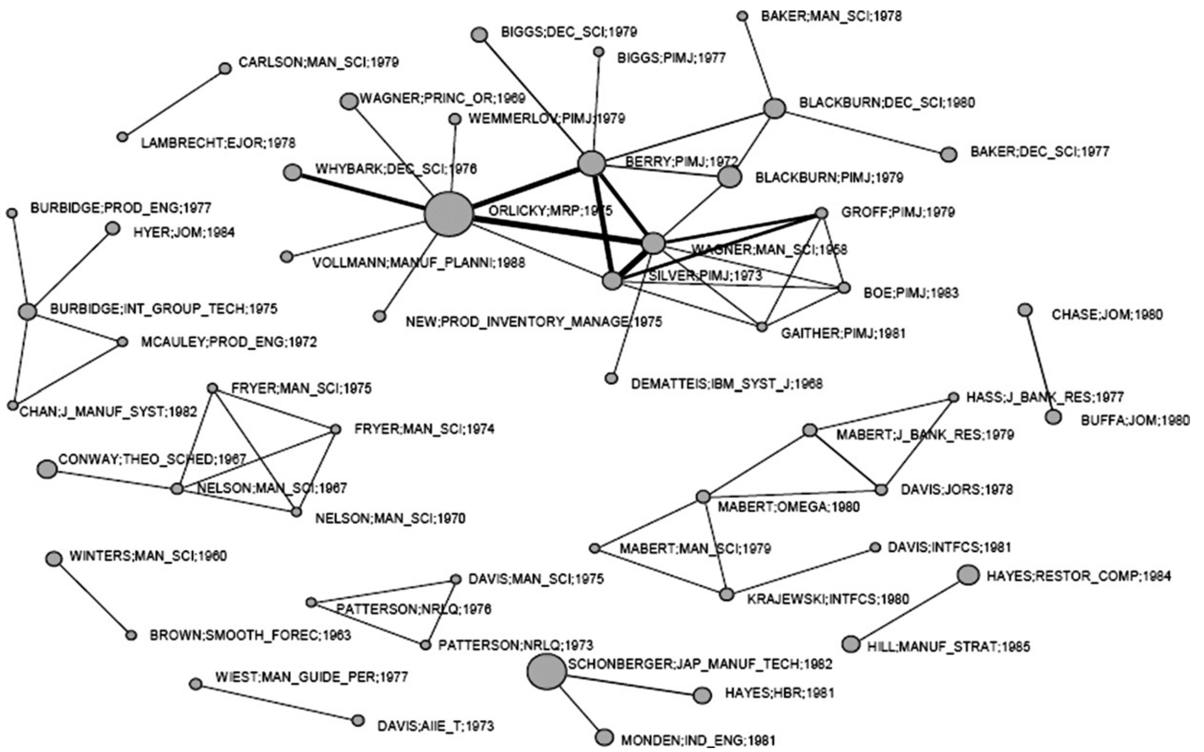


**Fig. 5.** General knowledge structure in the 1980s.

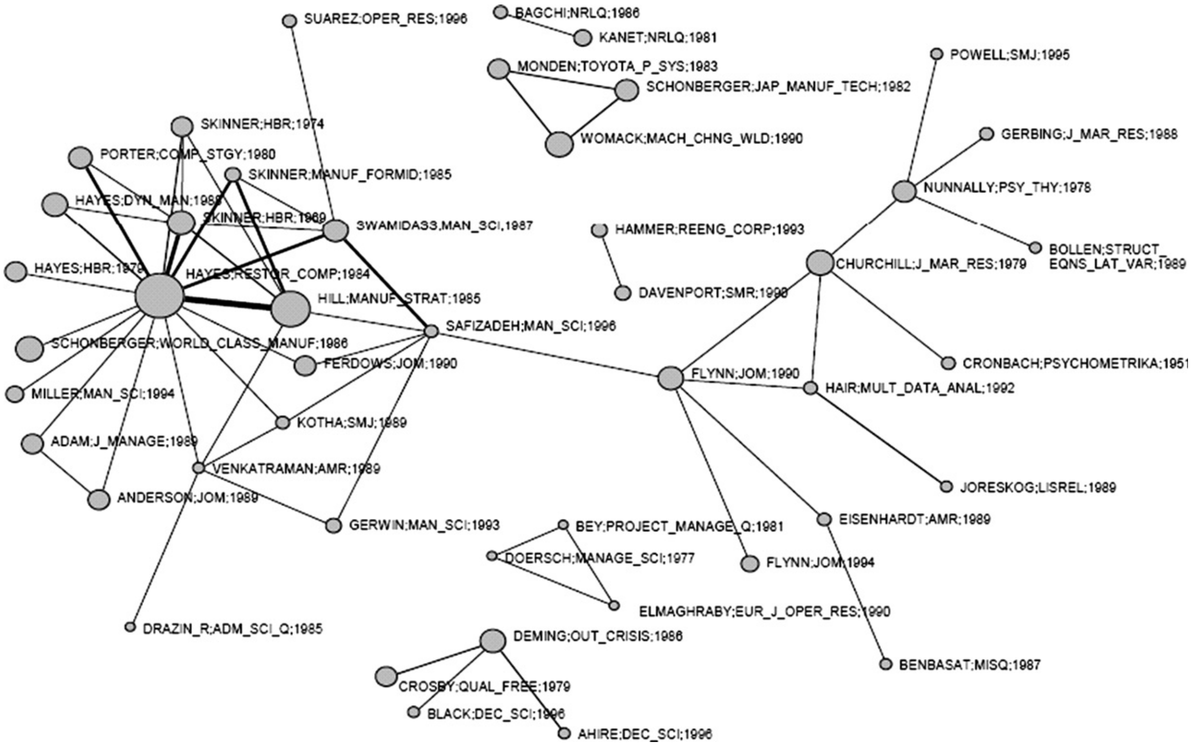


**Fig. 6.** General knowledge structure in the 1990s.

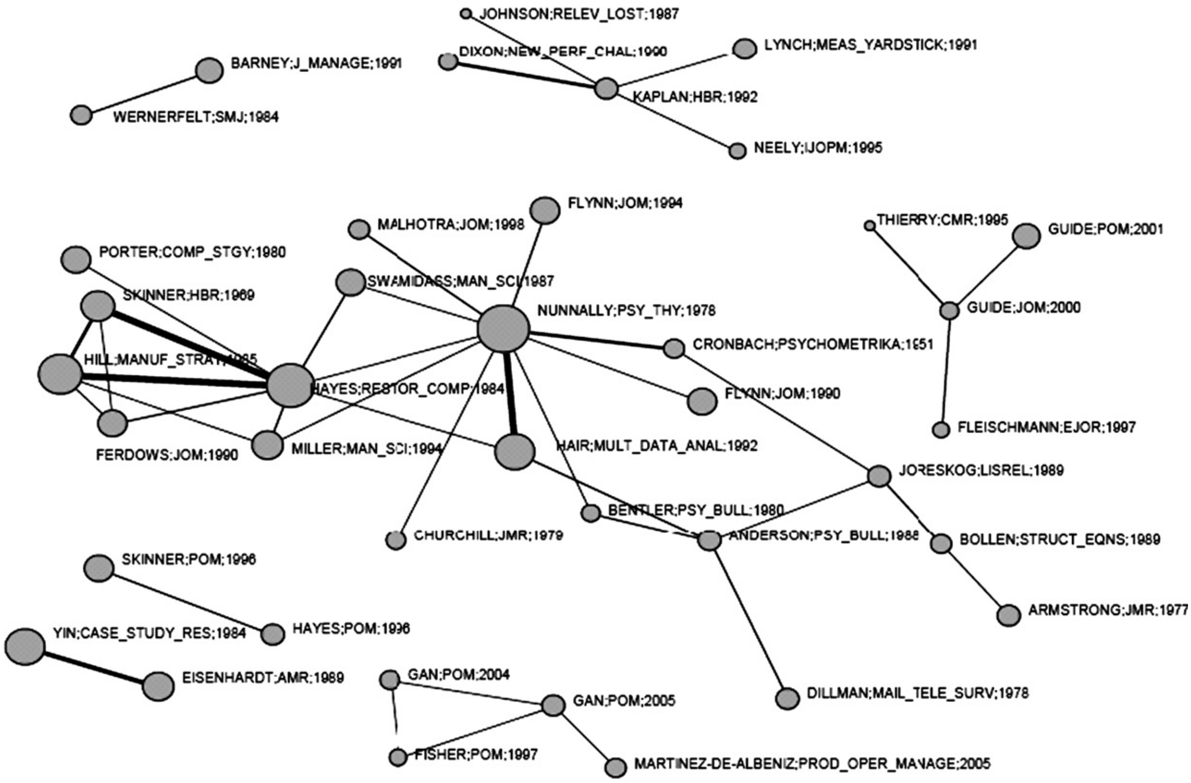


**Fig. 7.** General knowledge structure in the 2000s.

each decade. The first test was to determine if the decade of the 1990s was different from that of the 1980s and if the 2000s was different from the 1990s, all based on the distribution of citations across the 12 factors. As seen at the bottom of Table 3, each was significantly different at a level of significance of 0.000, indicating that the direction of the field changed significantly across these decades.

To illustrate the intellectual structure of the field by decade and its evolution, we diagrammed the most highly co-cited references across the three journals for each decade separately, using a co-citation rate for each decade that gave us the most visually understandable diagram with about the same number of nodes. Thus, Figs. 5–7 present the knowledge structure existing in the 1980s, the 1990s, and the 2000s, respectively. As seen in Fig. 5, the primary knowledge structure in the 1980s concerns MRP (top center) and its links to strategy, process design, and inventory control publications. But illustrating the somewhat fragmented nature of the field at that time, there are many ancillary knowledge groups as well concerning scheduling, Japanese manufacturing, group technology, forecasting, project management, services, and other areas.

Moving to the 1990s illustrated in Fig. 6, we see a marked difference in the knowledge groups. Now manufacturing strategy is the primary area of interest (left center), with competitiveness and strategy being the major topics, and many ties to related publications. Toward the right is the beginning of the new empirical orientation of OM with no strong central publications but lots of related links through Flynn et al. (1990), who could be interpreted as a "bridging" publication to strategy. Toward the bottom are two small groups related to quality and to project management, while at the top are three small groups related to lean/Japanese manufacturing, reengineering, and scheduling. The field appears to be more integrated than in the 1980s, with more interest in strategic issues and research methodologies, and fewer ancillary knowledge groups. Then in the 2000s (Fig. 7) the field reinvents itself again, with empirical methods taking center stage but closely integrated with strategy, and some smaller knowledge groups around the edge relating to case study methodology (another empirical method), and then supply chain management, remanufacturing, performance measurement, and the resource-based view of the firm, all four of which could be considered aspects of strategy. The reason for the absence of links showing ties to the two main areas is due to the co-citation setting used for plotting the diagram rather than any separation of the knowledge groups. Thus, we reach the 2000s with a much more integrated field, one that uses rigorous research methods and studies more macro, strategic issues.

## 5. Summary and conclusions

Relative to our goals for this study, we analyzed the most frequently cited publications in three operations management research journals over a period of 27 years and found that books dominated the references, with seminal journal articles coming second. In fact, books played a major role in the knowledge structure of the field in all three decades, with MRP, group technology, and Japanese manufacturing being highly referenced in the 1980s. Similarly, manufacturing strategy and quality books were highly referenced in the 1990s, and qualitative and case study research, as well as performance measurement books were the center of attention in the 2000s. A clue to the more recent direction of the field was provided by those citations that continued to increase in popularity during the 2000s: statistical empirical methodology, quality management, competitiveness, and case study methodology. However, more recent (i.e., 2000s) publications are less likely to be cited as popular over an earlier 27-year period so we moved to a co-citation analysis to determine the major knowledge groups, their interrelationships, and their evolution over the decades.

A factor analysis of the co-citations revealed 12 major knowledge groups, with manufacturing strategy the most popular over the entire time span of the study. A graphical analysis of the knowledge groups showed the centralized location of manufacturing strategy as well, and its very close ties to quality, statistical methodology, flexibility, and the resource-based-view theory. There was also a strong interaction between quality and statistical methodology. Somewhat further removed were process design, qualitative methods, and innovation, which only interacted with manufacturing strategy. And most removed at the fringes were services, supply chains, measures/balanced scorecard, and inventory, having little interaction with the other knowledge groups.

Analysis of the knowledge groups by decade showed a large number of independent topics of interest during the 1980s, with only production planning having any extensive network of ties. But by the 1990s, the field has largely coalesced around two major knowledge groups: manufacturing strategy (the largest group) and statistical methodology. Now in the 2000s, the statistical methodology knowledge group has become the largest and the manufacturing strategy group has receded somewhat. In all three decades, however, there have always been separate topical interests and we would expect this to continue indefinitely.

In general, the field appears to be moving away from the more tactical interests of OM such as inventories, processes, and measurements, and even cutting back its interest in strategy, in favor of more strategic and macro issues such as supply chains and research methodology. This macro view was called for by Richard Chase long ago in the first issue of *JOM* (1980), and the recent interest in theory building (e.g., RBV) and empirical research methods may be a reflection of a field pausing in its topical interests to rearm itself with more useful tools for conducting its research, whereupon it will again venture forth into the new topics of the future better equipped to address them.

Although it might be thought that the apparent evolution of the field shown here is an artifact of the most popular publications simply getting older, this is not the case. First, the most popular publications are actually *not* the ones that load most heavily on each of the identified subject area factors; popular publications tend to load on multiple factors as they are frequently referenced in many tangential topics, so their loading is not all that strong in any one subject area. Second, some of the publications such as Yin and Nunnally actually grew more popular over the decades as the subject areas they represented became more popular. And in some cases, newer publications in a subject that is becoming more popular may replace the older, popular ones. Last, although all the lower group of publications in Fig. 2 that lost popularity between the 1980s and 1990s were written prior to 1986, fully one-third of the upper group of publications in the figure were also written prior to 1986.

Finally, it is worth noting that there are some publications that have served as bridges between the knowledge groups, such as that of Flynn et al. (1990) in Fig. 6 or Nunnally (1978) in Fig. 7. Such publications play a major role in the evolving intellectual structure of a field by tying separate knowledge groups together and showing their important relationships. This facilitates the growth and maturation of each of the knowledge groups.

In conclusion, this study has found the field of operations management to be a dynamic area experiencing substantial change since the initiation of its three research journals. The field has moved away from its narrow occupation with tactical, fragmented topics toward more strategic, integrated, and macro subjects, borrowing theories from other fields (e.g., RBV) and developing new research methodologies (e.g., case studies, ethnography) and techniques (e.g., statistical survey analysis, structural equation modeling). For example, instead of studies in the tactical, standalone areas of "Inventory" and "Process Design," researchers are now looking at the entire "Supply Chain" and organization-wide "Flexibility," respectively.

### 5.1. Limitations

The limitations of this study are multiple. One is the inability to fully capture, quantify, and display the total intellectual structure of the field. For example, we could well have used some measures of the level of integration of the field, or the quality of its evolution, or its "maturity." And we have been limited to displaying in two dimensions rather than the full dimensional range developed by our mathematical analyses. We were also limited in showing all the structure of the field due to the inability to include it on limited sizes and numbers of pages. As a result, only a portion of the structure can be displayed, but perhaps that is sufficient to give readers a sense of the structure. As well, we could not show all the co-citations we found, not to mention the OM co-citations from other journals both within the field (e.g., *Manufacturing and Service Operations Management*) as well as outside of it (*Decision Sciences*, *Management Science*).

The study is also limited in terms of the references that are included in the articles. For instance, authors have various reasons for including particular references in their papers, such as listing important books in the field even if the author has not read that book. As well, different journals have different editorial policies and expectations about referencing, some expecting many and others few, for example. And it was noted earlier that the journal reviewing and publication delay means that appropriate references for some papers will be missing. And we also noted earlier that this study uses only the first authors of articles rather than considering all authors.

Finally, there are limitations in terms of our treatment of the data within the study, such as our somewhat arbitrary division of the 27-year span into decades rather than equal sizes. Perhaps more significantly, our choice of co-citation limits for the diagrams substantially affects the positioning and structure of the resulting display. We attempted to find limits that would show as many citations and links as possibly without being so crowded that the structure was hard to discern.

### 5.2. Implications for research

The implications of this study for research in the field are considerable. We see the field as entering a dynamic period with substantial changes in its research methods that are continuing to evolve. The use of theory in OM has always been contentious, but we are beginning to see the adoption of accepted theories from outside the field such as the Resource-Based View. This may portend the adoption and use of other theories as well, and perhaps even the development of some of our own. And the topics being researched are also in flux, with interest in supply chains growing substantially, as might be expected, but interest in services decreasing or flat, which certainly was not expected. Some topics, which lost interest between the 1980s and 1990s have seen interest reawaken, such as innovation, while others have continued to lose interest, such as process design.

### 5.3. Future research

Considerably more could be done with this type of data, including a deeper analysis of the top-cited or co-cited authors in the field, such as their characteristics, the number of areas in which they publish, why they are so popular, and so on. Special attention to authors who provide links between the major knowledge groups would also be of interest, such as the kinds of work these links represent and the questions they address. As well, much more could be done with the specific journals in terms of their predilections for particular types of papers, topics, research methods, and such. We also hope that this type of study is repeated in the future, perhaps every decade, as the field continues to evolve.

## References

Amoako-Gyampah, K., Meredith, J.R., 1989. The operations management research agenda: an update. Journal of Operations Management 8, 250–262.

Bensman, S.J., 2004. Pearson's r and author co-citation analysis: a commentary on the controversy. Journal of the American Society for Information Science and Technology 55 (10), 935–936.

Borgatti, S.P., Everett, M.G., Freeman, L.C., 2002. Ucinet 6 for Windows. Harvard, Analytic Technologies.

Buffa, E., 1980. Research in operations management. Journal of Operations Management 1, 1–7.

Chase, R.B., 1980. A classification and evaluation of research in operations management. Journal of Operations Management 1, 9–14.
Cottrill, C., Rogers, E.M., Mills, T., 1989. Co-citation analysis of the scientific literature of innovation research traditions: diffusion of innovations and technology transfer. Knowledge: Creation, Diffusion, Utilization 11, 181–208.
Cronbach, L., 1951. Coefficient alpha in the internal structure of tests. Psychometrika 16, 297–334.
Culnan, M., 1986. The intellectual development of management information systems. Management Science 32, 156–172.
Garfield, E., 1977. Citation Indexing—Its Theory and Application in Science, Technology, and Humanities. Institute for Scientific Information, ISI Press, Philadelphia.
Gupta, S., Verma, R., Victorino, L., 2006. Empirical research published in Production and Operations Management (1992–2005): trends and future research directions. Production and Operations Management 15, 432–448.
Hill, A.V., Scudder, G.D., Haugen, D.L. (1988–1989). The operations management research agenda for the 80's: a progress report for Ph.D. dissertation research, Operations Management Review, Fall 1988 & Winter 1989, 24–32.
Hoffman, D.L., Holbrook, M.B., 1993. The intellectual structure of consumer research: a bibliometric study of author co-citations in the first 15 years of the Journal of Consumer Research. Journal of Consumer Research 19, 505–517.
Kamada, T., Kawai, S., 1989. An algorithm for drawing general undirected graphs. Information Processing Letters 31 (1), 7–15.
Karki, R., 1996. Searching for bridges between disciplines: an author co-citation analysis on the research into scholarly communication. Journal of Information Science 22, 323–334.
Ketokivi, M., Schroeder, R., 2004. Strategic, structural contingency and institutional explanations in the adoption of innovative manufacturing practices. Journal of Operations Management 22, 63–89.
Leong, S.M., 1989. A citation analysis of the Journal of Consumer Research. Journal of Consumer Research 15, 492–497.
Leydesdorff, L., 1987. Various methods for the mapping of science. Scientometrics 11, 291–320.
Leydesdorff, L., Vaughan, L., 2006. Co-occurrence matrices and their applications in information science: extending ACA to the web environment. Journal of the American Society for Information Science & Technology 57, 1616–1628.
Mabert, V.A., 1982. Service operations management: research and application. Journal of Operations Management 2, 203–209.
Meredith, J., 1979. We are proud to announce ... "The Journal of Operations Management". The Operations Management Newsletter 1, 14.
Meredith, J.R., Amoako-Gyampah, K., 1990. The genealogy of operations management. Journal of Operations Management 9, 146–167.
Miller, J.G., Graham, M.B., Freeland, J.R., Hottenstein, M., Maister, D.H., Meredith, J., Schmenner, R.W., 1981. Production/operations management: agenda for the '80s. Decision Sciences 12, 547–580.
Neely, A., 1993. Production/operations management: research process and content during the 1980s. International Journal of Operations and Production Management 13, 5–18.
Nerur, S.P., Rasheed, A.A., Natarajan, V., 2008. The intellectual structure of the strategic management field: an author co-citation analysis. Strategic Management Journal 29, 319–336.
Pagell, M., Krause, D., 2004. Re-exploring the relationship between flexibility and the external environment. Journal of Operations Management 21, 629–649.
Pannirselvan, G.P., Ferguson, L.A., Ash, R.C., Siferd, S.P., 1999. Operations management research: an update for the 1990s. Journal of Operations Management 18, 95–112.
Pilkington, A., Fitzgerald, R., 2006. Operations management themes, concepts and relationships: a forward retrospective of the IJOPM. International Journal of Operations and Production Management 11, 1255–1275.
Pilkington, A., Liston-Heyes, C., 1999. Is production and operations management a discipline? A citation/co-citation study. International Journal of Operations and Production Management 19, 7–20.
Ramos-Rodriguez, A.-R., Ruiz-Navarro, J., 2004. Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, 1980–2000. Strategic Management Journal 25, 981–1004.
Scott, J., 1991. Social Network Analysis. Sage, London.
Scudder, G.D., Hill, C.A., 1998. A review and classification of empirical research in operations management. Journal of Operations Management 16, 91–101.
Sharplin, A., Mabry, R., 1985. The relative importance of journals used in management research: an alternative ranking. Human Relations 38, 139–149.
Small, H., 1973. Co-citation in the scientific literature: a new measure of the relationship between two documents. Journal of the American Society for Information Science 24, 265–269.
Sower, V.E., Motwani, J., Savoie, M.J., 1997. Classics in production and operations management. International Journal of Operations and Production Management 17, 15–28.
Stremersch, S., Verniers, I., Verhoef, P.C., 2007. The quest for citations: drivers of article impact. Journal of Marketing 71, 171–193.
Vokurka, R.J., 1996. The relative importance of journals used in operations management research: a citation analysis. Journal of Operations Management 14, 345–355.
Voss, C.A., 1984. Production/operations management: a key discipline and area for research. Omega: The International Journal of Management Science 12, 309–319.
Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge University Press, New York.
White, H.D., 1990. Author co-citation analysis: overview and defense. In: Borgman, C.L. (Ed.), Scholarly Communication and Bibliometrics. Sage, Newbury Park, CA, pp. 84–106.
White, H., Griffith, B.C., 1981. Author co-citation: a literature measure of intellectual structure. Journal of the American Society for Information Science 32, 163–171.
White, H.D., McCain, K., 1998. Visualizing a discipline: an author cocitation analysis of information science, 1972–1995. Journal of the American Society for Information Science 49, 327–355.

## Database citations

Adam, E., Swamidass, P., 1989. Assessing operations management from a strategic perspective. Journal of Management 15 (2), 181–204.
Ahire, S., Goldhar, D., Waller, M., 1996. Development and validation of TQM implementation constructs. Decision Sciences 27 (1), 23–56.
Anderson, J.C., Gerbing, D.W., 1988. Structural equation modeling in practice: a review and recommended two-step approach. Psychological Bulletin 103 (3), 411–423.
Anderson, J., Cleveland, G., Schroeder, R., 1989. Operations strategy: a literature review. Journal of Operations Management 8 (2), 133–158.
Armstrong, J., Overton, T., 1977. Estimating nonresponse bias in mail surveys. Journal of Marketing Research 14 (August), 396–402.
Asher, H., 1956. Cost–Quantity Relationships in the Airframe Industry. RAND Corporation Study No. R-291.
Bagchi, U., Sullivan, R., Chang, Y., 1986. Minimizing mean absolute deviation of completion times about a common due date. Naval Research Logistics Quarterly 33, 227–240.
Baker, K., 1974. Introduction to Sequencing and Scheduling. Wiley.
Baker, K.R., 1977. An Experimental Study of Rolling Schedules in Production Planning. Decision Sciences 8, 19–27.
Baker, K.R., Bertrand, J.W.M., 1981. An investigation of due-date assignment rules with constrainted tightness. Journal of Operations Management 1/3, 109–120.
Baker, K.R., Dixon, P., Magazine, M.J., Silver, E.A., 1978. An algorithm for the dynamic lot-size problem with time-varying production capacity constraints. Management Science 24 (16), 1710–1720.
Barney, J., 1991. Firm resources and sustained competitive advantage. Journal of Management 17 (1), 99–120.
Benbasat, I., Goldstein, D.K., Mead, M., 1987. The case research strategy in studies of information systems. MIS Quarterly 11:3, 369–386.
Bentler, P., Bonett, D., 1980. Significance tests and goodness of fit in the analysis of covariance structures. Psychological Bulletin 88 (3), 588–606.
Berry, W.L., 1972. Lot sizing procedures for requirements planning systems: a framework for analysis. Production and Inventory Management Journal 13, Second Quarter (2).
Berry, W.L., Vollman, T.E., Whybark, D.C., 1979. Master Projection Scheduling. American Production and Inventory Control Society, Washington, DC.
Bey, R.P., Doersch, R.H., Patterson, J.H., 1981. The net present value criterion: project scheduling. Project Management Quarterly 12, 35–45.
Biggs, J.A., 1979. Heuristic lot sizing and sequencing rules in a multistage production and inventory system. Decision Sciences 10, 96–115.
Biggs, J.A., Goodman, S.H., Hard, S.T., 1977. Lot sizing rules in a hierarchical multi-stage inventory system. Production and Inventory Management 18, 104–115.
Black, S., Porter, L., 1996. Identification of the critical factors of TQM. Decision Sciences. Winter 27 (1), 1–23.
Blackburn, J.D., Millen, R.A., 1979. Selecting a lot-sizing technique for a single-level assembly process. Production and Inventory Management Journal 20, 42–47.

Blackburn, J.D., Millen, R.A., 1980. Heuristic lot-sizing performance in a rolling schedule environment. Decision Sciences 11, 691–701.
Boe, W., Yilmaz, C., 1983. The incremental order quantity. Production and Inventory Management 24 (2), 94–100.
Bollen, K., 1989. Structural Equations with Latent Variables. Wiley, New York.
Brown, R.G., 1963. Smoothing, Forecasting and Prediction of Discrete Time Series. Prentice-Hall, Englewood Cliffs, New Jersey.
Buffa, E., 1984. Meeting the Competitive Challenge. Dow-Jones Irwin, Homewood, IL.
Burbidge, J.L., 1975. The Introduction to Group Technology. John Wiley & Sons, New York, NY.
Burbidge, J.L., 1977. A manual method for production flow analysis. Production Engineer 56, 34–38.
Carlson, R.C., Jucker, J.V., Kropp, D.H., 1979. Less nervous MRP systems: a dynamic economic lot-sizing approach. Management Science 25 (8), 754–761.
Chaiken, J.M., Dormont, P., 1978. A patrol car allocation model. Management Science 24, 1280–1300.
Chan, H.M., Milner, D.A., 1982. Direct clustering algorithm for group formation in cellular manufacture. Journal of Manufacturing Systems 1, 65–75.
Chase, R., 1978. Where does the customer fit in a service corporation? Harvard Business Review November–December, 137–142.
Chase, R.B., 1981. The customer contact approach to services: theoretical bases and practical extensions. Operations Research 29 (4), 698–706.
Churchill, G., 1979. A paradigm for developing better measures of marketing constructs. Journal of Marketing Research 16 (1), 64–74.
Clark, K., Fujimoto, T., 1991. Product Development Performance: Strategy, Organization, and Management in the World Auto Industry. Harvard Business School Press.
Cleveland, G., Schroeder, R., Anderson, J., 1989. A theory of production competence. Decision Sciences 20 (4), 655–669.
Conway, R.W., 1965. Priority dispatching and job lateness in a job shop. Journal of Industrial Engineering 16, 228–237.
Conway, R.W., Maxwell, W.L., Miller, L.W., 1967. Theory of Scheduling. Addison-Wesley, Massachusetts.
Corbett, C.J., Kirsch, D.A., 2001. International diffusion of ISO 14000 certification. Production and Operations Management 10 (3), 327–342.
Craig, C.E., Harris, R.C., 1973. Total productivity measurement at the firm level. Sloan Management Review 13–29.
Crosby, P., 1979. Quality is Free. McGraw-Hill.
Davenport, T., Short, J., 1990. The new industrial engineering. Sloan Management Review 31 (4), 11–37.
Davis, E.W., 1973. Project scheduling under resource constraints: historical review and categorization of procedures. AIIE Transactions 5 (4), 297–313.
Davis, E.W., Patterson, J.H., 1975. A comparison of heuristic and optimum solutions in resource constrained project scheduling. Management Science 21 (8), 944–955.
Davis, S.G., Reutzel, E.T., 1981. Joint determination of machine requirements and shift scheduling in banking operations. Interfaces 11 (1), 41–42.
Davis, S.G., Swanson, L.A., 1978. A computerized operations scheduling model for the reduction of commercial bank float. Journal of Operational Research Society 29, 559–564.
De Matteis, J.J., 1968. An economic lot-sizing technique: the part-period algorithm. IBM Systems Journal 7, 30–38.
De Meyer, A., Nakane, J., Miller, J., Ferdows, K., 1989. Flexibility: the next competitive battle the manufacturing. Strategic Management Journal 10 (2), 135–145.
Deming, W., 1986. Out of Crisis. Cambridge University Press.
Dillman, D., 1978. Mail and Telephone Surveys: The Total Design Method. Wiley, New York.
Dixon, J., Nanni, A., Vollmann, T., 1990. The New Performance Challenge. Irwin.
Doersch, R.H., Patterson, J.H., 1977. Scheduling a project to maximize its net present value: a zero-one programming approach. Management Science 23 (8), 882–889.
Dow, D., Samson, D., Ford, S., 1999. Exploding the myth: do all quality management practices contribute to superior quality performance? Production and Operations Management 8 (1), 1–27.
Drazin, R., Van de Ven, A.H., 1985. Alternative forms of fit in contingency theory. Administrative Science Quarterly 30, 514–539.
Ebrahimpour, M., Fathi, B.M., 1985. Dynamic simulation of a Kanban production inventory system. International Journal of Operations and Production Management 5, 5–14.
Eisenhardt, K., 1989. Building theories from case study research. Academy of Management Review 14 (4), 532–550.
Elmaghraby, S.E., Herroelen, W.S., 1990. The scheduling of activities to maximize the net present value of projects. European Journal of Operational Research 49, 35–49.
Feigenbaum, A., 1961. Total Quality Control. McGraw-Hill.
Ferdows, K., Demeyer, A., 1990. Lasting improvements in manufacturing performance. Journal of Operations Management 9 (2), 168–184.
Fine, C., 2000. Clockspeed-based strategies for supply chain design. Production and Operations Management 9 (3), 213–221.
Fisher, M.L., Hammond, J.H., Obermeyer, W.R., Raman, A., 1997. Configuring the supply chain to reduce the cost of demand uncertainty. Productions and Operations Management 6 (3), 211–255.
Fitzsimmons, J.A., Fitzsimmons, M.J., 1998. Service Management: Operations, strategy and information technology. McGraw Hill.
Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., van der Laan, E., van Nunen, J.A.E.E., Van Wassenhove, L.N., 1997. Quantitative models for reverse logistics: a review. European Journal of Operational Research 103, 1–17.
Flynn, B.B., Sakaribara, S., Schroeder, R.G., Flynn, E.J., 1990. Empirical research methods in operations management. Journal of Operations Management 9 (2), 250–284.
Flynn, B.B., Sakaribara, S., Schroeder, R.G., 1994. A framework for quality management research. Journal of Operations Management 11 (4), 339–366.
Fornell, C., Larcker, D., 1981. Evaluating structural equation models with unobservable variables and measures. Journal of Marketing Research 18 (1), 39–50.
Forrester, J., 1961. Industrial Dynamics. M.I.T. Press, Cambridge, MA.
Fryer, J.S., 1974. Labor flexibility in multiechelon dual constrained job shops. Management Science 20 (7), 1073–1080.
Fryer, J.S., 1975. Effects of shop size and labor flexibility in labor and machine limited production systems. Management Science 21, 507–515.
Gaither, N., 1981. The effects of inflation and fuel scarcity upon inventory policies. Production and Inventory Management 22, 37–48.
Gan, X., Sethi, S., Yan, H., 2004. Coordination of supply chains with risk-averse agents. Production and Operations Management 13 (2), 135–149.
Gan, X., Sethi, S., Yan, H., 2005. Channel coordination with a risk-neutral supplier and downside-risk-averse retailer. Production and Operations Management 14 (1), 80–89.
Garvin, D., 1987. Competing on the eight dimensions of quality. Harvard Business Review 65 (6), 101.
Gerbing, D., Anderson, J., 1988. An updated paradigm for scale development incorporating unidimensionality and its assessment. Journal of Marketing Research 25 (2), 186–192.
Gerwin, D., 1993. Manufacturing flexibility: a strategic perspective. Management Science 39 (4), 395–410.
Goldratt, E., Cox, J., 1984. The Goal. North River Press, Croton-on-Hudson, NY.
Groff, G.K., 1979. A lot sizing rule for time-phased component demand. Production and Inventory Management 20, 47–53.
Guide, V.D.R., 2000. Production planning and control for remanufacturing: industry practice and research needs. Journal of Operations Management 18 (4), 467–483.
Guide, V.D.R., Van Wassenhove, L.N., 2001. Managing product returns for remanufacturing. Production and Operations Management 10 (2), 142–155.
Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1992. Multivariate Data Analysis. Prentice Hall, Upper Saddle River, New Jersey.
Hall, R., 1983. Zero Inventories. Dow Jones-Irwin.
Hammer, M., Champy, J., 1993. Reengineering the Corporation. Harper.
Hass, G., Zoltners, A.A., 1977. A computerized bank check collection vehicle routing system. Journal of Bank Research 8, 148–158.
Hayes, R., 1981. Why Japanese factories work. Harvard Business Review 59 (4), 56–66.
Hayes, R., Pisano, G., 1996. Manufacturing strategy: at the intersection of two paradigm shifts. Production and Operations Management 5 (1), 25–41.
Hayes, R., Wheelwright, S., 1979. Link manufacturing process and product life-cycles. Harvard Business Review 57 (January), 133–140.
Hayes, R., Wheelwright, S., 1984. Restoring our Competitive Edge: Competing Through Manufacturing. Wiley.
Hayes, R., Wheelwright, S., Clark, K., 1988. Dynamic Manufacturing. Free Press.
Heskett, J.L., Sasser, W.E., Schlesinger, L.A., 1997. The Service–Profit Chain. The Free Press, New York.
Hill, T., 1985. Manufacturing Strategy: the Strategic Management of the Manufacturing Function. Macmillan.
Hyer, N.L., 1984. The potential of group technology in U.S. manufacturing. Journal of Operations Management 4, 183–202.

Johnson, H., Kaplan, R., 1987. Relevance Lost. Harvard Business School Press.

Jöreskog, K., Sörbom, S., 1989. Lisrel 7: A Guide to The Program and Applications. SPSS, Chicago, IL.

Kanet, J., 1981. Minimizing the average deviation of job completion times about a common due date. Naval Research Logistics 28 (4), 643–651.

Kaplan, R., Norton, D., 1992. The balanced scorecard—measures that drive performance. Harvard Business Review January–February, 71–79.

Kotha, S., Orne, D., 1989. Generic manufacturing strategies—a conceptual synthesis. Strategic Management Journal 10 (May–June (3)), 211–231.

Krajewski, L.J., Ritzman, L.P., Mckenzie, P., 1980. Shift scheduling in banking operations—a case application. Interfaces 10 (2), 1–6.

Lambrecht, M., Vandereecken, J., 1978. Capacity constrained single-facility dynamic lot-size model. European Journal of Operational Research 2 (2), 132–136.

Lawrence, P., Lorsch, J., 1967. Organization and Environment: Managing Differentiation and Integration. Harvard University, Boston.

Lee, S.M., Ebrahimpour, M., 1984. Just-in-time production system: some requirements for implementation. International Journal of Operations and Production Management 4 (1), 3–15.

Lee, H., Padmanabhan, V., Whang, S., 1997. Information distortion in a supply chain: the bullwhip effect. Management Science 43 (4), 546–558.

Lynch, R., Cross, K., 1991. Measure Up! Yardstick for Continuous Improvement Basil Blackwell.

Mabert, V.A., 1979. Case-study of encoder shift scheduling under uncertainty. Management Science 25 (7), 623–631.

Mabert, V.A., Fairhurst, R., Kilpatrick, M., 1979. Chemical Bank's encoder daily shift scheduling system. Journal of Bank Research 10 (3), 173–180.

Mabert, V.A., Mckenzie, J.P., 1980. Improving bank operations—a case-study at Bancohio-Ohio-National-Bank. Omega-International Journal of Management Science 8 (3), 345–354.

Malhotra, M., Grover, V., 1998. An assessment of survey research in POM: from constructs to theory. Journal of Operations Management 16, 407–425.

Martinez-De-Albeniz, V., Simchi-Levi, D., 2005. A portfolio approach to procurement contracts. Production and Operations Management 14 (1), 90–114.

McAuley, J., 1972. Machine grouping for efficient production. The Production Engineer 53–57.

McElroy, K., 1982. Robots take detroit. Automotive Industries January, 20–30.

McLaren, B.J., 1977. A study of multiple level lot sizing techniques for material requirements planning systems. Ph.D. dissertation, Purdue University.

Miller, J., Roth, A., 1994. A taxonomy of manufacturing strategies. Management Science 40 (3), 285–304.

Monden, Y., 1981. What makes the Toyota production system really tick? Industrial Engineering January, 36–46.

Monden, Y., 1983. Toyota Production System. Industrial Engineering and Management Press.

Neely, A., Gregory, M., Platts, K., 1995. Performance measurement system design. International Journal of Operations and Production Management 15 (4), 80–116.

Nellemann, D.O., Smith, L.F., 1982. Just-in-time vs. just-in-case production systems borrowed back from Japan. Production Inventory Management 23, 12–21.

Nelson, R.T., 1967. Labor and machine limited production systems. Management Science 13 (9), 648–671.

Nelson, R.T., 1970. A simulation of labor efficiency and centralized assignment in a production model. Management Science 17 (2), 97–106.

New, C., 1975. Safety stocks for requirements planning. Production and Inventory Management 16 (2), 1–18.

Noble, M.A., 1995. Manufacturing strategy: testing the cumulative model in a multiple country context. Decision Sciences 26 (5), 622–693.

Nunnally, J., 1978. Psychometric Theory. McGraw Hill, New York.

O'Leary-Kelly, S.W., Vokurka, R.J., 1998. The empirical assessment of construct validity. Journal of Operations Management 16, 387–405.

Orlicky, J.A., 1975. Material Requirements Planning. McGraw-Hill, New York.

Patterson, J.H., 1973. Alternate methods of project scheduling with limited resources. Naval Research Logistics 20 (4), 767–784.

Patterson, J.H., 1976. Project scheduling—effects of problem structure on heuristic performance. Naval Research Logistics 23 (1), 95–123.

Porter, M., 1980. Competitive Strategy: Techniques for Analyzing Industries and Competitors. Free Press.

Porter, M., 1985. Competitive Advantage: Creating and Sustaining Superior Performance. Free Press.

Powell, T., 1995. Total quality management as competitive advantage: a review and empirical study. Strategic Management Journal 16 (5), 15–37.

Prahalad, C.K., Hamel, G., 1990. The core competence of the corporation. Harvard Business Review 68 (May–June (3)), 79–92.

Rice, J.W., Yoshikawa, T., 1982. A comparison of Kanban and MRP concepts for the control of repetitive manufacturing systems. Production and Inventory Management Journal 1–13.

Safizadeh, M., Ritzman, L., Sharma, D., Wood, C., 1996. An empirical analysis of the product–process matrix. Management Science 42 (11), 1576–1591.

Sasser, W.E., Olsen, R.P., Wyckoff, D.D., 1978. Management of Service Operations. Allyn & Bacon, Boston, MA.

Schmenner, R.W., 1988. The merit of making things fast. Sloan Management Review 30 (1), 11–17.

Schmenner, R., Swink, M.L., 1998. On theory in operations management. Journal of Operations Management 17, 97–113.

Schonberger, R., 1982. Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity. Free Press.

Schonberger, R., 1986. World Class Manufacturing: The Lessons of Simplicity Applied. Collier Macmillan.

Schroer, B.J., Black, J.T., Shou, X.Z., 1985. Just-In-Time (JIT) with Kanban, manufacturing system simulation on a microcomputer. Simulation 45 (2), 62–70.

Silver, E.A., Meal, H.C., 1973. A heuristic for selecting lot size quantities for the case of a deterministic time-varying demand rate and discrete opportunities for replenishment. Production and Inventory Management 2nd Quarter 64–74.

Skinner, W., 1969. Manufacturing—missing link in corporate strategy. Harvard Business Review 47 (3), 136–145.

Skinner, W., 1974. The focused factory. Harvard Business Review 52 (3), 113–121.

Skinner, W., 1978. Manufacturing in the Corporate Strategy. Wiley.

Skinner, W., 1985. Manufacturing the Formidable Competitive Weapon. Wiley.

Skinner, W., 1996. Manufacturing strategy on the 'S' curve. Production and Operations Management 5 (1), 3–14.

Stalk, G., 1988. Time—the next competitive advantage. Harvard Business Review 66 (4), 41.

Stalk, G., 1990. Competing Against Time. Collier Macmillan, New York, NY.

Sterman, J.D., 1989. Modeling managerial behavior: misperceptions of feedback in a dynamic decision making experiment. Management Science 35 (3), 321–339.

Suarez, F., Cusumano, M., Fine, C., 1996. An empirical study of manufacturing flexibility in printed circuit board assembly. Operations Research 44 (1), 223–240.

Sugimori, Y., Kusunoki, K., Cho, F., Uchikawa, S., 1977. Toyota production system and Kanban system: materialization of JIT and respect for human system. International Journal of Production Research 15 (6), 553–564.

Swamidass, P., Newell, W., 1987. Manufacturing strategy, environmental uncertainty and performance. Management Science 33 (4), 509–524.

Taylor, B.W., Davis, K.R., 1977. Corporate productivity—getting it all together. Industrial Engineering 9 (3), 32–36.

Thierry, M., Salomon, M., Vannunen, J., Van Wassenhove, L., 1995. Strategic issues in product recovery management. California Management Review 37 (2), 114–135.

Thompson, J., 1967. Organizations in Action: Social Science Bases of Administrative Theory. McGraw-Hill, New York.

Venkatraman, N., 1989. The concept of fit in strategy research: toward verbal and statistical correspondence. Academy of Management Review 14 (3), 423–444.

Vickery, S.K., Droge, C., Markland, R.E., 1993. Production competence and business strategy —do they affect business performance. Decision Sciences 24 (2), 435–455.

Vollmann, T., Berry, W., Whybark, D., 1988. Manufacturing Planning and Control Systems. Irwin.

Wagner, H., 1969. Principles of Operations Research. Prentice-Hall, Inc., Englewood Cliffs, NJ, USA.

Wagner, H., Whitin, T., 1958. Dynamic version of the economic lot-size model. Management Science 5, 89–96.

Wemmerlov, U., 1979. Design factors in MRP systems: a limited survey. Production and Inventory Management Journal 20, 15–34.

Wernerfelt, B., 1984. A resource-based view of the firm. Strategic Management Journal 5 (2), 171–180.

Wheelwright, S.C., 1981. Japan—where operations really are strategic. Harvard Business Review 59 (4), 67–74.

Whybark, D.C., Williams, J.G., 1976. Material requirements planning under uncertainty. Decision Science 7, 595–606.
Wiest, J.D., Levy, F.K., 1977. A Management Guide to PERT/CPM: With GERT/PDM/DCPM and Other Networks. Prentice-Hall, New Jersey.
Winters, P.R., 1960. Forecasting sales by exponentially weighted moving averages. Management Science 6, 324–342.
Womack, J., Jones, D., Roos, J., 1990. The Machine that Changed the World. Macmillan, London.
Wright, T.P., 1936. Factors affecting the cost of airplanes. Journal of Aeronautical Science 3 (2), 122–128.
Yin, R., 1984. Case Study Research: Design and Methods. Sage, Beverly Hills, CA.