ON GENERALISING SCIENTOMETRIC JOURNAL MAPPING BEYOND ISI'S JOURNAL AND CITATION DATABASES

R. J. W. TIJSSEN, TH. N. VAN LEEUWEN

Centre for Science and Technology Studies (CWTS), University of Leiden,
P.O. Box 9555, 2300 RB Leiden (The Netherlands)

This article presents results of a study on the applicability of journal mapping of knowledge domains beyond the databases produced by the Institute for Scientific Information (ISI). The utility and validity of this generalisation is discussed with an emphasis on its added value in comparison to 'traditional' ISI-based journal maps, i.e. those restricted to (predominantly English-language) ISI-covered journals, and journal-to-journal citation data retrieved from ISI's *Journal Citation Reports*. The mapping methodology was applied to Manufacturing technology and management – a multidisciplinary domain situated on the interface of science and technology. The *International Journal of Production Economics* was singled out as a special case for the validation study of the maps. Results of this study, involving several subject experts, indicate that a journal content-based map was not only far superior to the journal citation map, but also outperformed the map derived from the combination of both types of data. The selection of periodicals from other databases such as COMPENDEX produced a substantial number of additional titles of which only half were also covered by ISI.

Journal mapping of knowledge domains

Learned journals are institutionalised manifestations of cognitive and/or organisational characteristics of scientific areas. The prominence of these journals within areas depends mainly on the extent to which they bring out good research publications, or, more in general, their role – as institutionalised media – in disseminating knowledge throughout a professional community.[1] Professional and trade journals as well as other types of periodicals such as conference proceedings can play a significant complementary role, especially in areas covering the science-technology interface and domains of technological R & D. Periodicals in general constitute clearly identifiable and useful empirical units for macro-level description across the entire spectrum of knowledge domains. They have been used as such from the 1920s onward, particularly in bibliometric studies of scientific activity (e.g. *Hulme*[2]).

The information explosion that took place after WW II spurred a proliferation of scientific and technological periodicals. For library and information science purposes it became not only more difficult and prohibitively labour-intensive, but also more urgent, to classify and assess the content and relevance of all those periodicals. The pace of accumulation of bibliographic information in the 1950's and early 1960's inspired *Garfield* to establish the *Institute for Scientific Information* (ISI) and launch ISI's *Science Citation Index* database.[3] Meanwhile, scholars of science such as *De Solla Price*[4] conducted quantitative analyses of such bibliographic data as part of comprehensive empirical studies of scientific areas. Both developments paved the way for more sophisticated studies conducted in the early 1970s aimed at describing features of dissemination and exchange of scientific information within scientific specific domains.[5-6] Extensive analysis of the rapidly growing bulk of bibliographic data was still in its early days. To paraphrase a quote by *Simon*[7] from that era: "The information-processing systems of our contemporary world swim in an exceedingly rich soup of information [..] the scarce resource is not information; it is the processing capacity to attend to information." In the late 1970's ISI introduced its *Journal Citation Reports* (JCR) consisting of aggregate data on the number of citations given to and received by each of the ISI-covered journals. This database offered the possibility to unfold macro-level cognitive structures within scientific areas.

The availability of the JCR-database opened up new avenues of bibliometric research. It became considerable less cumbersome to conduct large-scale journal citation studies aimed at extracting and describing the internal structure of knowledge domains on (sub)disciplinary levels. Increasingly detailed and large-scaled numerical analyses of JCR-data proved to be a useful and valid tool for studying the journal-to-journal citation networks within scientific fields. These studies addressed questions about journal interrelationships, the relative standing of journals within these citation networks, communication flows within and between scientific areas, and establishing the existence of and shifts in foci of R & D activity.[8-12] The outcome of these sophisticated journal citation analyses are often presented by graphs ('maps') depicting the way in which the journals organise themselves on such a map relative to one another. The journals and their relative location reveal relevant basic features of the underlying cognitive structure. These maps may therefore present an aggregate-level overview of a domain's cognitive structure.

Simon's plea for exploitation of information is still valid in the present-day electronic age. Analysis of the past, present and future of scientific and technological

domains has become of great strategic importance to policy makers and R & D managers in modern industrialised societies. Bibliometric mapping of the cognitive structure underlying the huge amount of bibliographic information embodied in the R & D literature provides a useful empirical point-of-entry for delineating and describing strategically important knowledge domains.[13-14] However, there are number of reasons why JCR-based studies, using only ISI-covered journals as units of analysis, may fail to provide adequate macro-level maps.

Drawbacks of journal-journal citation mapping

Traditionally, citation-based journal mapping studies were especially appropriate for areas of basic research that are driven by common research paradigms (mostly within the natural and life sciences). These fields tend to have a clearly-defined cognitive structure and are characterised by a community of researchers who share a strong tendency to publish in the scientific journal literature, while adhering to more or less uniform citation practices. Journal citation analysis provides a reasonable valid method for stratification of learned journals and placing them relative to one another within the journal citation network. Moreover, studies have shown that expert opinions as to which journals are the most important within an area correlate significantly with quantitative information.[15]

Nevertheless, even in the case of the natural and life sciences, JCR-based studies may suffer from some serious conceptual, technical and operational drawbacks.[16] First and most important, aggregated citation data are not an unbiased measure of the strength of cognitive links between scientific journals. Citations given in reference lists are just one of the modes indicating exchange of information. Moreover, journal citation flows are not only influenced by (sub)disciplinary-dependent citation habits but also by external factors such as the type of journal (language, size of circulation, readership, links with professional societies). Furthermore, JCR-data are readily available only for journals covered by ISI. Although the SCI journal collection, comprising of about 3500 learned journals, encompasses the majority of the important international scientific journals in the natural and life sciences, its coverage of the world-wide journal literature is unavoidably limited.

The above problems tend to become worse when journal citation analysis is applied to fields in the more heterogeneous social and behavioural sciences, where scholars are less likely to share paradigms and publication and citation practices may differ considerably. Such cognitively ill-structured fields with fuzzy boundaries may

seriously hamper a satisfactory delineation and description in terms of a journal set. A similar situation may arise in the case of inter-disciplinary or multi-disciplinary fields of science.

As one moves into the domain of engineering and the interface of science and technology, these drawbacks exacerbate due to the large variety of types of periodicals playing distinctly different roles in the organisation and transfer of knowledge and know-how.[17] Publications in professional and trade journals are less likely to contain (extensive) reference lists. Citation data will therefore tend to be scarce and may not be very representative for the direction and strength of information flows.[18]

Generalised journal mapping

The drawbacks mentioned above can be dealt with from two different angles. First, a more satisfactorily representation of knowledge domains may require the inclusion of other (non-ISI) periodicals. Extending the publication coverage should also help avoid ISI's time-lag for including new scientific journals in their databases (particularly those launched in rapidly developing specialist areas), and ISI's bias in favour of journals from English-speaking countries (especially those from the USA). Secondly, one can use bibliometric data on journal interrelationships other than journal-to-journal citation frequencies for mapping purposes. Data on the journal's contents represents an obvious source of information. In general, one may presuppose a partial resemblance between citation-based and content-based representations of field's cognitive structure. Researchers and technicians publishing in periodicals are obviously more inclined to read, use and cite periodicals whose content is cognitively linked to their publication outlet(s). Previous citation studies of fields in the natural sciences and based on ISI-covered journals have indeed demonstrated that citation and content data do tend to produce journal configurations with similar basic features.[10, 19, 20]

Including non-ISI periodicals adds a new element to journal mapping. In most areas such an addition is likely provide a more complete macro-level representation of a knowledge domain and perhaps a better understanding of its cognitive structure. Extending JCR-based journal mapping raises a number of questions: will non-ISI periodicals significantly affect the representation of the cognitive structure as compared to (citation-based and/or content-based) maps derived from ISI-journals only? what kind of results may one obtain across the spectrum of scientific

disciplines? in which instances should one expect significant added value *vis-a-vis* 'traditional' ISI-journal citation-based maps?

This article describes findings of a first exploratory application of such a 'generalised' mapping method in an attempt to shed some light on these issues. The study concerns three kinds of journal maps. One based on JCR citation data, one derived from quantitative information on the journals' content, and a joint map that combines both types of data. The second and third map include ISI-covered scientific journals as well as other (non-ISI) periodicals. The JCR-based map is used as a point of reference for examining the added value of the other two maps. The mapping method is applied to a domain on the interface science and technology, which presents an illustrative example of the limited value of 'traditional' citation-based journal mapping.

Application: Manufacturing technology and management

Introduction

The basic objective of this case study was to test the generalised mapping methodology to its limits of application. More specifically, to establish its relevance and utility in an area on the interface of science and technology. We were particularly interested in finding out whether or not additional relevant journals (ISI-covered and others) appear, and to assess the validity of the different types of bibliometric maps. The prime concern was the comparison of journal maps emerging from a JCR-based citation analysis with those derived from content-based mapping. Special emphasis was placed on adequate coverage of the science-technology interface through the inclusion of engineering periodicals.[21]

The study concerns an applied scientific and technological domain that can be described as *Manufacturing technology and management*. This multidisciplinary area is situated on the intersection of engineering, computer science, business & economics, and management. It covers academic scientific research, industrial R & D, as well as industrial practice relevant to manufacturing. Its broad scope includes topics concerning means, materials, machines, expenditure, manpower and management for the production of services and goods. Typical examples are: product life cycles, product design, product development, product testing, and material flow cycles.

In this particular study we focused on the subject area covered by *International Journal of Production Economics* (*IJPE*) and its former title *Engineering Cost and Production Economics* (*ECPE*). This change of title (and editorial policy) occurred in 1991. The analysis was therefore partly designed to identify possible differences in location of both journals on the bibliometric maps.

Selecting seed journals

The study started from *IJPE/ECPE* and a carefully chosen set of three additional seed ISI-covered journals, comprising of both general and more specialist journals, each of which representing one or more important distinctive features of the domain.[22]

- *International Journal of Production Research* (*IJPR*);
- *Robots and Computer-Integrated Manufacturing* (*RCIM*);
- *Computers in Industry* (*CI*);

ISI allocates all journals except *CI* to the field of Engineering, Technology & Applied Sciences, but not to any specific ISI Subject Category. *Computers in Industry* belongs to the field of Computer Sciences, which is incorporated in ISI's COMPUMATH database.

Selecting databases

Considering the multidisciplinary nature and wide scope of the field we chose three comprehensive databases in search of useful bibliographic data and relevant other periodicals:

- ISI's Journal Citation Reports was used as a source of journal citation data and to identify other ISI-covered journals.
- *Ulrich's International Dictionary of Periodicals* provides general information on a wide range of publication outlets, including learned journals, professional and trade periodicals, as well as popular magazines on science and technology. Journal classification schemes were used to select additional periodicals.
- *COMPENDEX* offers an extensive coverage of the engineering literature, including industrial engineering. This database comprises a large number of learned and professional periodicals (ISI and non-ISI) as well as an abundance of non-journal literature (conference proceedings in particular). This database was used for retrieving additional periodicals (i.e. ISI-covered journals as well as non-ISI

periodicals). The subject classification headings attached to their publications in COMPENDEX were used to describe the general content of all selected periodicals.

The data were derived from the most recent version of the bibliographic data available at the time of the study (mid-1993). That is, COMPENDEX for 1991–1992, JCR for 1990–1991, and Ulrich's 1992 version. The bibliographic records were extracted from the CD-ROM versions of these databases.

The basic idea is that each database presents a distinctly different source of information and will provide a somewhat different set of journals related to those seed journals. Collectively, these sources should then be able to identify the large majority of those related journals. Moreover, we assume that the information retrieved from those databases (i.e., citations, publication classification headings, journal classification headings) cover enough relevant features of the periodicals to describe the main structure of cognitive relationships between them.

Clearly, those three types of data differ strongly by nature and rationale. Citations are an intrinsic part of the activity in the public research publication system and the concomitant communication system by which academic researchers acknowledge the work of one another. Subject classification headings also refer to individual publications, but are assigned by database indexers in compliance with fixed classification schemes which are mostly based on disciplinary distinctions among research publications. Moreover, content profiles of periodicals derived from such subject classification headings are limited to the publications indexed by the database producer. Ulrich classifications on the other hand are governed by the view of bibliographers concerning the content of a periodical as a whole. Obviously, one will have to take these considerations into account when comparing journal maps based on different types of bibliographic data.

Unlike ISI's cover-to-cover approach, COMPENDEX indexers in most cases do not enter all publications belonging to a periodical, but select them according to their content and perceived relevance. Some ISI-covered journals may be indexed quite extensively by COMPENDEX, others only to a minor degree or not at all. ISI-covered journals with a low coverage by COMPENDEX are clearly less reliable as a source of information in a study aimed at combining and comparing citation data and content data. Periodicals included in COMPENDEX that are not covered by ISI, and vice versa, present another methodological problem. These periodicals are deemed relevant by COMPENDEX indexers and should therefore not be discarded *a priori* in a comprehensive coverage of a field. This is especially true for relatively new periodicals. Considering the exploratory nature of this study it was therefore decided

to incorporate all selected journals, irrespective of their coverage in either database, and to treat them as equally relevant in the analytical procedure. Interpretation of the outcome will however focus on those periodicals that are sufficiently covered by COMPENDEX.

Selecting additional periodicals

The aggregate content of each seed journal was determined by collecting all subject classification headings assigned to its publications in COMPENDEX. The unified and fixed description of these headings, and their controlled assignment by database-indexers make them particularly suited for general descriptions of journal content (in comparison to the more specific author-given keywords).[23] Subject classification headings offer concise search terms for quick and comprehensive scanning of all COMPENDEX publications.[24]

The aggregate content of each seed journal was determined by collecting all headings assigned to its publication output. The journal's 'content profile' was defined by the distribution of relative frequencies in which those headings occurred across its publications. The profiles of the seed journals were derived from the 1991–1992 publications covered by COMPENDEX.[25]

Those profiles are dominated by the following headings on the main (3-digit) classification level: Computer Software (code 723); Automatic Control Principles (731); Industrial Economics (911); Production Engineering & Management (912); Production Planning & Control (913); Applied Mathematics (921); Statistical Methods (922). Additional headings were, for instance, Mechanical Design (601) and Machine Tools (603). Next, a specially developed analytical routine was applied to identify periodicals within COMPENDEX with profiles resembling those of one or more of the seed journals.[26] This routine produced a set of 20 periodicals, including 12 non-ISI covered periodicals, which are mainly conference proceedings. The periodicals with the highest level of content similarity with *IJPE/ECPE* were, apart from *IJPE* (versus *ECPE*) and *ECPE* (versus *IJPE*): *Computer and Operations Research* and *European Journal of Operational Research*.

The profile data were also collected for the 20 ISI-covered journals that were selected on the basis of their citation ties and covered by COMPENDEX. Finally, we used both classification systems offered by Ulrich (i.e., Dewey codes and Library of Congress codes) to select additional periodicals with classification codes similar to a seed journal. This third point-of-entry produced another 2 periodicals, both non-ISI and covered by COMPENDEX. The list of selected periodicals is shown in Table 1.

It is shown that about 50 per cent of them appear in both the JCR and COMPENDEX. COMPENDEX covers an average of about 40 per cent of the publications in journals that are also indexed for the JCR database.

Table 1

Complete selection of periodicals, sorted alphabetically by database, including the share (in %) of publications in ISI journals covered by COMPENDEX*

Periodical	%	Periodical	%
ISI		COMPENDEX	
Artificial Intelligence**	na	Computers and Structures	54.0
Artificial Intelligence Magazine	na	Electronics Letters	40.2
Communications of the ACM	5.3	*Elektrosvyaz*	na
Computer Aided-Design	30.3	IEEE T. Information Theory	36.8
Computer Graphics	45.2	IEEE T. Power Delivery	65.8
Computer-Integrated Manufacturing Systems	na	IEEE T. Power Systems	51.5
Computers and Industrial Engineering	na	Int. J. of Production Economics***	81.9
Computers and Operations Research	51.2	*Izvestiya Vuz: Radioelektronika*	na
Computers in Industry	76.9	Microelectronics and Reliability	81.8
Decision Science	na	*Nippon Kikai Gakkai Ronbunshu-C Hen*	na
Engineering Cost and Production Economics***	na	*P. Ann. Conf. Eng. in Medicine & Biology*	na
European J. Operational Research	49.9	*P. Human Factors Society* na	
IEEE T. Computer Graphics	17.6	*P. IEEE Int. Conf. Acoustics*	na
IEEE T. Education	44.7	*P. IEEE Int. Conf. Robotics & Automat.*	na
IEEE T. Pattern Analysis & Machine Intelligence	75.4	*P. IEEE Int. Conf. Systems-Man & Cybernet.*	na
IEEE T. Robots and Automation	21.1	*P. IEEE Int. Symp. Circuits & Systems*	na
IEEE T. Systems-Man and Cybernetics	62.2	*P. Int. Geosci. & Remote Sensing Symp.*	na
IIE Transactions	na	*P. Int. Society Optical Engineering*	na
Int. J. Computer-Integrated Manufacturing	na	Production and Inventory Management J.**	na
Int. J. of Control	5.3	*SAE Technical Papers*	na
Int. J. of Production Research	45.5		
Int. J. of Systems Science	17.3	ULRICH	
J. Engineering for Industry	na	*Finite Elements in Analysis and Design*	na
J. Intelligent Manufacturing	na	*Management Systems*	na
J. Manufacturing Systems	na		
J. Operations Research Society	na		
Machine Learning	28.6		
Management Science	5.9		
Mathematical and Computer Modelling	2.2		
Naval Research Logistics	9.4		
Neural Networks	58.2		
Omega-Int. J. of Management Science	na		
Operations Research	12.2		
Robots and Computer-Integrated Manufacturing	30.4		

*   Boldfaced titles: fully covered by ISI and (partially) covered COMPENDEX. Italicised titles: not covered by ISI. Other titles: covered by ISI.
**   No ISI data on number of publications.
*** The International Journal of Production Economics superseded Engineering Cost and Production Economics in 1991.
na   not available in COMPENDEX and/or not covered by ISI (as a source journal).

Mapping journal citation interrelationships

The set of journals entered into this citation analysis includes only ISI-covered journals, that is those journals of which the cited and/or citing mode are covered by JCR. Tape versions of the JCR database were used to select all journals either cited by or citing to at least one of the seed journals during the period 1990–1991. The threshold for inclusion was set at 1% of the total number of citations received or issued by the respective seed journal. The selection comprises of n = 34 journals (see Table 1). In view of the prohibitively labour-intensive process of manually collecting citation data we did not consider including other periodicals.

The number of citations between each pair of journals was assembled in a (n∗n) data array where the rows and columns represent these selected journals in the same order. The main-diagonal of this array consists of the number of citations referring to the journal itself. Descriptive statistics resulting from the analysis pointed out that only 19.4% of the total amount of citations given and received by these 34 journals are linked to the other selected journals (self-citations included). So it seems that within-group citation data among these journals provides a rather limited account of all their citation interrelationships. This outcome indicates a relatively diffuse and heterogeneous field in terms of citation traffic.

Citation data is asymmetric by nature. The cited mode of journal refers to the whole knowledge archive embodied in all previous publications of the journal, whereas its citing mode refers to the set of references given by the publications in a journal within a specified time-window. The citing mode therefore reflects the content profile of a journal as its draws on its present knowledge base. Hence, a comparison with the journal content profiles requires an analysis of the citing distribution across the other 33 journals. The cosine-index was used as a measure to establish the pairwise similarity of those journal citing profiles.[27] This set of relational data was then converted to positional data by feeding the array of cosine values into a multidimensional scaling technique (using nonmetric MDS implemented in the program ALSCAL which supported by the software package SPSS). MDS produces a geometric representation of the underlying relational structure. Each journal is represented by a vector of co-ordinates in an $n-1$ dimensional space. Usually, these co-ordinates are projected on a two-dimensional Euclidean space. The distances between the points in this space each representing a journal, are inversely related to the degree of citation linkage between the respective journals.

The MDS analysis was done in three dimensions in order to achieve a parsimonious representation while retaining a sufficiently high degree of coverage of the relational information buried in the data array. In this case, 90% of the information was accounted for (RSQ = 0.90; Stress = 0.13). That is, only 10% is lost by converting citation frequency data to distance data. Figure 1 exhibits the first two dimensions of the spatial configuration. The relative location of journals in the third dimension is represented by the label attached to their title. This number refers to their cluster membership derived from cluster analysis (complete linkage clustering) applied to their co-ordinates in all three dimensions. One of most distinctive features of this configuration is the concentration of relatively strong citation relationships around the seed journal *IJPR*, a journal with a broad subject scope. On the right side of the graph one can observe a scattering of journals. The upper-right side shows a focus on journals linked to the specialist journal *ECPE* which focuses on operations research and management. The lower-right of the configuration is shaped by the other two seed journals dealing mainly with applications of artificial intelligence in industrial production and design. Note that journals with titles suggesting a similar scope are not always near each other on this map (e.g. *Operations Research* and *European Journal of Operational Research*).

Although a substantial number of cells in the 1990–1991 journal citation array contains low citation frequencies (59.6% equals zero; 84.3% is less than 5) the combined data should be able to produce a sufficiently robust representation of the main features of the configuration. These main features also tend to change only very slowly over time. This journal configuration should therefore also suffice to represent the state of affairs during the years 1991–1992 for which data were collected on the content of the journals.

Mapping journal content similarities

The content-profile similarity data for the 42 selected periodicals covered by COMPENDEX were collected in a symmetric array and were also analysed by means of nonmetric MDS. Again a three-dimensional space was chosen instead of two dimensions in view of its significantly higher fit. The three-dimensional co-ordinates cover 87% of the information (RSQ = 0.87; Stress = 0.16). Figure 2 displays the first two dimensions of the resulting journal configuration. This is also accompanied by journal groupings based on cluster analysis of the spatial information in all three dimensions.

| Engineering Cost and Production Economics 1 |

Management Science 1

Computers and Operations Research 1

Int. J. of Systems Science 1

Eur. J. Operational Research 1

Mathematical and Computer Modelling 1

Decision Science 2

Computers and Industrial Engineering 2

| Robots and Computer-Integrated Manufacturing 2 |

Int. J. Computer-Integrated Manufacturing 2

J. Engineering for Industry 1

Artificial Intelligence 2   Computer-Integrated
                               Manufacturing Systems 2

| Computers in Industry 2 |

Communications ACM 2

Computer Aided-Design 2

IEEE T. Robots and Automation 2   Computer Graphics 2

Artificial Intelligence Magazine 2

J. Operation Research Society 2

Omega-Int. J. Management Science 2

Operations Research 3

IIE Transactions 3

IEEE T. Pattern Analysis and Machine Intelligence 3
Int. J. of Control 3
        J. Manufacturing Systems 3
        Neural Networks 3

Machine Learning 3   IEEE T. Education 3   IEEE T. Computer Graphics 3
Naval Research Logistics 3
        J. Intelligent Manufacturing 3
IEEE T. Systems-Man and Cybernetics 3
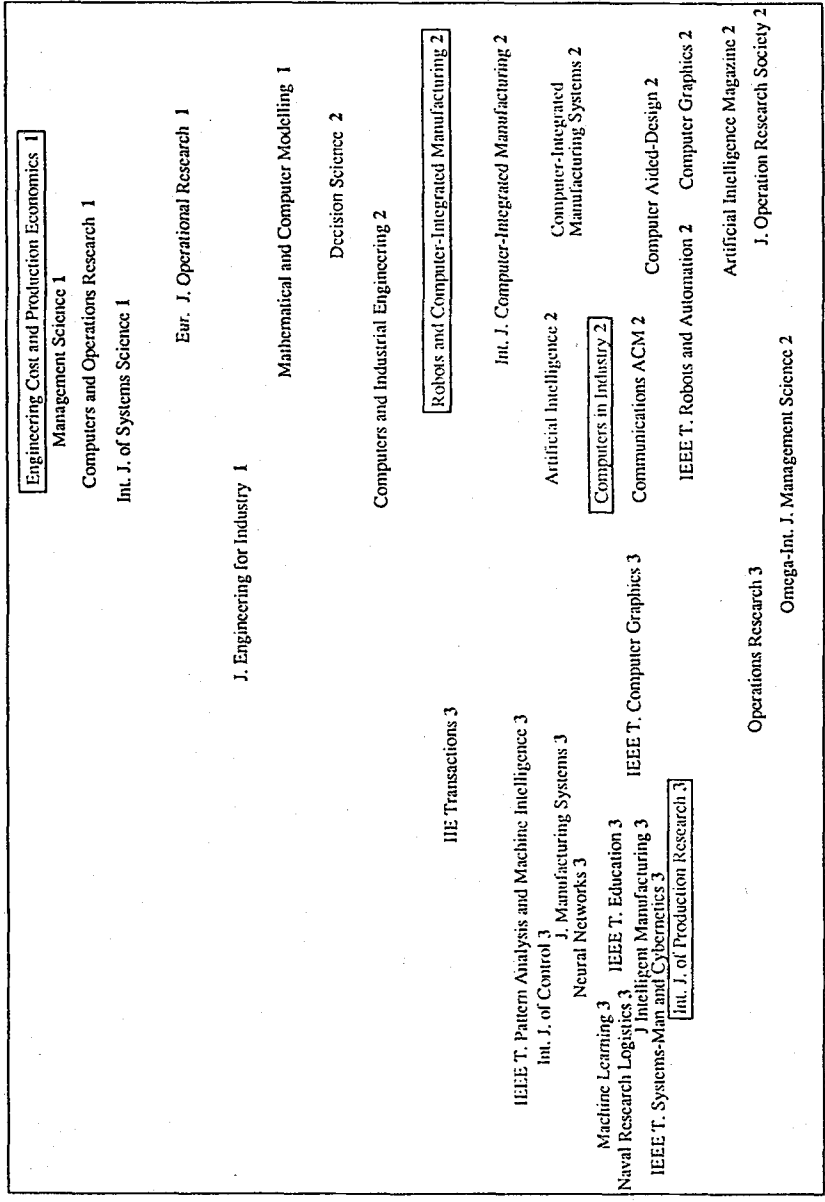 | Int. J. of Production Research 3 |

Fig. 1. ISI journal map of Manufacturing technology and management. Derived from journal citing profiles. Based on journal-journal citation frequency data extracted from the 1990 and 1991 Journal Citation Reports compiled by ISI. The seed journals are indicated by boxes. The number after each titel refers to clusters within the three-dimensional space

Int. J. of Control 2

Int. J. of Systems Science 2

Nippon Kikai Gakkai Ronbunshu-C Hen 2

Mathematical and Computer Modeling 2

IEEE T. Robots and Automation 1
P. IEEE Int. Symp. Circuits and Systems 1
Finite Elements in Analysis & Design 1
Microelectronics and Reliability 2
J. Engineering for Industry 1
P. Human Factors Soc. 1

IEEE T. Information Theory 1
Computers and Structures 1
SAE Technical Papers 3
Elektrosvyaz 1   P. IEEE Int. Conf. Robotics & Automation 3
Electronics Letters 1   IEEE T. Power Delivery 3
P. Int. Soc. Optical Engineering 3   IEEE T. Power Systems 3
P. IEEE Int. Conf. Acoustics 1   P. Int. Geosciences and Remote Sensing Symp. 3
P. IEEE Int. Conf. Systems-Man and Cybernetics 2   Management Systems 1
Int. J. of Production Research 4
IEEE T. Education 4   P. Annu. Conf. Engineering in Medicine & Biology 2
Naval Research Logistics 2

Int. J. Production Economics* 3

Izvestiya Vuz: Radioelektronika 1

IEEE T. Systems-Man and Cybernetics 1

Engineering Cost and Production Economics* 1

Operations Research 2
Management Science 3
Production and Inventory Management J. 3

Computers in Industry 1

Neural Networks 1   Communications ACM 4
IEEE T. Pattern Analysis and Machine Intelligence 1
Computer Graphics 1

Eur. J. Operational Research 1
Computers and Operations Research 1

Machine Learning 1
IEEE T. Computer Graphics 1

Robots and Computer-Integrated Manufacturing 4

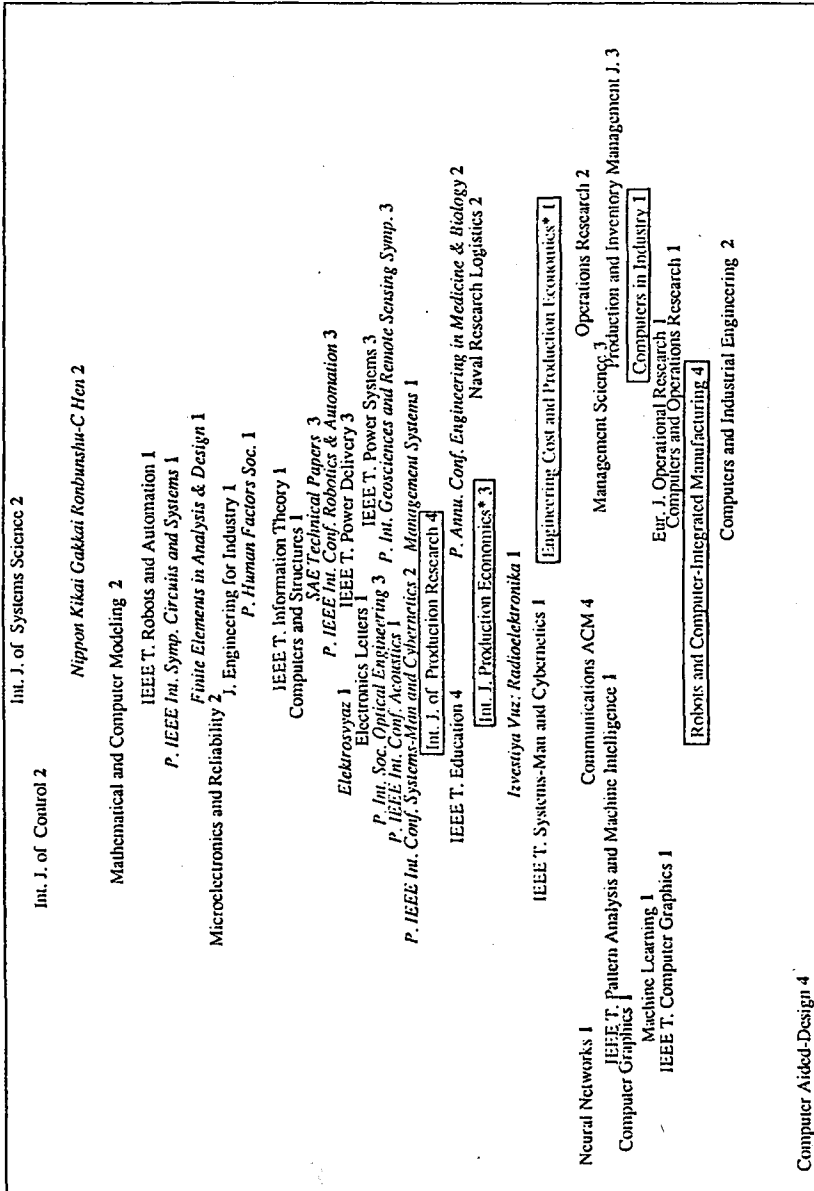Computers and Industrial Engineering 2

Computer Aided-Design 4

Fig. 2. Map of periodicals in Manufacturing technology and management. Based on their content profile derived from COMPENDEX (1991–1992). Labelling of titles: ISI-plain print; non-ISI – italics print. The seed journals are indicated by boxes. The number after each titel refers to clusters within the three-dimensional space. *The International Journal of Production Economics superseded Engineering Cost & Production Research in 1991

Clearly, quite a different journal structure emerges compared to the citation-based map. The non-ISI covered periodicals are concentrated in the central and upper part of the configuration.[28] The upper part is occupied by journals dealing with topics on automatic control in connection with applied mathematics and statistical methods. Journals such as *International Journal of Control* and *International Journal of Systems Science*, that were quite far apart in Figure 1, now appear to have relatively similar content profiles. The lower-left hand area of the configuration comprises of journals with a content emphasising on applications of computer software in relation to production planning and control. The journals on the lower right-hand side also cover these topics, but are more oriented toward industrial engineering and management.

Periodicals near the centre of the map (e.g. *IJPR*) tend to have profiles that cover a majority of the selected subject classification headings . This is also the section on the map consisting of periodicals such as *IJPE* that deal with issues on industrial economics. Judging by *IJPE*'s more central position this journal has acquired a slightly more broad subject scope as compared to its predecessor *ECPE*. Periodicals located above the centre share a focus on electronic engineering. As one proceeds toward the upper periphery, the emphasis on applied mathematics and statistics becomes stronger. One of the few similarities in comparison with the citation-based map concerns a group of journals in the lower-left hand side of the map dealing with computer graphics and related subjects. *Operations Research* and *European Journal of Operation Research* are now located near each other, although differences in content has resulted in a membership of different subclusters.

The COMPENDEX coverage rates of ISI journal journals range from 2.2% to 81.9% (see Table 1). The seed journals have a satisfactory coverage in COMPENDEX – particularly the *IJPE* and *CI*. The periodicals with low rates are found among the systems and control journals located at the upper part of the configuration (e.g. *International Journal of Control*) and those situated in the production management-oriented area at the lower-right hand side (e.g. *Operations Research*).

Joint mapping of journal relationships

The considerable different between the maps in Figs 1 and 2 confirms that data on journal citations and their content do not necessarily match in knowledge domains covering applied science and technology. Journal citation-based maps are probably

too limited in the sense that they emphasise relevance and utilitarian value of journals as perceived and expressed by those researchers (and technicians) that contribute to the public body of knowledge by publishing in the serial literature. In this case, content-based maps are likely to provide a more comprehensive and valid representation considering the fact that journal content similarity primarily indicates cognitive resemblance in terms of scientific and technological topics, irrespective of the type of periodical, its goals and its readers. Alternatively, one may hypothesise that the two maps share certain basic features that reflect a common underlying cognitive structure, where each map adds its own unique set of complementary features to that structure.

In the next step we tested this hypothesis by combining the configurations on both maps to see whether or not this might produce a valid common configuration. This joint map was obtained by applying a data-analytical technique known as *procrustus analysis* to both sets of spatial co-ordinates. Basically, this technique reconciles two or more spatial configurations through a process of rotation and re-scaling (i.e., stretching and shrinking) aimed at optimising the fit between them.[28] However, standard procrustus analysis techniques are ill-equipped to optimise the match of configurations composed of an unequal number of elements. In this particular case, the two configurations that share only 23 periodicals out of the total of 56. We therefore applied a generalised version of this technique that is able to deal with large numbers of missing data in a computationally sound manner.[30] The generalised procrustus analysis resulted in a fit measure equal to 90%, indicating that both three-dimensional configurations can indeed be matched and combined into a joint representation without substantial loss of information on the relative locations of the periodicals as compared to each of the separate maps.[31]

Figure 3 exhibits the first two dimensions of that joint configuration. A structure emerges that appears to be a compromise between the configurations depicted in Figs 1 and 2. Journal clusters based on the three-dimensional co-ordinates helps unravel parts of this configuration. One of the most noticeable features is cluster #1, the group of periodicals related to *ECPE* that was also clearly visible in Fig. 1. Most non-ISI periodicals are once more located in the centre of the map. *IJPE* is now quite distinct from *EPCE*. *Operations Research* and *European Journal of Operational Research* are again at a large distance from each other.
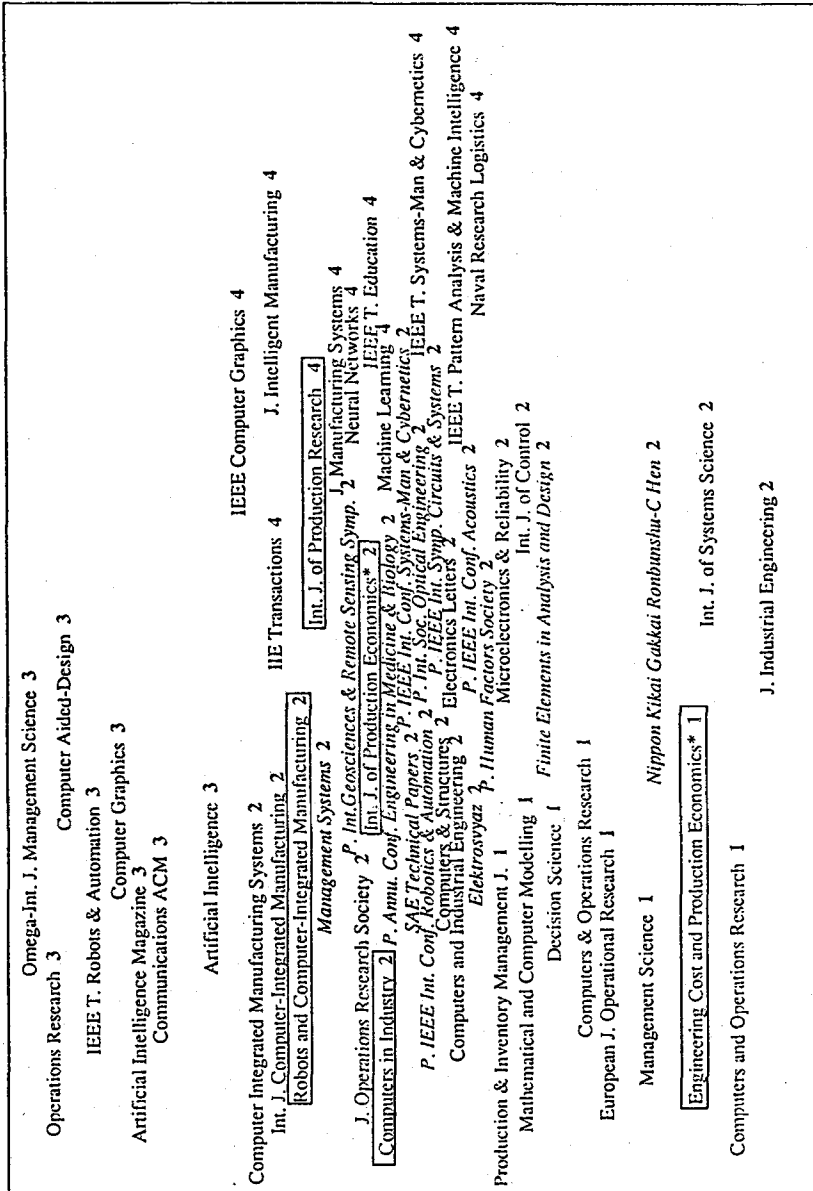
Fig. 3. Map of journal titles and other periodicals in Manufacturing technology and management. Based on citing profile similarities (1990–1991) and/or their content profiles derived from COMPENDEX (1991–1992). Labelling of titles: ISI – plain print; non-ISI – italics print. The seed journals are indicated by boxes. The number after each titel refers to clusters within the three-dimensional space. *The International Journal of Production Economics superseded Engineering Cost & Production Research in 1991

Omega-Int. J. Management Science 3

Operations Research 3   Computer Aided-Design 3

IEEE T. Robots & Automation 3
               Computer Graphics 3
Artificial Intelligence Magazine 3
        Communications ACM 3

        Artificial Intelligence 3

                                        IEEE Computer Graphics 4

Computer Integrated Manufacturing Systems 2   J. Intelligent Manufacturing 4
Int. J. Computer-Integrated Manufacturing 2
        Robots and Computer-Integrated Manufacturing 2
        Management Systems 2   IIE Transactions 4   Manufacturing Systems 4
    J. Operations Research Society 2 P. Int.Geosciences & Remote Sensing Symp. 2   Neural Networks 4
                                      Int. J. of Production Research 4 IEEE T. Education 4
    Computers in Industry 2 Int. J. of Production Economics* 2   Machine Learning 4
                SAE Technical Papers 2 P. IEEE Int. Conf. Engineering in Medicine & Biology 2 IEEE T. Systems-Man & Cybernetics 4
        P. IEEE Int. Conf. Robotics & Automation 2 P. IEEE Int. Conf. Systems-Man & Cybernetics 2
                Computers and Industrial Engineering 2 P. Int. Soc. Optical Engineering 2 IEEE T. Pattern Analysis & Machine Intelligence 4
                                      Electronics Letters 2
                Elektrosvyaz 2 Human Factors Society 2 P. IEEE Int. Conf. Acoustics 2   Naval Research Logistics 4
Production & Inventory Management J. 1   Microelectronics & Reliability 2
        Mathematical and Computer Modelling 1   Int. J. of Control 2
                Decision Science 1   Finite Elements in Analysis and Design 2

        Computers & Operations Research 1
European J. Operational Research 1

        Management Science 1   Nippon Kikai Gakkai Ronbunshu-C Hen 2

                                        Int. J. of Systems Science 2
        Engineering Cost and Production Economics* 1

Computers and Operations Research 1   J. Industrial Engineering 2

Clearly this joint image has something in common with both previous maps. The key question remains whether or not this combined map actually represents the basics of a cognitive structure. If not, which of the other two maps might then be considered a valid representation of the cognitive structure: the content-based map, the citation-based one, or perhaps neither? Moreover, are the non-ISI periodicals important additional elements in these configurations? A subsequent validation study was conducted to address these questions.

Validation study

The validity of the three bibliometric maps was investigated by including data from an independent third source of information, namely a group of subject experts. The principal aims of this triangulation study were (i) to determine to what extent the procedure had actually succeeded in identifying periodicals that are relevant to the domain – more in particular whether or not COMPENDEX or Ulrich have provided useful additional periodicals, and (ii) to assess the accuracy of the maps by comparing them to journal similarity data supplied by those experts.

The size and broad scope of the domain ruled out a comprehensive validation study covering all periodicals on the map. Instead we limited our attention to the seed journal *IJPE* that judging by the maps in Figs 2 and 3, covers the core of the domain. All 35 members of the international editorial board of this journal were sent a questionnaire which listed the periodicals depicted on the joint map. They were asked to mark their familiarity with these periodicals on a three-point scale(1-not/slightly familiar, 2-moderately familiar, 3-very familiar). They were also requested to judge the relevance of each periodical within the subject area covered by *IJPE* (1-not/slightly relevant, 2-moderately relevant, 3-very relevant). A distinction was made between relevance for industrial practice and relevance for research (academic or otherwise). Relevant but missing periodicals were to be added to the list and should be judged on both accounts.

Completed questionnaires were returned by 18 respondents. This sample was found to be representative for the different groups of experts on the editorial board.[32] The main results of the questionnaire are presented in Table 2. It concerns the subset of periodicals of which at least three members of the editorial board felt they were sufficiently familiar. The aggregated scores on familiarity and relevance were re-scaled to values varying between 0 and 100.[33] The periodicals are sorted and divided into three groups according to the degree of their familiarity. The first group comprises of the most familiar periodicals, most of which dealing mainly with

operations research and management. These journals are also considered to be the most relevant within the scope of *IJPE* in terms of relevance for academic research and for industrial development and practice. The fact that the *IJPE* itself is not the most well known among the experts is probably due to the relatively recent re-direction of this journal (introduced in 1991 under this new title). The second group is more divers, consisting mainly of journals covering computer applications in association with manufacturing systems. Large differences occur with respect to the relevance of those journals. The third and least familiar group of periodicals shows a stronger emphasis on engineering (e.g. the IEEE Transactions volumes) and other, more peripheral, issues such as computer graphics and computer aided design. Only two of these periodicals (*IIE Transactions* and *Computers and Industrial Engineering*) were considered really relevant for the subject area covered by *IJPE*. This group includes four non-ISI periodicals amongst which the Japanese journal *Nippon Kikai Gakkai Ronbunshu-C Hen* and the *Proceedings of the International Conference on Systems-Man and Cybernetics*.

The findings in Table 2 show a high incidence of ISI-covered journals. This outcome is no doubt partly a result of the academic nature of *IJPE* and the research backgrounds and interests of its editorial board. However, these findings do not support the conclusion that these experts are entirely focused on the ISI journal literature. Apart from acknowledging their familiarity with non-ISI periodicals not listed in Table 2, seven editors also used the opportunity to supply an additional set of 22 periodicals they considered important enough within the scope of *IJPE*. Only 3 of them were covered by ISI. However, none of these 22 were seen as highly relevant and only two of them (both ISI-covered) were mentioned three times.[34] So, on the whole one may conclude that the selection procedure succeeded in identifying the vast majority of important periodicals belonging to the subject area covered by *IJPE*. All of these journals are covered by ISI.

Although some of the journals were seen as more relevant, either for industrial practice (*Computers in Industry, Journal of Manufacturing Systems*) or for research purposes (*IIE Transactions*), the large majority of these journals are judged equally important for both types of application. This finding is probably typical for important scientific journals in areas covering to the interface of science and technology. One may further assume that periodicals with a high score on industrial relevance reach a divers readership consisting of researchers, engineers and technicians. Part of those readers are probably not very actively involved in academic scientific research and thus less likely to contribute to the scientific research literature and cite the work of others. The low impact factors of these journals seem to confirm this assumption.[32]

Table 2

Characteristics of selected periodicals in the subject area covered by the International Journal of Production Economics. Sorted by level of familiarity among experts. Non-ISI periodicals are printed in italics

Periodical	Familiarity*	Relevance for:**	
		Industry	Research
Group 1 (familiarity score ≥ 66.6):			
Int. J. of Production Research	88.9	75.9	76.9
Int. J. of Production Economics	86.1	80.6	82.4
European J. Operational Research	75.0	46.3	42.6
Management Science	75.0	46.3	46.3
Omega-Int. J. of Management Science	75.0	59.3	57.4
Naval Research Logistics	69.4	41.7	41.7
J. Operations Research Society	66.7	44.4	44.4
Group 2 (33.3 ≤ familiarity < 66.6):			
Operations Research	61.1	34.3	34.3
Int. J. Computer-Integrated Manufacturing	58.3	21.3	20.4
Computer Aided-Design	55.6	6.5	6.5
Computers in Industry	55.6	27.8	24.1
Decision Science	52.8	13.9	13.9
Production and Inventory Management J.	52.8	46.3	46.3
Computer-Integrated Manufacturing Systems	47.2	30.6	29.6
J. Manufacturing Systems	44.4	35.2	29.6
Computers and Structures	38.9	3.7	3.7
Group 3 (11.1 ≤ familiarity < 33.3):			
IEEE T. Computer Graphics	30.6	5.6	5.6
Int. J. of Systems Science	30.6	16.7	16.7
J. Intelligent Manufacturing	27.8	17.6	15.7
IIE Transactions	19.4	39.8	43.5
Int. J. of Control	19.4	8.3	8.3
Microelectronics and Reliability	19.4	7.4	9.3
Nippon Kikai Gakkai Ronbunshu-C Hen	19.4	9.3	9.3
Computers and Industrial Engineering	13.9	35.2	33.3
Mathematical and Computer Modelling	13.9	8.3	8.3
P. IEEE Int. Conf. Systems-Man and Cybernetics	13.9	8.3	8.3
Computer Graphics	11.1	11.1	11.1
IEEE T. Education	11.1	2.8	2.8
Machine Learning	11.1	3.7	7.4
Management Systems	11.1	8.3	8.3
P. IEEE Int. Conf. Robotics & Automation	11.1	5.6	5.6
Robots and Computer-Integrated Manufacturing	11.1	6.5	6.5

* Standardized scores ranging from 0 (none of experts are moderately or very familiar with the periodical) to 100 (all experts are very familiar with the periodical).
** Standardized scores based on opinions of those experts who were either moderately or very familiar with the periodical. Ranging from 0 (judged by all experts as irrelevant for the subject area) to 100 (very relevant).

High scores on familiarity and relevance indicate a substantial cognitive link between those periodicals and *IJPE*. The periodicals that were assigned relevance scores larger than 33.3 were defined as the 'core' within this journal's subject area. This core comprises of the seven periodicals in the first group listed in Table 2 and two out of each of the other groups. Note that all but one (*Production and Inventory Management Journal*) were already selected through their citation links with the seed journals.

If the maps are a valid representation of a macro-level cognitive structure, it is likely that these 11 periodicals are located in the vicinity of *IJPE*. The content-based map (Fig. 2) clearly lives up to this expectation. The subset of 9 core periodicals that are covered by COMPENDEX indeed appear in the lower-right hand quadrant, along with *IJPE*'s predecessor *ECPE*. Moreover, journals that were attributed low relevance scores (e.g. *International Journal of Control, Computers and Structures*, and *Computer-Aided Design*) are indeed located at larger distances from *IJPE*. In contrast, the core periodicals are spread out across the combined configuration represented in Fig. 3. Adding citation data to journal content data seems to negatively affect the validity the configuration. This implies that journal citation data are probably inadequate for describing the cognitive structure within this particular domain. This observation is corroborated by comparing the expert data with the citation-based map (Fig. 1). Assuming that *ECPE* is sufficiently similar to its successor, only 3 of those 11 core periodicals are located in its immediate neighbourhood: *Management Science, European Journal of Operation Research*, and *Computers and Industrial Engineering*. One can only conclude that citation interrelationships do not correspond with how these experts judge the relevance of journals and perceive their content similarities.

General conclusions

The case study described in this article illustrates the cognitive limits of ISI-based journal mapping. The first limitation concerns the ISI's journal coverage. Adding journal content as an additional information source extended the original set of 33 ISI-covered journals (selected according to citation interrelationship) to a total of 56 related journals. 15 of those additional periodicals were not covered by ISI (conference proceedings mainly). The inclusion of a Japanese and Russian journal indicates that on the whole such an extension can (partially) counteract ISI's bias in favour of English-language serial literature. Results of a small-scale validation study

focusing on the *International Journal of Production Economics* indicated that ISI's coverage of relevant journals in this subdomain was quite satisfactory. In contrast, the same validation study pointed out that journal selection routine failed to identify a small number of (mostly non-ISI) periodicals that were mentioned by the subject experts. Since these periodicals were judged as only slightly relevant one may assume than this discrepancy can be ascribed to the inevitable limitations of defining and capturing a domain's periphery.

Secondly, the results of this study indicate that JCR-based citation maps are likely to produce invalid macro-level representations of areas that lack an established scientific publication and citation culture. Generalisation of journal mapping beyond the limits set by ISI citation data is probably a necessity to describe the cognitive structure of an applied scientific and technological area. In this particular instance, a joint map based on citations and content (combining ISI-covered and non-ISI periodicals) did yield a slightly better representation, but was still inadequate according to a comparison with expert data. The map based exclusively on journal content data proved to be a fairly accurate representation.

We surmise that this outcome is typical for most areas covering the interface of science and technology. Content-based maps including both ISI-covered and non-ISI periodicals are therefore strongly recommended in those areas where (one should assume that) journal citation data are no longer valid indicators of cognitive links between journals. Moreover, using data on the journal content may prove helpful, not only for macro-level mapping of scientific areas within the natural and life sciences with a diffuse journal citation networks, but also for areas that lack common research paradigms such as disciplines within the social and behavioural sciences.

Obviously, these findings and conclusions are of limited value considering that they are based on journal maps of only one area and a validation study focusing on just one of its key journals. It remains an open question to what extent this outcome can be generalised to the other journals, and for that matter to other areas with (more or less) similar bibliometric characteristics. Nevertheless, this application of generalised journal mapping has clearly demonstrated that this type of macro-level bibliometric mapping constitutes a fruitful extension beyond the realm of ISI. Including sources other than ISI's journal-journal citation data and adding periodicals not covered by ISI (e.g. conference proceedings) produced not only a better journal coverage of the domain, but also more valid graphical representations of the domain's cognitive structure. Judging by these results we are inclined to believe that generalising journal mapping beyond ISI's databases will in most

instances, provide new and interesting information on macro-level features of knowledge domains, particularly on the applied side of science and the science-technology interface.

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21. A comparison between ISI and Ulrich shows that only 9% of the periodicals listed in Ulrich with descriptors refering to engineering are also covered by ISI. The ISI share rises to 72% for those periodicals in Ulrich that are classified as being refereed.

22. These journals were selected in collaboration with subject experts at Elsevier Science Publishers.

23. We refrained from using controlled keywords for establishing profiles in view of the differences in content of those journals and the large number of keywords involved (an attempt to proceed along this line left us with several hudreds of keywords).

24. A previous bibliometric example of the application of classification headings for such a purpose is presented in: R. J. W. TIJSSEN, A quantitative assessment of interdisciplinary structures in science and technology: co-classification analysis of energy research, *Research Policy*, 21 (1992) 27–44.

25. The content data on the *International Journal of Production Economics*, is limited to 1992, while the profile of its former title *Engineering Cost and Production Economics* is based on 1991 data.

26. The routine involves two stages. It started with a selection of periodicals on main features only, that is, using the most frequently occurring headings in the seed journals, irrespective of their order of appearance. (Bibliographic records in this database are often assigned more than one heading, where the first heading on the list represents the primary descriptor of the content, the second heading refers to additional features of secondary importance, et cetera.) In this first stage, the threshold for inclusion was set at 0.75% of the total number of headings assigned to the periodical for either selected code. This first sweep of COMPENDEX produced 65 periodicals with a basic content that was sufficiently similar to one or more of the seed journals. In the second stage, the content of those selected periodicals were compared on a more detailed level based on an extended profile consisted of the 23 most frequently occurring headings. This set consisted mainly of the same set of six headings but now taking into account their order of appearance (i.e. either as the first, second or third descriptor). A weighted content profile was defined as the relative occurrence (in %) of each of those headings relative to the total number of headings assigned to a periodical. A profile similarity measure D was defined by calculating the sum of the absolute differences between the respective percentages across each of the 23 headings. The threshold for inclusion in the final selection was set at $D = 0.5$ (i.e. a total difference of 50%) for at least one of the seed journals.

27. The cosine-index is a pattern similarity measure defined as:
$C_{x,y} = \Sigma x_i y_i / \sqrt{((\Sigma_i x_i^2)(\Sigma_i y_i^2))}$, where x and y denote different journals and x_i the number of citations given by x to the i-th other journal (i = 1,...,n). The journal self-citations are excluded.

28. We checked the effect of including those non-ISI periodicals by constructing a content-based map derived from the ISI-covered journals only. Adding non-ISI periodicals did not appreciably affect the main features of the journal configuration. It merely strengthened its internal structure by inserting the non-ISI periodicals at their appropriate location.

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30 See, J. J. F. COMMANDEUR, *Matching Configurations*, Leiden: DSWO Press, 1991.
Alternative methods for combined analysis and representation, such as the MDS technique INDSCAL (see e.g., Ref. 20), proved to be less adequate when dealing with large numbers of missing data. Trials with INDSCAL produced sub-optimal solutions. Moreover, the INDSCAL model presupposes a fixed common space which introduces an inappropriate *a priori* restriction on the joint solution in case of large and diffuse knowledge domains where systematic differences may occur between the data sources.

31. The location of journals with missing data is determined by the new location of the journals without missing data. That is, the technique preserves the relative locations (after rotation and re-scaling) with respect to journals that are present in both maps.

32. The editorial board of *IJPE* consists of experts on production economics, on maintenance management, on material flow, and experts from the Asia-Pacific region on non-specified subjects.
33. The relevance score for each periodical was calculated from the scores of those experts who declared they were either moderately familiar or very familiar with the periodical. Each expert's opinion on the relevance was weighed according to their familiarity with the respective periodical, where 'moderately familiar' is assigned a weight equal to 1 and 'very familiar' is weighted double.
34. The non-ISI selection consisted of a large variety of periodicals, including two from Japan, each mentioned only once. The ISI-covered journals, *Interfaces* and *Journal of Industrial Economics* were mentioned three times.
35. The 1992 Impact Factors of the 11 selected 'core' journals range from 1.01 for *Management Science* and 0.78 for *Operations Research* to only 0.06 for *International Journal of Production Economics*. All journals, except the first two, have IF-scores less than 0.35.