PRINTING WITHOUT PAPER?

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FOREWORD

This report represents a piece of truly international research work done in 1982 by the Information Technology Task of IIASA's former Management and Technology Area.

The authors, Drs Maurer, Sebestyen, and Charles wrote this report with the help of the most modern computer supported messaging system from their home offices in Graz and Laxenburg in Austria, and also from Menlo Park in California, USA.

This report explores the impact of information technology on other sectors or branches of national economy, again mainly on the role of paper and printing in a new situation. The authors try to trigger off some new ideas on a potential new technology that would utilize the advantages of a printed medium, while getting rid of its drawbacks, such as waste of natural resources and energy, and pollution of the environment.

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Printing without paper?

H.A. Maurer, I. Sebestyen and J. Charles

Abstract: More and more information is being read from cathode ray tube (CRT) screens. Despite improvements in many areas — display technology, readability of character sets, usable amount of information on a frame, software for handling pages — a glaring fact remains: reading and browsing through information is still more pleasant using a stack of sheets of paper than using a display screen and electronically stored information. Yet, the preparation of hard-copy pages for once-only (or never) reading seems expensive and wasteful. It is our contention that this need not be the case if new concepts, such as printing on demand, and a concept we shall call multi-time paper (M-paper, for short) are used.

The current situation

The penetration of society by computers and telecommunications devices is increasing, and these machines are changing society in many ways. One change is in how we read and write. Increasingly, for example, CRT devices are replacing paper. This occurs when we use a TV-type terminal for interactive computing; when we compose a letter, document, or file using a screen editor; when we retrieve data from an online data bank; use a home terminal for carrying out such transactions as banking; use broadcast or wire videotex systems of any kind; and when we are using a computer display for any of the other 1001 present and future applications of such devices.

The quest for a 'paperless' office, though still a flight of fancy, is rooted in the problem that more and more hard-copy printed materials create enormous problems of storage, handling, and information overload. The proponents of the electronic office of the future see a solution in the substitution of electronic signals for paper. There is already a budding movement toward paperless information systems [7]. How people will react to an increasingly paperless environment is not clear, nor are the nature and type of functions that will still require hard copy printed material, electronic devices notwithstanding.

Printed material, in the form of documents, has been the traditional way in which we formally communicate (can you see a government bureaucracy with fewer forms?). For informal communication, the printed paper has also been a way of life. A substitutable electronic system is a new form of human communication, so human factors (social and psychological) will be important in the transition. Some of these factors have to do with the health and safety standards of electronic devices, particularly the problems of muscular and visual fatigue from prolonged work at video display terminals. Among other human concerns are ease of use, reliability, and people's resistance to change.

In many situations, CRT displays are indeed ideally suited for what they are used, with little negative spinoff. This is particularly

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true in all applications with a heavy communication or processing component, such as online retrieval of small amounts of data, transaction applications, interactive computing, and so on.

In other situations, the use of display screens has both positive and negative effects. If the positive ones outweigh the negative ones then there is an overall benefit in going from paper to electronic display. Typical instances of positive applications are the uses of editing systems for the preparation of documents of any kind. The fact that changes can be made conveniently without rewriting or retyping large amounts of material far outweighs the fact that the use of notes, the simultaneous working in various paragraphs, etc., is still more convenient using a 'loose-leaf paper approach' than any text-editing systems.

On the other hand, if exceedingly fast and exceedingly good typists at little cost did exist we believe that text-editing systems would have less penetration, no matter how sophisticated they might get.

On the negative side, CRT displays may not be the best solution for systems that are used to electronically store or communicate moderate to large amounts of information that will be read actively thereafter. Some applications of videotex are this type: information (such as from an electronic newspaper) is retrieved and then studied at length. (Such services as Green Thumb and News Update available via the public telephone network in the United States make use of that fact by providing a 'single transaction mode' to retrieve a moderate amount of information in one burst). Often, the printed form is preferable to the electronic form for newspapers, incoming mail and personnel files. Although developments such as electronic newspapers do make the use of displays more and more attractive, we think that foreseeable technological developments may not be able to produce display techniques that will match some of the conveniences of printed material.

In contrast to printed material, current CRT displays suffer from a number of drawbacks: the 4000 characters available on a two-page spread of an opened encyclopedia are hard to squeeze onto a screen; the convenience of scattering dozens of pages of notes over a desk is still hard to match even with very sophisticated software. Paper is more portable than display screens. From a physiological point of view, it is well established that the distance between the eyes of a reader and the characters to be read should be easy to vary by the user, which can be more easily done with printed material than with a CRT unit. With the development of very large, flicker-free, easy-to-read, super-thin, light weight, battery-operated software and storage-supported display units (no thicker than a pocket book and as easy to read), material printed on paper may not have that many advantages any more. Development along this line is very intense in all parts of the world. For instance, at the Central Research Laboratory of Thomson CSF in France, the first results of a direct view flat-panel display for computer terminal applications were presented and proved to be useful [1]. The main physical characteristics of the panel for telephone terminal applications are:

- Resolution of $250 \times 270 = 60{,}000$ black and white pixels.
- Pitch of 0.375 mm.
- Useful display area of 94×90 mm^2.
- Frame change time of 5 sec, which matches the information rate through the telephone.

At Thomson CSF, a flat-screen liquid crystal display was presented which was able to fulfil the requirements of the videotex technology (such as 25 rows of 40 characters). At the same time in Japan, liquid crystal display (LCD) pocket-TV development has proceded extremely well [2] (Table 1).

At present, however, the LCD pocket TV is in its early infancy. Even the best models have only 30 per cent resolution of standard black-and-white TV devices, and development of colour LCD panels is only in its earliest phase. Thus, the LCD technology developments for acceptable price are still a long way down the road.

Paper has disadvantages as well as advan-

Table 1. *LCD pocket-TV developments in Japan [2].*

Manufacturer	*Display area mm*	*Number of pixels (lines) × (pixels) = (total)*	*Equipment cost US $*
Toshiba	41 × 51	220 × 240 = 52,800	?
Matsushita (JVC)	44 × 56	240 × 240 = 57,600	400
Hitachi	45 × 60	120 × 160 = 19,200	300
Seiko	24 × 33	210 × 210 = 44,100	160

tages. For example, the production of paper demands the consumption of many materials, uses vast amounts of energy, and impacts the environment severely. (Healthy trees are felled and rivers polluted.) Moreover, according to a report of the National Bureau of Standards [5], the American paper industry is the fourth largest waste-producing industry in the country — 7.3 million tons per year, which is about 10 per cent of all United States industrial waste. Further, the recycling rate of paper is still relatively low. According to 1967 data [6] only 19 per cent of all paper produced in the United States was recycled after usage. The recycling rate for paper is even lower than the average for all raw materials, which is about 25 per cent. The recycling rates for other countries are usually higher than the US; Eire, for example, according to OECD Sources, achieved a recycling rate of 66.4% (!) [8] in 1974 for paper, whereas the Scandinavian countries and Canada, leaders in the Forest Industry, only reached 3–7%.

Table 2. *Percentage of utilization rates in waste paper.*

Countries	*1960*	*1963*	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*
F.R. of Germany	39.9	41.7	45.6	44.6	44.1	46.0	44.6	43.8	46.4	45.9	45.9	45.2
Belgium-Luxembourg	29.7	26.5	27.6	25.3	25.2	21.8	21.8	22.4	18.7	18.5	18.7	18.4
Denmark	34.3	29.3	16.1	22.2	21.7	22.7	32.9	32.0	40.3	48.5	48.7	48.6
France	28.2	30.0	30.9	31.5	32.0	31.7	31.4	32.2	35.0	35.2	35.7	36.0
Eire	29.0	28.0	41.7	35.6	37.3	35.6	39.5	34.5	n.a.	n.a.	41.3	66.4
Italy	21.6	22.0	24.5	28.1	28.9	27.1	28.3	28.8	32.4	33.2	34.3	40.6
Netherlands	20.3	22.7	23.1	24.5	31.0	31.7	33.2	34.0	40.0	38.2	40.4	42.6
U.K.	32.3	34.1	35.7	34.4	35.7	36.0	37.9	38.2	43.2	41.8	44.3	45.8
EEC	31.2	32.2	34.2	34.0	34.9	35.2	35.6	35.9	39.3	38.8	40.1	41.4
Austria	17.2	18.1	19.5	19.8	21.5	18.3	22.7	24.6	25.2	26.4	26.0	24.3
Spain	28.4	32.8	32.4	26.4	33.2	34.6	29.3	30.1	29.4	36.2	34.1	37.5
Finland	4.0	2.9	4.1	4.2	3.3	3.2	2.9	4.6	3.3	2.8	2.8	3.2
Norway	5.4	6.1	7.1	7.2	6.9	6.6	6.5	6.7	7.1	6.7	7.1	7.4
Sweden	7.9	5.5	5.9	6.5	5.5	6.7	6.3	6.0	6.1	6.8	6.7	7.3
Switzerland	30.8	31.5	31.5	31.9	31.3	31.6	31.2	30.6	35.1	34.6	36.1	40.0
Canada	3.4	3.3	4.2	3.4	2.7	2.9	3.3	5.0	6.0	6.0	6.3	6.4
U.S.A.	n.a.	n.a.	23.0	21.3	21.1	20.6	20.1	21.1	21.2	22.1	20.8	20.6
Japan	n.a.	n.a.	35.3	34.9	35.4	36.2	35.7	35.0	33.8	35.1	37.6	37.1

Source: OECD, *The Pulp and Paper Industry*, Annual Reports (Paris: OECD).
Note: n.a. = not available.

Table 3. *Environmental impact comparison for 1000 tons of low grade paper.*

Environmental effect	*Unbleached kraft pulp (virgin)*	*Repulped waste paper (100%)*	*Change from increased recycling (%)**
Virgin materials use (oven-dry fiber)	1000 tons	0	−100
Process water used	24 mill. gallons = 91,000m^3	10 mill. gallons = 38,000m^3	−61
Energy consumption	17,000 × 10^6 BTU	5000 × 10^6 BTU	−70
Air pollutants† effluents (transportation, manufacturing, and harvesting)	42 tons	11 tons	−73
Waterborne waste discharges —BOD†	15 tons	9 tons	−44
Waterborne waste discharges — suspended solids	8 tons	6 tons	−25
Process solid wastes generated	68 tons	42 tons	−39
Net postconsumer wastes generated	850 tons‡	−250 tons§	−129

Source: Midwest Research Institute, "Economic Studies in Support of Policy Formation on Resources Recovery." Unpublished data, 1972.

*Negative numbers represent a decrease in that category, or a positive change from increased recycling.
†Based primarily on surveys conducted in 1968–1970.
‡This assumes a 15% loss of fiber in the papermaking and converting operations.
§This assumes that 1100 tons of waste paper would be needed to produce 1000 tons of pulp. Therefore, 850 − 1100 = −250 represents the net reduction of postconsumer waste.

On the bases of Turner *et al.* [8], let us present two further tables on the material and other resource demand of paper production which shows some environmental impacts as well. The tables also show the environmental impact as well. The tables also show the environmental impact comparisons for manufacturing 1000 tons of low grade paper using either virgin pulp or repulped waste paper (Table 3) and manufacturing 1000 tons of bleached virgin kraft pulp and its equivalent from de-inked pulp (Table 4).

Table 3 suggests that all constituent environmental impacts are reduced if waste is used for the manufacture of low grade paper and that most impacts are reduced if higher grade paper is manufactured but that the de-inking process in the latter case gives rise to significant increases in process solid wastes and in waterborne suspended solids. In both cases, energy 'costs' (i.e., expressed in energy units) are reduced.

Table 4 indicates the well-known problem that de-inking tends to generate a water pollution problem in the form of suspended solids. Tables 3 and 4 thus indicate that both production and recycling leading to higher grade paper such as needed in printing and data processing is always connected with high use of material and energy and has large environmental pollution effects. Thus the best way of reducing this is to save paper (and to consume and produce less paper). Paper production not only requires huge amounts of water (500–1000 tons per ton of paper) but also substantial amounts of energy: to produce a ton of paper takes more than twice as much energy as to produce a ton of plastic-material and

Table 4. *Environmental impacts resulting from the manufacture of 1000 tons of bleached virgin kraft pulp and equivalent manufactured from de-inked and bleached waste paper.*

Environmental effect	*Virgin fiber pulp*	*De-inked pulp*	*Increased recycling change (%)**
Virgin materials use (oven-dry fiber)	1100 tons	0	− 100
Process water used	47 mill. gallons = 178,000m^3	40 mill. gallons = 151,000m^3	− 15
Energy consumption	$23{,}000 \times 10^6$ BTU	9000×10^6 BTU	− 60
Air pollutants (transportation, manufacturing, and harvesting)	49 tons	20 tons	− 60
Waterborne waste discharges — BOD†	23 tons	20 tons	− 13
Waterborne waste discharges — suspended solids	24 tons	77 tons	+ 222
Process solid wastes	112 tons	224 tons	+ 100
Net postconsumer waste generated	850 tons‡	− 550 tons§	− 165

Source: Midwest Research Institute, *op. cit.*

*Negative numbers represent a decrease in that category resulting from recycling.

†Based on surveys conducted in 1968–1970.

‡This assumes a 15% loss of fiber in the papermaking and converting operations.

§This assumes that 1400 tons of waste paper is needed to produce 1000 tons of pulp. Therefore, 850 − 1400 = − 550 represents the net reduction in postconsumer solid waste.

almost two thirds of the energy needed to produce a ton of iron [10]. The core of this note is to describe 'printing' technologies which would lead to reduced use of paper.

We believe that the problem of too much paper might be reduced in other ways, and we believe this can be done if the concept of *printing on demand* is developed and/or a new kind of print material is developed, which we call *multi-time paper*.

As to the paper industry, the last aspect to be considered is what percentage of the paper consumed might be affected by the technologies proposed below. The US statistical data on paper and paperboard production and consumption are given in Table 5 [9]. Taking the 1977 data as an example, in Table 6 we have predicted what 'maximum effect' new technologies of 'printing' could achieve if these technologies were used exclusively. Such a scenario would obviously be an unrealistic one, but indicates those paper consumption classes which might be affected to an unknown degree.

Printing on demand

With the advent of new information technologies vast amounts of computer-readable information can be stored and processed. Through the advent of optical disc technology, for example, even today's systems are able to record and store 128 GByte of information [3], which is about equal to 32 million A4 pages of paper. Such systems cost about $200,000 (US), thus, are much cheaper than the equivalent amount of printed paper and appropriate library facilities. For such systems not only is their archival life much longer than for other storage media, but also

Table 5. *U.S.A. paper and paperboard-production and consumption: 1965 to 1979.*

Item	Production 1965[1]	1970[1]	1975	1977	1978	1979 prel.	Consumption 1965	1970	1975	1977	1978	1979 prel.
Total paper and paperboard[2,3]	44.2	53.6	52.9	62.1	64.3	67.0	49.2	58.0	56.1	66.5	70.4	72.7
Paper	19.2	23.6	23.3	27.4	28.3	29.8	25.2	30.1	28.3	33.8	36.2	37.5
Newsprint	2.1	3.3	3.7	3.9	3.8	4.1	8.4	9.8	9.4	10.3	11.2	11.2
Coated printing, converting	2.8	3.3	3.2	4.3	4.4	4.5	2.8	3.2	3.1	4.3	4.6	4.6
Book paper, uncoated	2.1	2.6	2.3	3.0	10.1 (with Other printing)	11.1 (with Other printing)	2.1	2.7	2.4	3.2	10.6 (with Other printing)	11.7 (with Other printing)
Other printing, writing etc.	4.2	5.1	5.5	6.6			4.3	5.3	5.3	6.6		
Packaging and industrial converting	5.0	5.4	4.6	5.4	5.8	5.8	4.8	5.3	4.3	5.2	5.8	5.7
Tissue and other mach. creped	2.9	3.8	4.0	4.3	4.2	4.5	2.9	3.8	3.9	4.3	4.2	4.5
Paperboard[2]	20.8	25.5	24.8	29.0	30.3	31.6	19.7	23.4	22.8	26.7	27.9	29.0
Unbleached kraft	7.8	11.6	11.5	13.7	14.4	15.2	6.9	9.9	10.5	12.4	12.9	13.6
Bleached kraft	2.3	3.4	3.3	3.7	4.0	4.0	2.2	3.3	3.1	3.3	3.5	3.6
Semichemical	2.7	3.4	3.7	4.3	4.4	4.7	2.6	3.4	3.6	4.1	4.4	4.7
Recycled furnish	8.1	7.0	6.2	7.3	7.5	7.7	8.0	6.9	6.2	7.3	7.5	7.7
Construction paper and board	3.9	4.3	4.6	5.5	5.8	5.6	4.1	4.4	4.7	5.8	6.2	6.0

[1]Compiled from U.S. Bureau of the Census reports.
[2]Consumption data adjusted for net exports of converted products.
[3]Includes wet machine board, not shown separately.
Source: American Paper Institute, New York, N.Y., *The Statistics of Paper and Paperboard* (annual).

their data compression capability in physical terms is much greater. Thus, the storage requirements for the systems are considerably less. The optical filing and storage system can be put in any small office: for the above amount of paper, however, a shelf of over 2 km length would be required.

With the concept of printing on demand, all documents should be stored only once. With access from terminals to a computer-controlled, document-filing system a user can select, retrieve, and browse through the preselected documents. Once the computer has helped to identify the document or article or book of interest, it will ask what format is desired for printed reproduction. Such CAMIS (Computer Asisted Makeup and Imaging Systems) [4] configurations give the option of selecting type font and paper size and kind. It will even print out the text in braille. After selecting the appropriate specifications, one can proceed to have the material printed and bound into a single volume.

When information is reproduced only on request at the time it is needed, it is called printing on demand. The need to print fixed quantities of any document or book, which led in the past to unread paper mountains in warehouses, will be considerably reduced. Vast amounts of paper, energy, labour and storage space can be saved, and the environment benefits because much less paper has to be produced.

CAMIS also allows documents to be continuously updated; out-of-date paper copies will not exist, hence not be wasted. Moreover, papers produced through CAMIS will be read and used; even if not recycled, they would not be regarded as wasteful of material and energy.

Table 6. *"Maximum effect" of new "printing" technologies (printing on demand, multi-time-paper) proposed on paper consumption based on U.S. statistical data.*

Item	*Consumption in 1977* *Million tons*	*in %*	*Maximum effect of new "printing" technologies proposed*
Total paper and paperboard	66.5	100	$\sum^* = 36\%$
Paper	33.8	51	
Newsprint	10.3	15	⟷ *
Coated printing, converting	4.2	6	⟷ *
Book paper, uncoated	3.2	5	⟷ *
Other printing, writing, etc.	6.6	10	⟷ *
Packaging and industrial converting	5.2	8	
Tissue and other mach. creped	4.3	7	
Paperboard	26.7	40	
Unbleached kraft	12.4	19	
Bleached kraft	3.3	5	
Semichemical	4.1	6	
Recycled furnish	7.3	10	
Construction paper and board	5.8	9	

Multi-time paper

Multi-time paper (M-paper, for short) is a kind of material that can be printed on and used much like ordinary paper, but it has one big advantage: it can be reused a (large) number of times.

Thus, the concept of M-paper is a step beyond the printing-on-demand concept, since it also insures the recycling of all printed 'papers'.

No manufacture or implementation of M-paper is known to us (if it were, we would probably hold a patent). But we think it can be developed. We will describe the operational use of M-paper, demonstrate the usefulness of M-paper by mentioning a few typical applications, and suggest how to implement it.

Operational use of multi-time paper

Imagine a folder containing 10 to 100 sheets of M-paper. The sheets are individually removable and reinsertable. Now imagine a terminal that provides a slot for the insertion of the folder. Material that could ordinarily be displayed on screen or printed in a standard fashion can be rerouted to the folder of M-paper and recorded on it. The user can now remove the folder, study the output at leisure, spread and shuffle the individual pages as desired. Eventually, the M-paper and the folder are replaced in the terminal slot and are ready for the recording of new information — M-paper can be reused many times, hence its name.

We would argue that M-paper is a logical solution to problems we have been trying to solve with perhaps the wrong tools. M-paper will allow data to be stored, processed, and transported as they should be (electronically), to be read and processed by humans as conveniently as possible (on easy-to-handle individual sheets of M-paper) — all this without wasting large amounts of paper as is the case with current hard copy techniques.

We can imagine many possible applications of M-paper. First, consider the electronic newspaper: the paper is transmitted electronically,* but is still available in the usual form, which is convenient to take along on a train, can be read by all family members, and yet does not increase the pile of paper thrown away daily.

Second, consider how much current and planned videotex systems would gain by M-paper: in future broadcast videotex, where hundreds of pages are broadcast in a circular fashion, those pages could be available (in their most current version) in printed form (!); in telephone videotex all information concerning some items could be retrieved in single-transaction mode, reducing telephone connect-time and making the information available in an easy-to-read and highly transportable form.

Third, consider the change M-paper would make in the much-talked-about, computerized, office-of-tomorrow; in the morning, upon arriving at the office, the delegated employee specifies 'mail'. At high speed, all electronically delivered mail is copied onto M-paper, which can then be read and pondered at convenience, while the 'originals' remain electronically stored. Similarly, when information from, say, a personnel file is required, it can be copied for convenient perusal without producing wastepaper. With M-paper, the electronic library, where journals and even books are computer-stored yet can be read in the fashion to which we are accustomed, may become reality. M-paper, offering the possibility of semi-permanent hard copy of any amount of information without wasting paper, opens many other doors. But it remains to be seen whether M-paper and an appropriate 'printing' device can be implemented. Although we do not have an immediately workable proposal, we think there are many avenues one could pursue to obtain a feasible realization. Typically, a smooth surface, such as a transparency used in an overhead projector, could be printed on with a water-soluble colour: by reusing the colour when it is washed off, one may be able to obtain a system that requires water as input (and energy for operating the printing jets), but just an occasional colour refill. On a more sophisticated level, imagine a chemical X that remains white at ordinary temperatures, turns black when heated above a threshold, and stays that way until cooled below another threshold: the writing process will then consist of locally heating patterns on the paper, the wiping-out process of cooling the printing surface. (This is not unlike the 'invisible' writing of kids, which some claim can be made with lemon juice.) Other processes such as magnetizing thin sheets of metal to locally change its appearance or to hold microscopic iron dust, or even the use of liquid crystal displays might also be considered.

In a way, something like the water soluble colour on a smooth surface method sounds particularly attractive to us, since the user may then scribble further notes (or erase information) on the M-paper.

Maybe at low speeds, overnight, and via broadcasting.

Summary

We have argued in this paper that printing on demand and reusable paper offer a new range of possibilities for the semi-permanent storage and display of information. While the former is already developed, the latter could likely be implemented with R & D effort. Both could have a tremendous impact on paper conservation and environmental protection. They could revolutionize printing as we know it.

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