15 years. Access to this information is provided by Western information services such as Chemical Abstracts Service as well as by various groups in Japan.

REFERENCES AND NOTES

(1) Presented at the Conference on Japanese Scientific and Technical Information, MIT-Japan Science and Technology Program/Japan Society of Boston, Boston, MA, April 6, 1984.
(2) U.S. Congress House Committee on Science and Technology "The Availability of Japanese Scientific and Technical Information in the United States". Hearings before the Subcommittee on Science, Research and Technology; House of Representatives, 98th Congress, 2nd Session: Washington, DC, 1984.
(3) Baker, D. B. *Chem. Eng. News* **1981**, *59* (22), 29.
(4) Dickman, J. T.; Platau, G. O. *J. Chem. Inf. Comput. Sci.* **1983**, *23*, 70.
(5) Pollick, P. J. *Sci. Technol. Libr.* **1981**, *2* (2), 3.

Productivity and Its Measurement at Chemical Abstracts Service†

GERARD O. PLATAU* and WLADYSLAW V. METANOMSKI
Chemical Abstracts Service, Columbus, Ohio 43210

Received September 28, 1984

The unprecedented growth of scientific literature and the availability of computers have led Chemical Abstracts Service (CAS) to new modes of information processing and delivery based on the best utilization and interaction of intellectual effort and computer support. In order to survive economically and better serve the growing number of information users, CAS introduced far-reaching innovations, all directed toward increased productivity of professional analysis, clerical tasks, and machine support. Examples of such innovations are unified intellectual document analysis, online editing, more efficient keyboarding techniques, and machine edits such as spelling-error detection and author-name verification programs. A unique approach to the measurement of productivity in the "knowledge industry", based on the classification of staff into measurable and nonmeasurable categories, is detailed. Productivity, defined as the ratio of outputs to inputs, is measured at CAS by revenue per employee, sales per employee, value added per employee, and value added per salary dollar and equipment dollar. The goal of the organization remains that of producing publications and services on the basis of the triad of completeness, timeliness, and quality.

INTRODUCTION

In the decade from 1972 to 1982, U.S. productivity virtually stagnated, growing at a rate of less than 2%, while that of Japan more than doubled and that of France and Germany grew more than 50%. Indeed, as Benjamin Franklin said some two centuries ago, "success breeds complacency". Thus, we saw many American producers' markets stripped away by more aggressive, efficient foreign trade rivals. One industry analyst, having surveyed 120 personnel directors and corporate managers, reported that the average American employee squandered about one-third of the day by not working. The difference between hours paid and hours worked was aptly labeled as the "productivity gap" and "an insidious threat to the economy".[1]

Fortunately, as *Business Week* pointed out in early 1984,[2] there is a revival of productivity under way in the U.S. fueled by technological advances, a more experienced work force, and proactive rather than reactive management. In other words, the U.S. seems to have turned away from Mancur Olson's model of a stable, nonproductive society controlled by interest groups that are overwhelmingly oriented to struggling over the distribution of income and wealth rather than producing additional output.[3]

IMPROVING PRODUCTIVITY AT CAS

At Chemical Abstracts Service (CAS), the unprecedented growth of scientific information mandated significant productivity improvements, if we were to survive economically. The result has been optimum utilization and interaction of intellectual effort and computer support.

Concerns about CAS's survival and economic viability are not new but have existed since the first issues of *Chemical Abstracts* (CA) were published in 1907.[4-6] An American Chemical Society (ACS) Punched Cards Committee, having as members James W. Perry then of MIT, Howard S. Nutting of Dow Chemical, and E. J. Crane of CAS, was first formed in 1946 for purposes of studying the application of keypunching techniques at CAS.[7] That research effort culminated in the creation of a separate Research and Development department at CAS in 1955 to take full advantage of technological advances in electronics and communication. To increase productivity and reduce costs has always been the goal of CAS management.

Eleven years ago, at the Fall 1973 ACS National Meeting in Chicago, CAS presented a symposium on "*Chemical Abstracts* in Transition", where Dale B. Baker, CAS Director, discussed in considerable detail modern methods of producing CAS publications and services and their effects on economics and pricing.[8] That CAS is a "production-line operation" was clearly recognized by Patrick P. McCurdy, then the editor of *Chemical & Engineering News*, who in a 1973 editorial observed that such an operation involved schedules, deadlines, controls, discipline, and nitty-gritty to get the finished product out on time at the required quality.[9]

Today, this observation is reflected more formally by the stated CAS mission:

> "to be the acknowledged leader providing a family of diversified information services and systems related to worldwide activities in chemistry and chemical engineering to meet the needs of the international scientific and technical community and the general public."

NEW TECHNOLOGY AND NEW METHODOLOGY

The early 1960s saw improvements in the preparation of the volume and collective indexes. Index entries were typed onto specially designed cards and these were filmed one line at a time with a special camera to produce a strip of film corresponding to a column of the index, thus eliminating the hot typesetting. In the late 1960s, the first computer-generated

† Presented before the Division of Chemical Information, 188th National Meeting of the American Chemical Society, Philadelphia, PA, Aug 29, 1984.

0095-2338/85/1625-0008$01.50/0

volume indexes were produced, which in turn eliminated the repeated handling of millions of 3″ × 5″ index cards and proofing of thousands of pages of galleys. Finally, by mid-1975 all CA abstract issues and indexes became completely computer produced.

The two most significant changes introduced in the 1970s concerning the document-analysis phase of our work were (1) the combining of abstracting and indexing operations into a single intellectual analysis step[10] and (2) online editing.[11] These changes, plus the urgent need for optimum currency, mandated the phasing out of the contributions of the volunteer abstractors to the point where today volunteers contribute only 4% of the abstracts, usually from difficult-to-read foreign documents. Nevertheless, CAS was able to show dramatic improvements in productivity in the face of sustained literature growth. Thus, between 1973 and 1983, the number of documents abstracted in CA increased by 41%; the number of volume subject index entries increased by 67%; and the density of indexing, that is, the number of index entries per document, increased by 19%. On the other hand, the professional staff who produce the abstracts and index entries increased by only 11.5%. This translates to an annual editorial staff growth of less than 2%. Furthermore, the number of the supporting clerical staff declined slightly during the same period.

With the introduction of online editing, we noted a 47% increase in productivity of the editing process, compared to the earlier manual process. Almost 5.5 million pieces of paper per year, the abstract and index proofsheets, were totally eliminated.[11]

Accuracy, consistency, and timeliness of CA have been improved by a variety of computer verification and editing routines. General Subject Index headings and other controlled-vocabulary terms are matched against the authority files, and some are automatically changed to a preferred term or a preferred grammatical form.[12] The personal author names are compared with names already on file and, then, are edited and expanded as necessary and when possible.[13] All text in CA is checked by a spelling error detection program, which in some cases automatically inserts the correct spelling.[14] An automatic abbreviation program is applied to the abstract text and the index entries.

The integrity and efficiency of the CAS Chemical Registry System also rely heavily on all kinds of machine support. Whenever a chemical substance name is matched against the authority file, necessary editing takes place. When chemical-substance names are generated, they are subjected to various editing and validation programs.[15] There are structure keyboarding shortcuts, which simplify the input of complex repetitive structure-building blocks.[16] The structures displayed in CAS ONLINE are algorithmically generated from the Registry connection tables.[17] Currently, we are proceeding with the registration of substances indexed in CA prior to 1965, that is, prior to the existence of any computer-readable records. We have found that the most economical way to do this is to convert the printed collective formula index data into computer-readable form with an optical character recognition device, followed by machine translation of substance names into structure records.

These few examples give ample evidence that the efficiency of operations at CAS and the productivity of our professional, technical, and clerical staff have always been of utmost concern to the CAS management.

MEASURING PRODUCTIVITY AT CAS

How to measure productivity in the CAS environment, which is a mix of intellectual effort, clerical tasks, and computer support, has been a rather elusive goal. To come to grips with this problem, CAS Director Dale Baker appointed a Task Force in 1982 with the charge to explore and develop meaningful methods to measure CAS productivity and to recommend further productivity improvements. Productivity is typically defined as the ratio of output to one or more corresponding inputs. The outputs at CAS are publications and services, the inputs, as in any other organization, are labor, capital, materials, and energy.

Productivity indicators or measurements are most commonly based on labor productivity. Labor productivity, or rather its changes, can be described in such vague qualitative terms as "doing more", "doing it right", or "getting the most and best out of what you put in". More ideally, it is expressed in terms of numbers or hard data.

The most popular measurements are those of partial productivity, as related to labor or capital, where physical units or dollars of output are measured against employee hours or capital input, respectively. The numbers reported, however, may be quite misleading. The labor productivity might show an improvement, but not necessarily because people work harder but possibly because they were given better, yet quite costly, equipment to support them. High cost of equipment may, on the other hand, adversely affect partial productivity reported in terms of capital productivity.

Total productivity measures may be expressed as ratios of gross output, be it tons of steel produced, number of abstracts published, or bits of information released on tape, to all the inputs including labor, capital, materials, and energy. It is important to note that under all circumstances a productivity level, which is a ratio at a given point in time, is meaningless unless compared to another ratio. The comparison may be from one time period to another, to a competitor's performance, or to some industry average.

Before we could tackle the productivity measurements at CAS, we had to decide how to classify our staff. The broad terms applied in similar organizations had their limitations. The category of "white-collar worker" seemed to encompass everybody at CAS including chemists and engineers, keyboard operators and data-processing staff, and salespeople and accountants, as well as managers and administrators, in other words, jobs of vastly different sets of authorities and roles.

On the other hand, the category of "knowledge worker" seemed to imply a distinct ability to plan, solve problems, innovate, and make decisions. This largely intellectual effort is nonrepetitive and cannot be quantified. It takes place often in response to unanticipated changes, and its results cannot be measured in a short period of time.

At CAS we have a large number of very knowledgeable and highly educated people, for instance, document analysts, who select papers and patents for coverage, prepare abstracts and index entries, and name chemical compounds; however, they are not typical knowledge workers. While the degree of difficulty of work performed varies greatly, their outputs can indeed be measured.

Therefore, we classified the CAS staff into two categories: (1) measurable and (2) nonmeasurable. We noted that 63% of CAS staff belong to the first category, which, in addition to document analysts, includes keyboarders and data-processing operators. The nonmeasurable group, on the other hand, consists generally speaking of managers, administrators, R&D staff, support staff, and secretaries.

We think that this is a new approach in the so-called "knowledge industry". With some exceptions, improving productivity among knowledge-industry workers has not been a focus of knowledge-industry management, because of a widespread perception that knowledge-industry workers, whose work is largely intellectual, do not produce measurable results.

Productivity Indicators. Our Task Force examined many potential productivity indicators and recommended that four

Table I. Annual Percentage Changes in Productivity Indicators

	1981	1982	1983	1984 probable
(1) revenue/FTE	16.1	9.2	10.9	18.1
(2) sales/FTE	6.2	5.5	4.9	11.4
(3) value added/FTE	7.0	6.0	5.3	11.5
(4) value added/salary \$ + EDP equipment \$	1.4	−4.3	−0.7	5.2
(a) value added/salary \$	4.8	−1.3	3.3	8.2
(b) value added/EDP equipment \$	−33.6	−27.8	−24.9	−4.9

general indicators be applied to the CAS environment. The first indicator (see Table I) is *revenue in actual dollars per employee*, where revenue includes income from sales and investments as well as cost recovery from the work performed for ACS, such as photocomposition of ACS primary journals and management of ACS subscription and membership services. FTE refers to full-time equivalent employees on the CAS payroll.

The second indicator is expressed in terms of *sales per employee*, and "sales" is defined as revenue minus the short-term investment income. The third is the *value added per employee*. Value added is defined as the total contribution of every employee in the transformation of raw materials through the utilization of human talent into useful publications and services. It is calculated as the difference between sales and cost of "outside input", such as expenses for the acquisition of journals and patents, consultants' fees, and the volunteer-abstractors' honorarium, as well as Japanese and United Kingdom input. Outside inputs are excluded because CAS cannot take credit for the talents of people who do not work directly for CAS.

The last indicator reflects *value added per employee salaries and benefits plus the capital expenses for electronic data-processing (EDP) equipment*. For all indicators, except the first, sales and expense amounts have been deflated to a constant-dollar 1976–1977 base according to the Consumer Price Index from the U.S. Department of Commerce.

As Table I so clearly shows, we are pleased to report that for the years studied our productivity has increased significantly each year. Furthermore, these annual increases become even more impressive if they are compounded each year. CAS is experiencing a continuous growth in terms of the variety, number, and size of publications and services. Yet, over the past 3 years our total staff growth averaged only 1.3% per year. Thus, the figures calculated per full-time equivalent point to the fact that basically the same staff is learning to do their tasks more efficiently. Obviously, the increasing computer support plays an important role in increasing that efficiency.

With reference to the fourth productivity indicator, it is useful to look at the components, salary dollars and EDP equipment dollars, separately. Productivity based on staff salary dollars has shown an upward trend over the last 4 years, although there was a small decrease in 1982. On the other hand, productivity based on equipment dollars alone has been negative. This can be ascribed to the fact that CAS is in the process of acquiring additional hardware in order to be able to provide many new and enhanced services to the users of CAS ONLINE and STN International. This additional investment in equipment will help ensure increased future revenues, ultimately resulting in greatly improved productivity in the 1987–1990 period.

The indicators presented here are the major measures of the total organizational performance. Obviously, it is the sum of many individual, sectional, departmental, and divisional contributions. For each level, individual or group, specific measurements have also been developed that are attuned to the type of work the individual or group does, be it the number of journals reviewed, the number of abstracts prepared, the number of chemical structures keyboarded, etc. Furthermore, the quality of the work is an important component of any measurement and evaluation.

ESTABLISHING THE RIGHT ENVIRONMENT

The Task Force also recommended a number of steps to ensure that CAS continues to improve the productivity of all its resources, of which the CAS staff are the most valuable. We consider this concept so important that its preservation and development has been recognized as one of the key CAS enduring objectives:

> "CAS strives to ensure the most effective recruitment, selection, compensation, motivation, and development of staff; and to nurture a working environment and support facility that provide job satisfaction, enhance effectiveness, and encourage high productivity. Specifically, CAS management emphasizes: (1) achieving and maintaining an environment that helps individuals realize their highest potentials in the context of CAS functions and (2) effectively employing human resources to achieve the objectives and enhance the productivity of the organization."

Some of the components of such an environment that are conducive to improvements in productivity are high-performance culture, job security, and small-scale improvements. By high-performance culture we mean understanding that performance improvement should be a routine part of everyday management and not a special event. To encourage and maintain such a cultural environment, CAS has instituted flexible working hours and installed workstations tailored to accommodate individual task requirements including the use of video display terminals. Improved productivity will enhance job security for staff and provide an ultimate sharing of gains in an equitable manner.

It is important to recognize that productivity improvements come not only from broad changes made by management, i.e., macrosystems, but also from continuous, small-scale improvements made by staff who know their job better than anyone else, i.e., microproductivity programs. In several departments, Quality Circles have been formed. These informal discussions have resulted in many suggestions for improving the quality and productivity. Seemingly small changes in keyboarding and proofing led to very salutary results.

We are aware of the experiences of other companies that introduced so-called "productivity improvement programs". These looked good on paper but did not necessarily work well in practice, primarily because they were prepared by the staff "thinkers" and ignored by the line "doers". The principal reasons for the failure of such programs are lack of commitment, lack of acceptance, lack of retraining, lack of rewards, and lack of feedback and correction. We have been determined to do otherwise and have taken into consideration three major factors: standards, which are quantifiable and communicated to employees; feedback, which is directed to all staff including supervisors; rewards, which are based on measurable factors. Rewards, of course, can take a variety of forms, financial remuneration, promotion, and other forms of recognition. Toward that end, CAS has in recent years established a formal award program that recognizes outstanding contributions and innovative ideas by staff.

CONCLUSIONS

We at CAS are very much aware of the fact that the user community will only gain maximum satisfaction from CAS publications and services if our productivity gains are coupled with the building of a database of highest technical integrity. Indeed, the CAS production operation is based on the triad

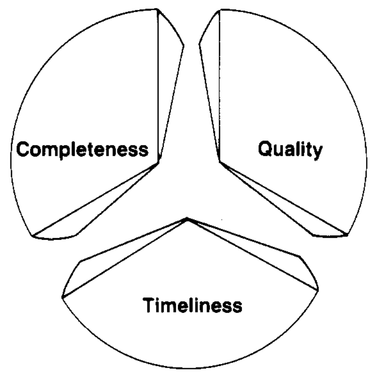

Figure 1. Tenets of CAS publication policies.

(see Figure 1) of completeness, timeliness, and quality that must be ever so carefully balanced with the economic realities of viable marketing strategies.

REFERENCES AND NOTES

(1) "Executive Update"; Dartnell Corp.: Chicago, IL, Jan 10, 1984; p 1.
(2) "The Revival of Productivity". *Business Week* **1984**, *Feb. 13*, 92-100.
(3) Olson, M. "The Rise and Decline of Nations"; Yale University Press: New Haven, CT, 1982.
(4) "CA Today: The Production of Chemical Abstracts"; American Chemical Society: Washington, DC, 1958.
(5) "Chemical Abstracts Service". In "A Century of Chemistry: The Role of Chemists and the American Chemical Society"; Skolnik, H.; Reese, K. M., Eds.; American Chemical Society: Washington, DC, 1976; pp 126-143.
(6) "The First 75 Years of Chemical Abstracts Service". *CAS Rep.* **1982**, *12*, 3-9.
(7) Perry, J. W. "The ACS Punched Card Committee—An Interim Report". *Chem. Eng. News* **1949**, *27* (11), 754-756.
(8) Baker, D. B. "CAS Economics and Pricing". "Proceedings of the Symposium on Chemical Abstracts in Transition", Chicago, IL, Aug 28, 1973; Chemical Abstracts Service: Columbus, OH, 1974. Baker, D. B. "The Economics of Chemical Abstracts Service". *CAS Rep.* **1974**, *3*, 3-7.
(9) McCurdy, P. P. "Some Sausages, Some Skin". *Chem. Eng. News* **1973**, *51* (24), 1.
(10) Rowlett, R. J., Jr. "Impact of the Computer System on CAS Editorial Processes and Publications and Services". "Report on the 14th Chemical Abstracts Service Open Forum", Chicago, IL, Sept 15, 1970; Chemical Abstracts Service: Columbus, OH, 1971.
(11) Weisgerber, D. W. "Applications of Technology to CAS Data-Base Production". *Inf. Serv. Use* **1984**, *4*, 317-325.
(12) Nelson, R. D.; Hensel, W. E.; Baron, D. N.; Beach, A. J. "Computer Editing of General Subject Heading Data for *Chemical Abstracts* Volume Indexes". *J. Chem. Inf. Comput. Sci.* **1975**, *15*, 85-94.
(13) Soukup, K. M.; Hammond, S. E. "Author Name Processing at Chemical Abstracts Service: Name Matching Using Nonunique Bibliographic Identifiers". *J. Chem. Inf. Comput. Sci.* **1982**, *22*, 172-176.
(14) Zamora, A. "Automatic Detection and Correction of Spelling Errors in a Large Data Base". *J. Am. Soc. Inf. Sci.* **1980**, *31*, 51-57.
(15) Gehring, S.; Rowlett, R. J., Jr.; Wigington, R. L.; Wood, J. L. "Automated Editing". *CAS Rep.* **1972**, *1*, 3-10.
(16) Farmer, N. A.; Tate, F. A.; Watson, C. E.; Wilson, G. A. "Extension and Use of the CAS Chemical Registry System". *CAS Rep.* **1973**, *2*, 3-10.
(17) Dittmar, P. G.; Mockus, J.; Couvreur, K. M. "An Algorithmic Computer Graphics Program for Generating Chemical Structure Diagrams". *J. Chem. Inf. Comput. Sci.* **1977**, *17*, 186-192.

Effect of Taxonomy Class and Spanning Set on Identifying and Counting Rings in a Compound

SEYMOUR B. ELK

Computer Science Department, William Paterson College, Wayne, New Jersey 07470

Received February 29, 1984

The word "ring" in chemical literature is, at best, ill-defined and, at worst, a constant source of ambiguity. In order to better understand the problem, different meanings for this word in current chemistry usage are examined, as well as a concomitant evaluation of the number of faces that a mathematical model of a chemical molecule will have. Of specific interest is the use (abuse) of projection. Fundamental mathematical differences that arise due to different size embedding spaces are shown to be the cause of an inherent inconsistency in presently used systems of chemical taxonomy generally and in systems of nomenclature, in particular.

WHAT DEFINES A RING?

Ambiguities in the meaning of the word "ring" occur frequently in chemical literature and play a major role in merely counting the number of rings that exist in a compound, let alone determining the composition of individual rings, their dimensionality for taxonomy purposes, or their nomenclature.

For most descriptions, and for every common nomenclature of organic chemistry, an important parameter that must be specified is the number of rings in a compound. Although, in most instances, this is relatively straightforward, such is not always the case. Consequently, before being able to simply count this number, it is necessary to delineate: what defines a ring?

First, it should be noted that the definition of ring is a function of the topology chosen.[1] Next, even in a given taxonomy class, there may exist a great deal of ambiguity; for example, consider the planar taxonomy of a cube: the description of a cube as the union of six faces contains the implicit assumption that the word "face" is limited to a single, simple, coplanar surface. Not only is this unnecessary; in some instances, it is not even desirable. Consequently, if the term ring is used to denote the boundary of a face, then the number of faces in any given figure, such as the cube, must also be redetermined.

There exist 2^6 (=64) combinations of a single faces that must be examined in order to determine the total number of faces and rings in a cube. Of these 64 possible configurations, four combinations (the set of zero simple faces and the three sets of two simple noncontiguous—diametrically opposed—faces) do not fit the extended definition of face. Thus, there exist the following: 6 "simple" faces[2]—each with 4 edges; 12 "double" faces[2]—each with 6 edges; 20 "triple" faces[2]—8 with 6 edges and 12 with 8 edges; 15 "quadruple" faces[2]—12 with 6 edges and 3 with 8 edges; 6 "quintuple" faces[2]—each with 4 edges; 1 "sextuple" face[2]—the entire cube (which is topologically transformable into a sphere and so has zero edges).

In order to now compute the number of rings, note that the sets of single and quintuple faces share a common boundary.

