# Citation Analysis

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If I have seen farther, it is by standing on the shoulders of giants.
*-Isaac Newton*[1]

## Introduction

AN ESSENTIAL PART of research papers, particularly in the sciences, is the list of references pointing to prior publications. As Ziman observes, "a scientific paper does not stand alone; it is embedded in the 'literature' of the subject."[2] A reference is the acknowledgment that one document *gives* to another; a citation is the acknowledgment that one document *receives* from another.[3] In general, a citation implies a relationship between a part or the whole of the cited document and a part or the whole of the citing document.[4] Citation analysis is that area of bibliometrics which deals with the study of these relationships.

There are many published studies exploring citation analysis and its applications. Some reviews of this literature have already appeared,[5] and Hjerppe[6] has compiled a bibliography of more than 2000 entries including many studies in citation analysis. Eugene Garfield's writings are a rich source of information on this subject, particularly his book on citation indexing[7] and many of his "Current Comments" columns reprinted from *Current Contents*.[8] The present paper does not attempt to review this extensive literature in detail. Instead, it focuses on the development of citation analysis as a research method, uses and abuses of this method, and prospects for the future.

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As noted above, a citation represents a relationship between the cited and citing documents. The nature of this relationship is somewhat difficult to characterize, however, due to the many reasons authors cite, such as the fifteen enumerated by Garfield:

1. Paying homage to pioneers
2. Giving credit for related work (homage to peers)
3. Identifying methodology, equipment, etc.
4. Providing background reading
5. Correcting one's own work
6. Correcting the work of others
7. Criticizing previous work
8. Substantiating claims
9. Alerting to forthcoming work
10. Providing leads to poorly disseminated, poorly indexed, or uncited work
11. Authenticating data and classes of fact—physical constants, etc.
12. Identifying original publications in which an idea or concept was discussed
13. Identifying original publications or other work describing an eponymic concept or term...
14. Disclaiming work or ideas of others (negative claims)
15. Disputing priority claims of others (negative homage).[9]

Bavelas suggests that "the two extremes of this array of reasons might be true scholarly impact at the one end (e.g., significant use of the cited author's theory, paradigm, or method) and less-than-noble purposes at the other (e.g., citing the journal editor's work or plugging a friend's publications)."[10] Furthermore, it is possible that norms for citing vary from discipline to discipline.

Just as there are a number of reasons why citations exist, there may be a number of reasons why a citing author has not provided a link to certain other documents. Although the most obvious reason is that a prior document is not relevant to the present work, it may also be due to the fact that the author was not aware of the document, or could not obtain it, or could not read the language in which it was published. As Kochen observes: "it is not surprising that there is a great deal of arbitrariness in the way authors select references for their bibliographies. Undoubtedly, many documents which should have been cited are missed; and many documents which the author does cite are only slightly relevant."[11]

In spite of the uncertainties associated with the nature of the citation relationship, citations are attractive subjects of study because they are both unobtrusive and readily available. Unlike data obtained by interview and questionnaire, citations are unobtrusive measures that do

not require the cooperation of a respondent and that do not themselves contaminate the response (i.e., they are nonreactive).[12] Citations are signposts left behind after information has been utilized and as such provide data by which one may build pictures of user behavior without ever confronting the user himself. Any set of documents containing reference lists can provide the raw material for citation analysis, and citation counts based on a given set of documents are precise and objective.

**Development of Citation Analysis**

The development of citation analysis has been marked by the invention of new techniques and measures, the exploitation of new tools, and the study of different units of analysis. These trends have led to a rapid growth in both the number and types of studies using citation analysis.

The easiest technique to use is a citation count, determining how many citations have been received by a given document or set of documents over a period of time from a particular set of citing documents. When this count is applied to articles appearing in a particular journal, it can be refined by calculating the impact factor, the average number of citations received by articles published in a journal during a specified time period. This measure allows one to compare the "impact" of journals which publish different numbers of articles. Pinski and Narin have developed further refinements of citation counts which take into account the length of papers, the prestige of the citing journal, and the different referencing characteristics of different segments of the literature.[13]

Two techniques have been devised to identify documents likely to be closely related: bibliographic coupling[14] and cocitation analysis.[15] Two documents are bibliographically coupled if their reference lists share one or more of the same cited documents. Two documents are cocited when they are jointly cited in one or more subsequently published documents. Thus in cocitation earlier documents become linked because they are later cited together; in bibliographic coupling later documents become linked because they cite the same earlier documents. The difference is that bibliographic coupling is an association intrinsic to the documents (static), while cocitation is a linkage extrinsic to the documents, and one that is valid only so long as they continue to be cocited (dynamic).[16] The theory and practical applications of bibliographic coupling and cocitation analysis have been reviewed by Weinberg and Bellardo, respectively.[17] Citation counts and bibliographic

coupling were the characteristic citation analysis techniques in the 1960s, but in the 1970s cocitation analysis became the focus of much research activity. Cocitation analysis is of particular interest as a means for mapping scientific specialties.[18]

Use of new techniques in citation analysis has been made possible by the availability of new tools. Early citation studies frequently were based on lists of references found in articles appearing in a small number of journals. Citations had to be transcribed and manipulated by hand. Because of the tediousness of this process, most studies were necessarily quite limited in scope. The availability of the computer has significantly improved this situation in two ways: through the production of printed indexes which contain citation data from thousands of documents,[19] and through the analysis of citation data available in machine-readable form. Products of the Institute for Scientific Information (ISI) now provide a wealth of data for citation analysis. Subject coverage has been expanded from the initial *Science Citation Index* (SCI) to include the *Social Sciences Citation Index* (SSCI) and the *Arts and Humanities Citation Index* (A&HCI) as well. And with each passing year the time coverage becomes more extensive—SCI dates from 1961, SSCI from 1966, and A&HCI from 1976. In 1973, ISI introduced the *Journal Citation Reports* (JCR), a companion volume to the citation index which includes rankings of journals by citations and by impact factor, as well as two ranked lists for each journal covered: those journals which cite a given journal most heavily, and those journals which a given journal most frequently cites.[20] At present, JCR volumes are available for both SCI and SSCI.

Although discussion thus far has suggested counting citations only for individual articles or journals, in fact various levels of aggregation are possible. The units of analysis can be individual articles or books, journals, authors, industrial organizations,[21] academic departments, universities, cities, states, nations, and even telescopes.[22] If one assumes that citations are indicators of importance, then one can use such analyses to determine the most important scholars, publications, departments, etc., in a particular discipline or subdiscipline. This assumption is just one of several which deserves closer scrutiny if the results of citation analyses are to be understood.

## Critique of Citation Analysis

Critics have questioned both the assumptions and methods of many studies found in the citation analysis literature. The strongest

advocates of citation analysis recognize its limitations and exercise care in its applications.[23] Unfortunately, other investigators seem to be unaware of these limitations and misinterpret the results of their analyses. This section of the paper will enumerate both the assumptions underlying citation analysis and the limitations of citation data, setting the stage for the discussion of applications which follows.

Assumptions frequently underlying citation analysis are described below, together with supporting evidence and/or counter-examples.

1. *Citation of a document implies use of that document by the citing author.* This assumption actually has two parts: (1) the author refers to all, or at least to the most important, documents used in the preparation of his work; and (2) all documents listed were indeed used, i.e., the author refers to a document only if that document has contributed to his work. Failure to meet these two conditions leads to "sins of omission and commission":[24] certain documents are underrated because not all items used were cited, and other documents are overrated because not all items cited were used. With respect to underrating, it should be evident to anyone who has written a paper that citation does not necessarily fully and faithfully reflect usage. Often what is cited is only a small percentage of what is read; not all that is read and found useful is cited. Although the author usually does not provide any evidence of omissions, there are exceptions. Consider a paper by Bottle which has as its reference 29: "Reference omitted to avoid embarrassing its author"![25] With respect to overrating, Davies offers a "fundamental law of reference giving": it is quite unnecessary to have read or even seen the reference yourself before quoting it.[26] Without looking at the text of both the citing and cited documents, it may not be possible to make a judgment as to whether a particular citation does indeed represent use of material in the cited document.

2. *Citation of a document (author, journal, etc.) reflects the merit (quality, significance, impact) of that document (author, journal, etc.).* The underlying assumption in the use of citation counts as quality indicators is that there is a high positive correlation between the number of citations which a particular document (author, journal, etc.) receives and the quality of that document (author, journal, etc.).[27] The use of citation analyses for evaluative purposes is the issue that has generated the most discussion. While Bayer and Folger note that measures derived from citation counts have high face validity,[28] Thorne argues that citation counts have spurious validity because documents can be cited for reasons irrelevant to their merit.[29] Nevertheless, this assumption has been tested and has found support in a number of studies, including

studies of scientific papers, journals and scholars.[30] In each case some nonbibliometric measure(s) of quality must be compared with bibliometric measures based on citation counts. The difficulty is that quality is a complex attribute, and there generally is no single widely accepted nonbibliometric measure. Furthermore, one cannot automatically assume that an infrequently cited document (author, journal, etc.) is without merit. In the case of journals, for example, the usefulness of citations as a measure of the journal's quality varies according to the function of the journal; news journals may be of high quality but infrequently cited. Until more is understood about the reasons for citing, citation counts can at best be viewed as a rough indicator of quality. Small differences in citation counts should not be interpreted as significant, but large differences may be interpreted as reflections of differences in quality and impact. Results of citation counts should be compared with alternative quality indicators to look for correlations. The validity of the measure is most fragile in citation counts for individual documents and authors. One can have more confidence in comparisons of counts based on larger units, such as journals.

3. *Citations are made to the best possible works.* One can better understand the nature of citations if one knows the population from which they are selected. If one assumes that citations are made to the best possible works, then one must imagine that authors sift through all of the possible documents that could be cited and carefully select those judged best. But studies of science information use have suggested that accessibility may be as important a factor as quality in the selection of an information source. Soper conducted a study to investigate the effect of physical accessibility upon the selection and use of references.[31] She found that the largest proportion of documents cited in authors' recent papers was located in personal collections, a smaller proportion was located in libraries in departments and institutions to which respondents belonged, and the smallest proportion was located in libraries in other cities and countries. Thus a paper might well have been cited because it happened to be on the citer's desk rather than because it was the ideal paper to cite. Accessibility of a document may be a function of its form, place of origin, age, and language. If a journal article, its accessibility may be determined by the journal's circulation, reprint policies, and coverage by indexing and abstracting services. Just as a document may be more or less accessible, a researcher may be more or less visible. An author is likely to be most aware of the work of his colleagues. Other scientists' work may come to the author's attention as a result of their discoveries, their leadership in the scientific community,

or their activities in the world of politics and controversy.[32] As with documents, researchers cited therefore do not necessarily represent the most outstanding in a particular field. It may be that anything which enhances a researcher's visibility is likely to increase his citation rate, irrespective of the intrinsic quality of his work.

4. *A cited document is related in content to the citing document; if two documents are bibliographically coupled, they are related in content; and if two documents are cocited, they are related in content.* To the extent that citation indexes can be used to retrieve relevant citing documents given a cited document, one has support for the first part of this assumption. Additional support is found in the results of an experiment conducted by Barlup in which authors were asked to assess the degree of relatedness of citations to their own work.[33] The authors judged 72 percent to be definitely related, and only 5 percent to be definitely not related. The difficulty with the second and third parts of the assumption becomes evident when one considers an early statement by Garfield regarding citation indexes: "If one considers the book as the macro unit of thought and the periodical article the micro unit of thought, then the citation index in some respects deals in the submicro or molecular unit of thought."[34] Given this observation, Martyn contends that a bibliographic coupling is not a valid unit of measurement because one does not know that two documents citing a third are citing the identical unit of information in it.[35] Thus, bibliographic coupling is merely an indication of the existence of the probability (possibly zero) of a relationship in the content of the two documents. The same applies to cocitation as well; the fact that two papers are cocited does not guarantee a relationship between their contents.

5. *All citations are equal.* This paper began with a discussion of the problematical nature of the relationship between cited and citing documents. Yet studies using citation counts generally assume that all citations (with the possible exception of self-citations) can be weighted equally. In recent years many investigators have sought ways to refine citation analysis which would not necessarily treat all citations to the same article (author, journal, etc.) as equivalent. These can be subdivided into two types of refinements: mechanical *v.* intellectual. Mechanical refinements require no judgment or inference; intellectual refinements require (at least at present) human analysis.

Mechanical refinements look at easily definable properties of a citation, such as multiple occurrence or location in a document. The hope is that knowing this property will allow one to predict something about the relationship between citing and cited documents. Bertram

investigated whether the level (or amount) of material actually cited by citing articles in science journals would vary significantly with the section of the source article in which the citation occurs.[36] She identified three levels [whole, part, word(s)] and three sections (title/introduction, results/discussion, experimental), and found that indeed the title/introduction tended to cite whole articles, results/discussion tended to cite only a part, and experimental tended to cite words. Thus, at least for the articles in Bertram's study, a significant relationship does exist between citation level and the section of the citing article in which a citation occurs. A study reported by Herlach tested and accepted the hypothesis that the mention of a given reference more than once within the same research paper indicates a close and useful relationship of citing to cited paper.[37] She further noted that use of multiple mention as a retrieval criterion would yield good precision but low recall. Voos and Dagaev agree that location and multiple mention can be used to distinguish citations of particular value.[38] Self-citations are also readily identifiable as a special class. Tagliacozzo completed a study to determine the extent to which authors of scientific articles cite their previous publications and to find the principal distinguishing features of this particular type of citation.[39] She found that self-citations were more recent than references to other authors. This suggests that conclusions about time distributions of citations would vary depending on whether or not self-citations were included.

In contrast to mechanical refinements, intellectual refinements rely on content analysis. As Small observes, "in the last few years sociologists of science have begun to explore the fine structure of citation practice by examining the contexts in which citations occur—specifically the text surrounding the footnote number."[40] Many of these studies have attempted to develop and apply classification schemes. An early classification scheme was that of Lipetz, who devised a set of indicators to characterize the citing article as well as the kind of relationships of the citing to the cited article.[41] Several other classification schemes have been developed in the last few years.[42] Categories suggested by these schemes include confirmative/negational—to distinguish material judged to be good from material judged to be bad—and organic/perfunctory—to distinguish necessary citations from dispensable ones. All these attempts at classification are useful supplements to simple citation counts.

Rather than trying to create exhaustive classification schemes, a more recent development is the interpretation of cited documents as concept symbols. As Small observes, the interpretation of citations in

this way is more closely related to the way citations are used by authors in scientific papers.[43] He notes that most citations are the author's own private symbols for certain ideas he uses. Where documents are frequently cited, their use as concept symbols may be shared by a group of scientists. Small has recently extended this approach through the development of cocitation context analysis.[44] Statements characterizing the structure of a cocitation map are obtained from an analysis of the contexts or passages in which documents are cocited.

The difficulty with such intellectual refinements is the time required to apply them. Human judgment is needed to analyze citation contexts and make inferences, so studies employing intellectual refinements are likely to be limited in scope. Nevertheless, both mechanical and intellectual refinements offer alternatives to treating citations as masses of undifferentiated units. Although for some applications it is sufficient to treat citations equally, for others it is appropriate to investigate "the fine structure of citation practice."

Given the difficulties with the assumptions which underly many citation analyses, one must also be aware of the problems which can exist in sources of citation data. Some of these problems are characteristic of all sources of citation data, while others only pose difficulties in the use of secondary sources, the citation indexes. Cole and Cole discuss many of these problems and ways of handling them in statistical analyses.[45] Problems include:

1. *Multiple authorship.* Cited articles listed in the citation indexes include only the first-named authors. To find all citations to publications of a given author, including those in which he is not first author, one needs a bibliography of his works so that all articles can be checked in the citation index. Errors can be introduced unless such complete counts are made.[46] There is also the problem of allocating credit in multiauthored works.[47] Should such works be treated the same as single-authored works in citation counts or should credit be divided proportionally? Should one consider the sequence of author names in allocating credit, as this sequence often is an indication of the contribution of each author to the work reported?
2. *Self-citations.* If self-citations are to be eliminated from citation counts, this is easily done for papers written by a single author. Again, multiauthored papers may require further checking. An even more difficult problem is to eliminate group self-citations, i.e., references from any member(s) of a research group to any other member(s) of that research group. In this case one would have to find a source identifying all members of the research group.

3. *Homographs.* Many scientists with the same name and initials could be publishing in the same field. To differentiate among them, additional information such as institutional affiliation is needed. Otherwise citations could be attributed incorrectly to an author, particularly if he has a common name.
4. *Synonyms.* Citations will be scattered unless a standard form for the author name can be established. Examples of "synonyms" in the context of citation indexes include an author's name with a variable number of initials (e.g., Licklider, J.; Licklider, J.C.; Licklider, J.C.R.), a woman's maiden and married names, different treatments of foreign names, and misspellings. Although ISI's editing programs manage to reconcile many of the differences introduced by citing authors, variations still occur.[48] Journal names may also create synonym problems when the task is to identify citations of articles appearing in a particular journal. In addition to variations in the abbreviated form for a given title, journals merge, split into new journals, change titles, and appear in translation. There is a need to establish which forms are equivalent for the purposes of citation analysis.
5. *Types of sources.* The type(s) of sources used in a citation analysis can influence the results, as demonstrated in a study by Line in the social sciences.[49] Analyses of references drawn from journals and monographs showed differences, some of them large, in date distributions, forms of material cited, subject self-citation and citations beyond the social sciences, and countries of publication cited. Line concludes that any citation analyses that are based on only a limited number and type of sources without specific justification must be regarded with suspicion. Oromaner notes that authors of any type of literature are advised to keep their audience in mind when writing, so materials for different types of audiences may have differing citation patterns.[50] Citation data found in the citation indexes are drawn from many journals and selected monographs which are international in scope and from a variety of disciplines. Although the citation indexes do not seriously suffer from limitations in number of sources, they are limited in type. This is not a hindrance where journals within a field give a complete and accurate reflection of all important aspects of scholarship. Brittain and Line describe advantages and disadvantages of various sources of citations for analysis purposes.[51] Choice of types and numbers of sources should depend on the purpose of the analysis.
6. *Implicit Citations.* Most citation analyses consider only explicit citations, and these are what generally is made available in citation

indexes as well. An exception is the A&HCI, which includes implicit citations when an article refers to and substantially discusses a work but fails to include an explicit citation.[52] But implicit citations are also frequently found in the form of eponyms in the scientific literature. Furthermore, papers containing important ideas will not necessarily continue to be highly cited. Once an idea is sufficiently widely known, citing the original version is unnecessary. If one were using citation analysis to measure the impact of an individual author, such implicit citations would fail to be included.

7. *Fluctuations with time.* There may be large variations in citation counts from one year to another, so citation data should not be too restricted in time.
8. *Field variations.* Citation rates (citations per publication) vary greatly in different fields, leading to difficulties in cross-discipline comparisons. Bates has proposed the criterion rate as a refinement of citation rate, because citation counts as a measure of the quality of a researcher's work are influenced not only by the inherent value of that work, but also by the size of the pool of available citers in a given field.[53] A researcher's work can be evaluated in relation to a criterion rate of citation, the citation rate of the top researchers in that field.
9. *Errors.* Of course, citation analyses, including those based on citation indexes, can be no more accurate than the raw material used. Although processing of citations for inclusion in citation indexes may introduce some errors while eliminating others, many errors due to citing authors remain. These can include errors in cited author names, journal title, page, volume, and year. The incorrect citing of sources is unfortunately far from uncommon. Two studies found the percentage of error for citations from various journals to range from 10.7 to 50 percent.[54]

This section has considered two types of limitations which can affect citation analyses: the assumptions made may not be true, and the data collected may have inadequacies. Invalid conclusions will be made unless these limitations are taken into account in the design of a study and in the interpretation of results. The most reliable results may be expected when citation abuses and errors appear as noise under conditions of high signal to noise ratio, i.e., the noise represents only a relatively small number of the citations analyzed.[55] The limitations of citation analysis do not negate its value as a research method when used with care. There are, in fact, several application areas where citation analysis has been used successfully.

## Applications

The applications described in this section reflect two major themes—use of citations as tools for the librarian and use of citations as tools to analyze research activity. Citations and cocitations are part of the range of empirical data available to historians and sociologists of science, as well as to librarians. For each application area, representative studies are mentioned to illustrate the types of questions which have been investigated through citation analysis. In addition, weaknesses of the method are identified, reflecting points made in the critique above.

1. *"Literature of" studies.* In this case one looks at citations in a particular subject area to describe patterns of citation. The sources of citation data may be as limited as a single journal in the field (e.g., Chen's study of references in articles appearing in the *Bulletin of the Medical Library Association*[56]), or they may encompass many sources, including types of material in addition to journals. Characteristics of cited materials frequently examined include types, age, highly cited authors and journals, languages and countries of origin, and subject distributions.[57] This type of study may also look for changes in these characteristics over time. A major problem with these studies is their lack of compatibility which makes comparisons and synthesis difficult. One application which has been suggested for this type of study is the definition of appropriate secondary service coverage and scope of retrospective bibliographies in a given subject area.[58] By studying the range of subjects, countries, languages, and document forms referred to by a group of known core sources, one can begin to establish the boundaries of a subject literature, with the limitation that citations do not reflect all literature use. The value of this method in the determination of current policies is a function of the extent to which these data can be projected forward in time. Bibliographic coupling and cocitation have been used to create mappings of the micro- and macrostructures and relationships of disciplines.[59] Small, for example, has used cocitation analysis to explore the relationship of information science to the social sciences.[60]

2. *"Type of literature" studies.* Citation analysis can be used to gauge the dissemination of results reported in certain types of literature, such as government documents, dissertations, or the exchange literature of regional scientific societies.[61] The source of citations used for analysis clearly can determine the generality of one's conclusions in this type of study. Nelson, in a study of citations to art collection catalogs, remarks that one must recognize the potential usefulness of what she terms "self-styled" citation methods.[62] In her case, citation analysis of the fine arts nonserial literature was the appropriate approach. Such studies can involve content analysis, documenting not only where but also how certain types of literature have been used.

3. *User studies.* Although studies in this category are descriptive, they have implications for collection development and design of services. One approach is the analysis of reference lists in works written by library users, e.g., term papers, theses/dissertations or technical reports, in order to determine types of materials, age of materials, subject, language, and whether locally owned.[63] An alternative approach is to test a specific hypothesis about information use, e.g., scientific literature is little used by engineers, or academic researchers use different information sources than practitioners.[64] It should be noted that citation analysis can be used to compare user behavior today with user behavior several years ago, with the understanding that citations do not strictly parallel use.

4. *Historical studies.* Historical research using citation analysis is based on a literary model of the scientific process.[65] In this model scientific work is represented by papers written and published to report it, and relationships between discrete pieces of work are represented by references in papers. Citations can be used to trace the chronology of events, relationships among them, and their relative importance. Missing and implicit citations obviously pose problems for such an analysis. The subject of study may range from the influence of a single idea (e.g., Smith's investigation of the influence of Vannevar Bush's memex on subsequent research and development in information retrieval) to an individual's entire scientific career (e.g., Ruff's study of Istvan Kovacs).[66] Patent citation networks offer a novel technique for displaying the history of a technical subject.[67] The changes in patterns of cocitation from year to year can reveal something about the history of ideas in a given specialty.[68] Patterns found through such an analysis can be validated through interviews with specialists and questionnaire surveys, as in Small's longitudinal study of collagen research.[69] Finally, cocitation context analysis has been proposed as a means for elucidating the structure of paradigms, the consensual structure of concepts in a field.[70]

5. *Communication patterns.* Citations can be thought of as plausible indicators of scientific communication patterns. Although citation linkages do not necessarily reflect social contacts, it is probable that there is a certain amount of congruence between documental and social structures. Of particular interest is the analysis of these patterns to identify problem areas in communication. These could include linguistic isolation, limited dissemination of new ideas, and barriers between basic and applied science or between specialists and the public at large. Shepherd and Goode, for example, sought to determine whether research workers quoted in newspapers were really representative of

their respective fields.[71] They examined whether authors quoted in newspapers were also highly cited by their peers.

6. *Evaluative bibliometrics.* In these studies, citation analysis is defined as the evaluation and interpretation of the citations received by articles, scientists, universities, countries, and other aggregates of scientific activity, used as a measure of scientific influence and productivity.[72] Although there is much about the meaning of citation rates that is not yet known (e.g., factors affecting rates, variation from field to field), citation analysis is being used with increasing frequency as an evaluative tool by science administrators.[73]

7. *Information retrieval.* Use of citation relations has perhaps had the greatest impact in information retrieval where citations have been used to augment more traditional approaches to literature searching. Experiments by Salton have confirmed that citations are useful supplements to keywords in identifying relevant documents.[74] Citation relations have been used in developing document representations, in automatic classification, and in various retrieval algorithms which make use of the ability to find "like" documents in the file independent of words and language.[75] Citations as a retrieval tool have the advantages that they are unaffected by changing terminology, they provide access to interdisciplinary literature, and they reveal papers relevant to a subject not found by using conventional indexes. Extensive use of citations in computer-based retrieval has been hindered by a lack of systems tailored specifically for citation manipulation. This may not prove to be a barrier in the future, however. Yermish describes an interactive information retrieval system which he developed to manipulate citation relations existing among bibliographic records efficiently.[76] Each document record has an associated REFLIST (list of all documents that have been cited by a given document) and CITELIST (list of all subsequent documents that cite a given document). These allow one to use direct citation and citation coupling search modes in addition to the more conventional keyword search. Two recent papers describe the use of cocitation as a search strategy to retrieve documents relevant to a given topic using commercially available search systems and the citation index data bases.[77] Both cocited author and cocited document searches are possible. Garfield has announced the pilot testing of BIOMED SEARCH, a retrieval system based on research front specialties defined through cocitation clustering.[78] Finally, O'Connor has investigated procedures for the computer identification of citing statements found in documents for which the full text is available in machine-readable form, so that a retrieved set could include not only the identification of citing documents but also the citing statements them-

selves.[79] As citation relations are more actively exploited for literature search purposes, it should be possible to develop a better understanding of the reasons for success and failure in this application area.

8. *Collection development.* It is appropriate to begin the discussion of citation analysis as a tool for collection development with Cayless's observation that "the main purpose of quantitative measures is to provide information on which to base qualitative judgments, not to replace them."[80] Citation analysis has been applied primarily to the development of journal collections, where decisions to be made include: to acquire or not acquire a particular title, to continue or discontinue a subscription, to weed or not to weed a backset. Beginning with a study by Gross and Gross published in 1927 which used citation frequency as a measure of journal significance, citation analysis has been advocated as a tool in journal evaluation.[81] This application has not been without critics. Brodman was perhaps the first to test the assumptions which underly the method: (1) the value of a periodical to a professional worker is in direct proportion to the number of times it is cited in the professional literature; (2) the journal(s) used as a source of citations is(are) representative of the entire field; and (3) if more than one journal is used as a source of citation data, all can be weighted equally.[82] She did not find support for these assumptions, and concluded that results of the method should be used with caution. Others question journal rankings by citation counts because such rankings may bear little relation to the frequency of journal use in a particular library, as citation analysis and use analysis measure different activities.[83] The difference in results of use studies in different libraries suggests the limited value of a generalized technique such as citation analysis. In addition, there is the problem of noncited journals, such as trade and technical journals and professional magazines.[84] Line and Sandison discourage the use of citation counts, instead advocating journal uses per unit of expenditure (purchase, processing, binding, storage) as a basis for selection and journal uses per unit of shelf space occupied as a basis for discarding.[85]

In spite of these criticisms, there is still a place for citation analysis as a tool in collection development. Even though he disapproves of the use of citation analyses in general, Line does acknowledge three uses to which ranked lists derived from citation counts can be put: (1) highly ranked journals not available locally and within subject scope are worth examining in more detail; (2) low-ranked journals that are taken locally should likewise be examined; and (3) lists based on source journals in a particular subject can indicate journals outside of that subject which may not yet have been acquired but may be valuable for local users.[86] In

his review of the applications of citation analysis to library collection building, Broadus concludes that in the absence of highly expert subject specialists on a library staff, citation studies can be of considerable value in choosing serials and even monographs.[87] Given the uncertainties involved in using citation counts in isolation, it is appropriate to consider their use in combination with other measures, as in the model for journal selection which gives highest priority to journals found to be highly cited, abstracted and used.[88] Although a tool like JCR gives citation rankings based on a large body of literature, librarians may also analyze citations found in their users' publications, as described above under "user studies." Kriz, for example, analyzed reference lists in engineering theses.[89] Finding books to be more frequently used than journals, he shifted funds from journal subscriptions to purchase more books. Citations are indicators of use, but there is probably a need for multiple indicators, as demand does not strictly parallel citation. Many materials are borrowed and read but not cited; authors who cite are only a subset of the total reading public. Other measures of use such as in-house use, circulation and interlibrary loan can be used to supplement citation analysis in developing a more comprehensive view of user needs as a basis for collection development.

## Future Developments

Thus far this paper has described the uses, as well as abuses, of citation analysis. Given the increasing availability of raw material for citation analysis (as A&HCI joins SSCI and SCI) and the development of computer systems with which to manipulate these data easily, it is safe to predict that citation analysis will continue to be a commonly used technique. But the large number of studies using citation indexes has led one critic to remark that uses of citation indexes other than for literature searching seem to be examples of Kaplan's law of the instrument: "Give a small boy a hammer, and he will find that everything he encounters needs pounding."[90] Superficially, citation analysis appears to be a simple technique to apply, and there is a danger that it will fall into disrepute through uncritical or overenthusiastic use. As with any methodology, citation analysis produces results whose validity is highly sensitive to the skill with which it is applied.

The critique of citation analysis in this paper outlined the assumptions often made and the problems which arise in data collection. In order to better understand the possibilities and limitations of citation analysis, more studies which test the assumptions and explore the problem areas are needed. Another way to strengthen studies using

citation analysis is to apply multiple methods in the study of a phenomenon, as in the coupling of citation analysis and content analysis. As no research method is without bias, citation analysis should be supplemented by methods testing the same variables but having different methodological weaknesses. For example, to investigate communication patterns among scientists, one could supplement citation data with those obtained via interview or questionnaire.

Not enough is known about the "citation behavior" of authors—why the author makes citations, why he makes his particular citations, and how they reflect or do not reflect his actual research and use of the literature. When more is learned about the actual norms and practices involved, we will be in a better position to know whether (and it what ways) it makes sense to use citation analysis in various application areas.[91] It would also be interesting to study in more detail the characteristics of documents which do not cite and/or are not cited, and to identify characteristics of documents which can be used to predict citedness.[92]

Advances in theory and practice have marked the development of citation analysis, and researchers are likely to continue contributing in both these areas. Gilbert, for example, has proposed a theory of citing which views referencing as persuasion.[93] In practice, simple citation counts have been supplemented by bibliographic coupling, cocitation analysis, evaluative bibliometrics, and cocitation context analysis. Garfield recently noted that one of the major methodological changes in his studies in the near future will be to shift from counting citations to counting "authors influenced by."[94]

To conclude this paper, two questions affecting the future of citation analysis will be posed. Is it possible that increased use of citation analysis will *cause* a change in citation behavior? How will citation behavior be affected by the increased use of electronic media for generation, storage and dissemination of information? Although both questions have already received some attention in the literature, the responses to them are necessarily somewhat speculative.

It has been suggested that the very existence of citation indexes and the growing abundance of citation analyses will likely have various feedback influences on the writing and citing habits of future authors.[95] Just as authors may title their papers more carefully to ensure their retrievability through keyword indexes, authors could be motivated to acknowledge their intellectual debts to prior documents accurately, lest their papers go undetected by the user of a citation index. Thus this paper is titled "Citation Analysis" rather than the more metaphorical "Standing on the Shoulders of Giants," and care has been taken to

reference accurately works by Garfield, Small and other key researchers in citation analysis, as well as to include one self-citation. In an article on the ethics of scientific publication, Price asserts that now that citations to previous work have become a valuable tool for literature indexing, referees and editors should summarily reject bibliographies that are either insufficient or padded.[96] Fears have been expressed regarding the possibilities for abuse: "[I]t might create a bandwagon effect whereby authors who wish their document to be used will cite, and try to get cited by, the most popular documents. This would be an aberration, a disease of the information system."[97]

Whether or not such feedback influences are felt, other changes are likely to come with the increased use of electronic media for information handling. The first question which arises is the form of bibliographic references for material available in machine-readable form. Proposals have already been put forward for both data files and computer conference comments.[98] Questions of quality control, accessibility and author's permission must be addressed before the latter can be handled as conventional publications. Whether the technological changes available to the next generation of researchers will undermine the role of the paper in the process of scholarship remains to be seen. What is already available are information facilities for electronic publishing and document handling such as the Xanadu Hypertext System.[99] The basic unit of this service is the windowing document. With the full text of documents available in machine-readable form, a reader may either explore a document or step through the window to explore the next document, such as one referred to in a footnote. After exploring a further document, the reader may return to the one that showed him to it, or proceed on tangents that become available. Thus the links which citations represent are converted to electronic form, and new possibilities for citation analysis arise. One can also imagine the use of graphics devices for the display of citation networks and cluster maps.

This paper began with a quotation from Newton, the image of science advancing by "standing on the shoulders of giants." In fact: "the process by which the boundaries of knowledge are advanced, and the structure of organized science is built, is a complex process indeed....[T]he whole effort is highly unorganized. There are no direct orders from architect or quarrymaster. Individuals and small bands proceed about their businesses unimpeded and uncontrolled, digging where they will, working over their material, and tucking it into place in the edifice."[100] Perhaps the greatest potential contribution of citation analysis lies in the new insights which it can offer into this process. It is

a process which concerns not only scientists and sociologists of science, but also those who work with the literature of science.

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