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https://doi.org/10.4224/20375812
Internal Report (National Research Council of Canada. Institute for Research in Construction); no. IRC-IR-666, 1994

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
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Internal Report No. 666

Date of issue: June 30, 1994

This is an internal report of the Institute for Research in Construction. Although not intended for general distribution, it may be cited as a reference in other publications.

Canada

THE ENERGY CONSERVATION POTENTIAL

OF POWER MANAGEMENT FOR FAX MACHINES

BY

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IRC Internal Report No. 666

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Acknowledgement

This project would not have been possible without the participation of many organizations who were willing to make the raw data on their fax machine usage available to us, and the co-operation of those individuals who devoted time to collecting these data and sending them to us. Contributing organizations were (in alphabetical order):

A.T. & T. (USA);

California Energy Commission (USA);

CENBG (France);

Computer & Business Equipment Manufacturers Assoc. (USA);

Electric Power Research Institute (USA);

Environment Canada (Canada);

Lawrence Berkeley Laboratory (USA);

Los Angeles Department of Water and Power (USA);

National Institute of Standards and Technology (USA);

National Research Council Canada (Canada);

Natural Resources Canada (Canada);

North Carolina Alternative Energy Corporation (USA);

Northern States Power Company (USA);

NUTEK & OMVarden (Sweden);

Ontario Hydro (Canada);

Pacific Gas & Electric (USA);

Southern California Edison (USA);

U.S. Department of Energy (USA);

U.S. Environmental Protection Agency (USA);

Wisconsin Centre for Demand Side Research (USA).

Thanks are also due to the staff of iScan (Ottawa, Canada) who efficiently converted the mountain of paper data into machine readable format.

Abstract

We measured the power draw, power quality, and operating profiles of a number of fax machines. Our aim was to quantify fax machine energy consumption and to evaluate the potential of energy conservation through power management. The results established that fax machines, when idle, draw between 7 and 30 % of nameplate rated power, with power factors around 0.5, and total harmonic distortion in the current of over 150 %. We then used fax machine activity reports to analyze the usage of 32 fax machines over a 12 week period. These fax machines were active for an average of only 3.7 % of the time they were switched on, although there was considerable variation about this mean. Further, an average of 86.4 % of on-time could be eliminated by automatically switching off the fax machines after 15 minutes of inactivity. Such power management could realize savings of around $ 19 per fax machine per year. In addition, we found that around 9.3 % of fax transactions were halted due to transaction errors, and that up to 23.8 % of faxed pages were cover sheets. Efforts to reduce transaction errors and the use of cover sheets could realize additional energy, time and paper savings, and reduce telephone charges.

Contents

1. Introduction

1.1 Fax machine energy consumption.

The fax machine was patented in 1843, 30 years before the telephone, and became popular with newspapers in the 1920s for transmitting photographs. Nevertheless, it was only with the arrival of cheap, fast, digital machines that the fax machine became a popular, and now indispensable, feature of the office workplace [Hunkin, 1993; Lovins & Heede, 1990].

Fax machine inventories have increased rapidly since the late-1980s. One estimate [Lovins & Heede, 1990] put the U.S. fax machine inventory in 1984 at 0.47 million, in 1989 at 2.47 million, and in 1993 at 12.11 million; another estimate [Patel, Teagan & Dieckmann, 1993] put the 1989 inventory at 3.7 million. Flavelle [1993] put the number of fax machines in Canada at about 1 million. Although sales reached a peak in 1988, when inventories almost doubled in that single year [Piette, Eto & Harris, 1991], inventories are still predicted to increase by between 5 and 10 % until the end of the decade [Piette, Eto & Harris, 1991; Patel, Teagan & Dieckmann, 1993]. In Canada, fax machine inventories increased by 11 % in 1991, when $ 106 million was spent on hardware [Haggett, 1993]. However, it is expected that fax modems and seamless electronic data transfer will eventually replace stand-alone fax machines[1].

In terms of U.S. energy consumption, fax machines represented the fastest growing office equipment category[2] in the years 1983 to 1991 [Piette, Eto & Harris, 1991]. This is a striking statistic since office equipment itself is the fastest growing electrical end-use, now consuming anywhere between 25 and 65 TWh per year[3] in the U.S., and responsible for between 5 and 20 % of electrical loads in office buildings [Piette, Eto & Harris, 1991; Patel, Teagan & Dieckmann, 1993; Lovins & Heede, 1990]. Nevertheless, fax machines account for only about 1 % of all office equipment energy consumption [Patel, Teagan & Dieckmann, 1993; Harris, 1992; Szydlowski & Chvala, 1994]. This relatively small fraction is explained by two facts: (1) individual fax machines draw far less power than most other pieces of office equipment (e.g. a typical fax machine might draw 25 W when idle, a typical PC and VDU might draw 125 W); and (2) fax machine inventories are relatively small compared to some other office equipment items (for example, whereas most office workers each have a PC, twenty or more office workers might share one fax machine). Estimates for the total annual

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[1] Indeed, fax modem sales in the U.S. are already increasing rapidly. Sales reached 655,000 in 1991 (double the previous year's sales), and there were expected to be 8 million in place by 1995, with 1995 sales worth $ 1.1 billion [Gianturco, 1992].

[2] The other categories being: PCs, printers, VDUs, copiers, typewriters, mainframes, and mini-computers.

[3] Equivalent to the output of between 5 and 13 1000 MW power stations.

energy consumption by fax machines in the U.S. in 1989/90 are between 140 and 400 GWh [Lovins & Heede, 1990; Patel, Teagan & Dieckmann, 1993]. At a conservative 5 ¢/kWh, this relatively small fraction of office equipment still amounts to between $ 7 and $ 20 million per year in energy costs alone.

1.2 Office equipment use patterns and power management

Despite the fax machine's unprecedented rate of market penetration, there are little data on fax machine power draw and use profiles that can be used to systematically address potential energy savings.

Numerous studies have observed that the actual power draw of the vast majority of office equipment is considerably lower than nameplate ratings [e.g., Piette, Eto & Harris, 1991; Lovins & Heede, 1990; Norford & Dandridge, 1993; BRECSU, 1993; Tiller & Newsham, 1993; Szydlowski & Chvala, 1994]. However, these studies have generally been limited to a narrow range of the available equipment. Typical true power draws are between 20 to 50 % of the nameplate values, and can vary widely between manufacturers of comparable machines, or (particularly for imaging equipment) between operating cycles. Therefore estimates based on nameplate values, or assumed power draws unrepresentative of the general population, are likely to be substantially in error.

In observing use profiles, PCs have probably received the most attention, and detailed use profiles have been recorded for a number of sites [Tiller & Newsham, 1993; Szydlowski & Chvala, 1994]. These data have significantly changed the prevailing opinion about desktop PC use, and highlighted the tremendous potential for energy savings which would otherwise have gone unrecognized. Indeed, the Energy Star guidelines [Quain, 1993], and Swedish initiatives [NUTEK, 1992], requiring low power "idling" modes, have been derived with direct input from the use patterns observed by Tiller & Newsham [1993]. Most of the major manufacturers which supply PCs to the U.S. market have agreed to build machines to Energy Star specifications. Demand for such machines will be strongly driven by a U.S. Federal Government decision to procure only Energy Star equipment from 1994 onwards. Energy Star computers could eventually produce $ 1 billion annual electricity savings across the U.S. [Gutfeld, 1992]; put another way, by the year 2000 Energy Star and other programs that promote energy efficient computer equipment should prevent 20 million tonnes of carbon dioxide emissions. In addition, a number of manufacturers have developed add-on devices to switch off PCs and peripherals when inactivity is detected [Stickney & Lovins, 1992]. These retrofit devices enable existing PCs to meet Energy Star guidelines.

However, progress in evaluating the potential energy savings, appropriate efficiency guidelines, and implementation of the guidelines into hardware has proceeded much more slowly for office equipment other than PCs. While concentration on PCs is justified by the fact that they are likely responsible for the majority of office equipment energy consumption [Piette, Eto & Harris, 1991; Szydlowski & Chvala, 1994], it would seem likely that similar studies of the operating profiles of other pieces of office equipment will also yield significant tangible benefits.

With few exceptions [Dandridge, 1994; Zemos, 1993] current fax machines do not utilize power management technology, despite the proven potential of power management for PCs [Norford & Dandridge, 1993]. Indeed, despite evidence to the contrary, several authors propose that energy savings for fax machines are best achieved through a more efficient printing process, rather than power management. For example, Patel, Teagan & Dieckmann [1993] take this line, despite estimating that fax machines are active for only 3 % of the time they are switched on, and that 311 of 389 GWh annual U.S. fax energy consumption represents consumption while idle.

In this study we collected available data on the true power draw of fax machines, and added a small number of field measurements of our own. Then we compiled hourly and weekly operating profiles for fax machines under normal office operation. From these data we calculated the energy saving potential of power management for fax machines, that is, automatically switching them into a "sleep" mode when they are not being used, and bringing them back to an active state in response to an incoming telephone call, or on demand from the host user.

2. Methods and Procedures

2.1 Electrical operating characteristics

A BMI 3060 Power Profiler was used to make field measurements of the power draw, and other electrical operating characteristics, of a small number fax machines. The majority of measurements were made when the machines were switched on but idle. This is the operating state of most interest to this study since it is only when machines are idle that power management savings can be achieved. Measurements taken when idle were: power, total harmonic distortion in the current, and power factor. Various active power measurements (when feeding paper, when printing a report) were also made while a sample fax page was sent to the same receiver machine. The BMI 3060 samples at one second intervals, and the idle-state values are the average of several (typically around 12) one second samples. The active-state values are the peak values that were observed during a single, relevant action, and it is important to recognize that the sampling frequency may cause the true peak value to be missed. The nameplate power draw was also recorded. Some machines do not specify a rated wattage on the nameplate, listing instead a rated current value. In these cases, the current was simply multiplied by the operating voltage (typically 115 V) to obtain a nameplate power value.

2.2 Operating profiles

Most fax machines automatically produce hard-copy reports summarizing incoming and outgoing transactions (for example, see Figure 1). These reports are generally issued after specific intervals of time (e.g. daily), or after a given number of transactions (typically 30 to 50). Such reports contain all the information needed to compile a composite operating profile for a given fax machine: mode (transmit or receive), telephone number of the remote fax machine, date and time of transaction, time taken for transaction, and number of pages. In other words, the machine monitors its own activity, and making use of these data, rather than utilizing other monitoring hardware, provided us with a relatively cheap and flexible means of characterizing fax machine use profiles.

A number of organizations in several countries were solicited for their help in this project. The organizations were approached through contact with individuals within the organizations who had previously expressed an interest in office equipment energy issues. The individuals were asked to send us, periodically, the activity reports from one or more fax machines in their organization. They were told that they could mask the telephone numbers on the reports (though, in the end, none of them chose to do so). The only incentive offered for participation was access to the results of the project, in the form of a complete final report. A total of 21 organizations (mostly government departments or public utilities) in 4 countries agreed to participate, and sent activity reports from a total of 66 fax machines. Data were collected over the period 1st January to 30th June, 1993, though, for a limited number of machines, data were made available for a period of up to 18 months.

Hard copy data were converted to digital form for analysis using a commercial scanning service, as the large quantity of data made key entry impractical.

Figure 2 shows the number of days data received for each of the fax machines; the machines are ordered according to the number of days for which data were available. However, the data were only useful if data were available in long series of continuous days. Figure 3 shows the longest string of continuous days of data for each of the fax machines; the machines are ordered according to the number of days for which continuous data were available.

At this point, it was decided we would have to sample from the total data set as resources were not available to analyze all the data collected. Figure 3 demonstrates that to compile the use profiles of at least 30 machines (deemed a reasonable sample size) would mean selecting machines from which continuous data were available for 84 days, or 12 weeks. In fact, a 12 week "cut-off" yields a sample of 32 machines.

The data from the 32 machines in the sample with at least 12 weeks of continuous activity reports were scanned and converted into a standard ASCII format. It is important to stress that although the 12 week series all fell within the six month period January to June, 1993, the 12 weeks selected for each machine differed. Table 1 lists the 12 week periods used, and the number of machines associated with each.

The data files were checked visually for errors by both the staff of the scanning company, and by ourselves; comparison with a limited, key entered, data set revealed that the error rate in the scanned data was considerably lower than the scanning company's claimed 0.5 %.

Table 1. The 12 week data periods used, and the number of fax machines associated with each.

Period (1993)	No. of machines
March 1st - May 23rd	21
January 11th - April 4th	7
March 8th - May 30th	3
April 5th - June 27th	1

2.2.1 Operating profile analysis

We had already developed software tools for the analysis of time series activity data [Tiller & Newsham, 1993], and therefore, for the sake of efficiency, we converted the data files into a form which could be read and analyzed by these tools. This involved converting the activity data into a continuous string of characters, each character representing one minute of real time. The character "N" represented a minute with no fax activity, the character "T" represented a minute with fax transmission activity, the character "R" represented a minute during which the fax machine received a message. We assumed that the machines were on 24 hours a day. Since the finest resolution is one minute, all fractions of a minute in the original activity data set were rounded up. In other words, a transmission taking 2 minutes and 17 seconds, would be assigned three "T"s in the converted data file.

For example, if we consider a single hour of the 12 week period, a string of characters representing an hour of fax idle time would appear as a string of 60 "N"s, as follows:

NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNN

If a 1 minute 45 second fax transmission occurred at a quarter past the hour, and a 5 minute 3 second fax was received at thirty-five minutes past the hour, the data file would look like this:

NNNNNNNNNNNNNNN**TT**NNNNNNNNNNNNNNNNNN**RRRRRR**NNNNNNNNNNN
NNNNNNNN

This rounding up of minutes might lead to a small overestimate in the active time of the fax machine. However, it is also true that fax machines remain "active" for longer than the time it takes to send or receive the message (which is what is recorded in the original data). Since it takes time for the operator to key in the telephone number, and time for the machine to print a confirmation report. Consequently, such rounding up is not unreasonable.

Our existing data analysis tools were then employed to read the strings of data for each fax machine (each string being 120960 characters long; 12 weeks x 7 days x 24 hours x 60 minutes), and to "bin" the data into daily or cumulative hourly totals. The data were subdivided into transmission and reception activity, and into weekday and weekend activity.

We attempted to estimate the potential for energy savings through power management for fax machines, that is, automatically switching fax machines to a “sleep” mode when they have been idle for a certain period, and switching them back on again whenever the next transaction occurs. We chose 15 minutes of inactivity as a reasonable, conservative switching criterion. To estimate the potential for power management, we scanned the character strings (using a software analysis tool) and removed all "N"s occurring after the fifteenth in a row, up until the next transaction, indicated in the string by an "R" or a "T". Taking the first of the earlier one hour examples (and assuming activity just before this hour started) after the fifteenth "N" the machine is considered to have entered sleep mode automatically. All "N"s following (shown underlined) would be removed from the string, thus saving 45 minutes of on-time, as follows:

NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNN

For the second example, (again, assuming activity just before this hour started) the transmission activity in the fifteenth minute prevents the fax machine switching to sleep mode automatically, there are only fourteen "N"s in a row from the start of the string. Fifteen minutes after the end of the transmission the machine automatically switches into sleep mode. However, only 4 minutes of on-time is saved (underlined) because in the thirty-fifth minute a message is received. We assume that this returns the fax machine to active mode for reception. Fifteen minutes after the end of the reception power management again switches the fax machine into sleep mode for the final 4 minutes of the hour (underlined), making a total of only 8 minutes on-time savings in the hour:

NNNNNNNNNNNNNN**TT**NNNNNNNNNNNNNNN<u>NNNN</u>**RRRRRR**NNNNNNNNNNN
NNNN<u>NNNN</u>

Of course, if there is no activity during the next hour, a full sixty minutes of on-time would be saved since the fax machine would already be off at the start of the hour.

3. Results

3.1 Electrical operating characteristics

Table 2 shows the nameplate and measured power draw for various fax machines. The upper part of the table reproduces figures quoted in the literature, and the lower part of the table are the results measured in this study.

Two indicators of power quality, total harmonic distortion in the current waveform (THD) and true power factor (PF) were also measured for a subset of the fax machines on the NRC campus, these measurements are shown in Table 3.

Table 2. Nameplate and measured power draw for various fax machines. Figures are from the literature, and our own measurements. Printing (or imaging) technology is also shown, if known.

Machine	Source*	Print Technology	Power Draw (W)		
			Nameplate	Idle	Active
Canon Fax 270	PT&D	?	276	12	100
Canon Fax 222	L&H	Thermal	210		
Sharp 510	L&H	Thermal	160		
Sharp 550	L&H	Thermal	230		
Sharp 750	L&H	Thermal	550		
Canon L770	L&H	Laser	570	15	
Canon Fax 920	L&H	Laser	1200		
Xerox 200	L&H	Thermal	500	25	
Xerox 295	L&H	Thermal	300	70	
Xerox 400I	L&H	Thermal	150	25	
Xerox 410	L&H	Thermal	400	25	70
Xerox 455	L&H	Thermal	360	115	
Xerox 485/495/I	L&H	Thermal	360	115	
Xerox 7007	L&H	Thermal		<10	
Xerox 7010/7011	L&H	Thermal	70	10	
Xerox 7017/7017SF	L&H	Thermal	260	15	
Xerox 7020/7021	L&H	Laser	173	30	
Panasonic UF300	L&H	InkJet	32	10	
Xerox 7033	NRC	Laser	230	25	78[a]
Xerox 7033	NRC	Laser	230	25	54[a]
Lanier 2260	NRC	Thermal	86		
Xerox 7033	NRC	Laser	230	26	70
Lanier 2230	NRC	Thermal	86		
Xerox 7020	NRC	Laser	175	12	196[a]
Xerox 7020	NRC	Laser	175		
Xerox 7020	NRC	Laser	175	12	116[a]
Harris/3M 2110	NRC	Thermal	345	25	74
Xerox 7033	NRC	Laser	230		
Xerox 7033	NRC	Laser	230		
PitneyBowes 8050	NRC	Thermal	518		
PitneyBowes 9550	NRC	Laser	633	18	416
PitneyBowes 9250F	NRC	Laser	518		
Ricoh 65	NRC	Thermal	145		
Pitney-Bowes 8000	NRC	Thermal	518		
Canon L770	NRC	Laser	575		

* L = Patel, Teagan & Dieckmann [1993], L&H = Lovins & Heede [1990], NRC = this study.

[a] note, the differences in peak active power draw between identical machines is probably principally a function of the one second sampling frequency, which is relatively long compared to the rate of change of power draw during activity.

Table 3. Total harmonic distortion in the current (THD) and true power factor (PF) for various fax machines. Printing (or imaging) technology is also shown.

Machine	Source	Print Technology	Power Quality	
			THD	PF
Xerox 7033	NRC	Laser	200	0.44
Xerox 7033	NRC	Laser	207	0.43
Xerox 7033	NRC	Laser	201	0.44
Xerox 7020	NRC	Laser	149	0.53
Xerox 7020	NRC	Laser	147	0.54
Harris/3M 2110	NRC	Thermal	150	0.55
PitneyBowes 9550	NRC	Laser	165	0.50

3.2 Operating profiles

3.2.1 Transaction rate

Figure 4 shows the actual measured distribution of transactions/week over the full 12 week period for the sample of 32 machines; the machines are ordered according to transaction rate. The wide range in number of transactions/week (the busiest machine had an average of 709 transactions/week, the least utilized had an average of only 9 transactions/week), suggests that aggregate mean results alone are likely to be a poor representation of the data. Visual inspection of Figure 4 suggests it is possible to divide the sample of machines into three sub-samples, based on transaction rate. This division is also depicted in Figure 4. Sub-sample "A" comprises the seven fax machines with the highest transaction rates, sub-sample "B" the thirteen fax machines with intermediate transaction rates, and sub-sample "C" the remaining twelve fax machines with lowest transaction rates.

3.2.2 Weekly profiles

Table 4 shows mean transaction activity for each of the 32 machines, with aggregate means by sub-sample, and an aggregate mean for all machines; the standard deviation in the total activity is also shown. It is clear that there is a wide variation in the ratio of transmissions to receptions. Further, the relatively high standard deviations for many of the machines indicates a considerable variation in the transaction activity from week to week. Although the standard deviations across the sub-samples are high they are far lower than the standard deviation across the whole sample of 32 machines, indicating that division by sub-sample is a better representation of the data than taking the sample of 32 machines as a whole.

Table 4. Mean transaction activity for the 32 fax machines.

Standard deviation (s.d.) in the total activity is also shown.

Fax Machine	Transaction Activity (hours/week)			
	TOTAL	(s.d.)	receive	transmit
sub-sample "A"				
1	30.71	(1.98)	28.66	2.06
2	19.87	(1.64)	12.65	7.22
3	17.15	(2.70)	9.86	7.30
4	18.37	(4.38)	4.11	14.26
5	14.50	(2.83)	5.60	8.90
6	12.51	(1.43)	6.04	6.47
7	8.21	(1.11)	4.62	3.59
sub-sample "A" mean	17.33	(7.02)	10.22	7.11
sub-sample "B"				
8	7.13	(1.07)	4.28	2.85
9	6.09	(3.01)	2.32	3.77
10	5.71	(1.97)	1.40	4.31
11	4.71	(1.32)	1.81	2.91
12	4.80	(1.01)	2.46	2.34
13	4.08	(1.46)	1.51	2.57
14	5.27	(1.64)	1.59	3.69
15	4.30	(0.60)	1.91	2.39
16	3.47	(1.10)	0.89	2.58
17	3.20	(0.90)	1.60	1.60
18	2.79	(0.67)	1.43	1.36
19	3.67	(1.01)	1.56	2.11
20	3.55	(0.97)	0.77	2.78
sub-sample "B" mean	4.52	(1.83)	1.81	2.71
sub-sample "C"				
21	3.34	(0.56)	1.42	1.93
22	1.32	(0.49)	0.76	0.56
23	1.73	(0.44)	1.05	0.68
24	2.66	(0.83)	1.72	0.95
25	2.09	(0.64)	1.07	1.03
26	1.62	(0.45)	0.78	0.84
27	1.57	(0.71)	0.82	0.76
28	1.71	(0.34)	0.85	0.86
29	1.69	(0.61)	0.93	0.77
30	1.17	(0.67)	0.40	0.77
31	0.45	(0.35)	0.38	0.07
32	0.32	(0.10)	0.18	0.14
sub-sample "C" mean	1.64	(0.96)	0.86	0.78
Grand mean	6.24	(24.5)	3.29	2.95

Mean transaction activity over all 32 machines is 6.24 hours/week (or 3.7 % of assumed on-time). The mean transaction activity for sub-samples "A", "B", and "C" is: 17.33 hours/week (10.3 % of assumed on-time), 4.52 hours/week (2.7 % of assumed on-time), and 1.64 hours/week (1.0 % of assumed on-time), respectively.

Figures 5 (a), 5 (b), 5 (c), 5 (d), 5 (e), 5 (f) are example plots of weekly transaction activity, for fax machines 1, 4, 9, 17, 20, and 21 respectively, and will be referred to again in the discussion. These particular examples were selected to demonstrate the variation in fax machine activity that can occur from week to week. Each point represents mean activity over the previous week. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

It is from the weekly profiles that we can calculate the energy savings potential of fax machines. The on-time savings due to power management with a 15 minute switching criterion are simply the difference between the prevailing on-time and the predicted on-time with 15 minute inactivity switch. Since the assumed prevailing on-time is continuous 24 hour operation, the prevailing weekly on-time is 168 hours/week for all machines. Table 5 presents the predicted mean on-time with automatic switching after 15 minutes of inactivity, and the percentage on-time savings for each of the 32 machines. The potential on-time savings range from 52.7 % to 98.7 %, from the highest to the lowest activity machines respectively. Mean on-time with power management for all 32 machines is 22.87 hours/week (or 86.4 % savings).

Table 5. Predicted on-time with automatic switching after 15 minutes of inactivity, and percentage on-time savings for each of the 32 machines.

Fax Machine	Predicted on-time with 15 min. switch (hrs/week)	saving (%)
sub-sample "A"		
1	79.45	52.7
2	54.56	67.5
3	53.18	68.3
4	46.00	72.6
5	40.35	76.0
6	49.88	70.3
7	34.08	79.7
sub-sample "A" mean	51.07	69.6
sub-sample "B"		
8	29.04	82.7
9	21.27	87.3
10	19.24	88.5
11	21.59	87.1
12	23.26	86.2
13	21.21	87.4
14	20.97	87.5
15	21.14	87.4
16	17.91	89.3
17	18.42	89.0
18	16.53	90.2
19	16.63	90.1
20	17.42	89.6
sub-sample "B" mean	20.36	87.9
sub-sample "C"		
21	13.93	91.7
22	11.30	93.3
23	11.65	93.1
24	12.53	92.5
25	11.86	92.9
26	9.46	94.4
27	9.33	94.4
28	9.20	94.5
29	9.35	94.4
30	5.26	96.9
31	3.48	97.9
32	2.20	98.7
sub-sample "C" mean	9.13	94.6
Grand mean	22.87	86.4

The mean on-time with power management for sub-samples "A", "B", and "C" is: 51.07 hours/week (mean savings of 69.6 %), 20.36 hours/week (mean savings of 87.9 %), and 9.13 hours/week (mean savings of 94.6 %), respectively.3.2.3 Hourly profiles

Figure 6 (a) is an hourly fax use profile. The curves are averages over all 32 machines and 60 weekdays (Monday to Friday) in the 12 week period. Each point represents the mean fax use over the previous hour. The upper curve is the assumed prevailing on-time, in minutes per hour; since the assumed prevailing on-time is continuous 24 hour operation, the upper curve is a horizontal line at 60 minutes per hour. The lower curve shows the mean minutes per hour for which there was activity. The middle curve shows the predicted mean on-time if power management automatically switched fax machines into a sleep mode after 15 minutes of inactivity.

More details on the transmit and receive activity are shown in Figure 6 (b). The upper curve represents mean transaction activity, and is the sum of the two curves below it, which plot mean hourly transmission and reception activity separately.

Figure 7 (a) shows the hourly fax use profile for sub-sample "A". The curves are averages over the 7 machines in the sub-sample, for all 60 weekdays (Monday to Friday) in the 12 week period. The transaction activity of sub-sample "A" is shown in Figure 7 (b). Figure 8 (a) is the hourly fax use profile for sub-sample "B". The curves are averages over the

13 machines in the sub-sample, for all 60 weekdays (Monday to Friday) in the 12 week period. The transaction activity of sub-sample "B" is shown in Figure 8 (b). Figure 9 (a) is the hourly fax use profile for sub-sample "C". The curves are averages over the 12 machines in the sub-sample, for all 60 weekdays (Monday to Friday) in the 12 week period. The transaction activity of sub-sample "C" is shown in Figure 9 (b).

3.2.4 Pages per transaction

Figure 10 shows the frequency, over all 32 machines, and over the whole 12 weeks, of transactions of a given number of pages; a pages/transaction rate of zero ("0") indicates an error in the transaction. The modal pages/transaction is 1 for receptions and 2 for transmissions, though the difference in frequency between these two intervals for each type of transaction is small. The mean number of pages per transaction across the whole sample was 3.05.

Figures 11 (a) and 11 (b) show, by sub-sample, the normalized frequency of faxes of a given number of pages received and transmitted respectively.

4. Discussion

4.1 Electrical operating characteristics

It is clear from Table 2 that the true power draw of fax machines is considerably lower than their nameplate rating. The idling power draw is between 7 and 30 % of nameplate, whereas the active power draw is typically 20 % of nameplate, though it can reach 65 or even 100 % of nameplate for some machines (Xerox 7020, PitneyBowes 9550). Obviously, basing estimates of fax machine energy consumption on nameplate power values would be likely to lead to significant overestimates.

Table 3 illustrates that fax machines exhibit very poor power quality, even worse than other electronic office equipment with switching power supplies [Tiller & Newsham, 1993]. Poor power quality may cause serious electrical problems in some installations. Various utilities and standards organizations are seeking standards to improve the power quality of electrical equipment. Targets are an upper limit on THD of, typically, 20 - 33 %, with PFs no lower than 0.9 [Gilleskie, 1993; CSA, 1992]. Our results show fax machines operate well outside these tolerances. Nevertheless, it is important to remember that fax machines are a very small fraction of the total building load, and improving their power quality would likely have an insignificant effect on power quality in the whole building.

4.2 Operating profiles

4.2.1 Weekly profiles

In section 3.2 we established that the range of transaction rates across our sample of fax machines indicates that it would be inaccurate to assume that any one fax machine is representative of the whole population of machines. Our analysis of weekly data indicated further that any single week's data from any particular fax machine is unlikely to be representative of the activity of that fax machine over a longer period. Some of the variability from week to week can be explained by a statutory holiday during Monday to Friday. For example, a number of machines (see Figures 5 (a), 5 (b), 5 (c), 5 (d), 5 (e), 5 (f)) show dips in activity for one or both of the weeks of April 11th and 18th, which might be explained by statutory holidays around Easter.

The weekly profiles established that the potential on-time savings with power management utilizing a 15 minute idle switching criterion are considerable. To translate these on-time savings into annual energy savings (Q_{saved}, kWh), we simply multiply the predicted on-time savings, extrapolated from 12 weeks to a year (T_{saved}, hours/year), by the machine idling power (P_{idle}, Watts), and divide by 1000[4]:

$$Q_{saved} = T_{saved} \bullet (P_{idle}/1000)$$

To further estimate the dollar value of these savings (C_{saved}, \$) we then multiply the energy savings by an appropriate electricity rate (E_{energy}, ¢/kWh) and divide by 100:

$$C_{saved} = T_{saved} \bullet (P_{idle}/1000) \bullet (E_{energy}/100)$$

Unfortunately, because most of the machines in the sample were located at great distances from our laboratory, getting idling power measurements for each of the machines was impossible. Therefore, to estimate energy and dollar savings, we chose a nominal idling power rate, based on the limited set of measurements recorded in Table 2, of 25 W. Obviously, savings estimates for a different power draw can easily be made by multiplying by an appropriate factor.

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[4] Note, we have assumed that when the machine is power managed due to inactivity its power draw drops to zero. In practice it might be necessary to maintain some "trickle" current to the machine to enable it to be available for immediate use.

Additionally, electricity rates vary by region, customer, total billed energy, and a number of other factors. Therefore, for the sake of simplicity, we chose a nominal electricity rate of 10 ¢/kWh (0.10 $/kWh). While this may be high for most commercial sites in Canada, it may not be inappropriate for other world locations. Obviously, savings estimates for a different electricity rate can easily be made by multiplying by an appropriate factor.

Note that we have made no attempt to account for associated savings in peak electrical demand or reduced HVAC load. While energy savings at the fax machine appear directly on the meter, peak electrical demand and HVAC loads depend heavily on what other equipment is in the building, utility billing structures, system characteristics, and a whole host of other site specific parameters. The kind of detailed, site-specific analysis necessary to assess these parameters was beyond the scope of this study. At any rate, the power density of fax machines is obviously so low that it is unlikely they will have a significant effect on whole building electrical demand or HVAC operation.

Table 6 summarizes the savings calculations, for each of the three sub-samples, and for the whole sample taken together.

The predicted savings, for the assumed idling power and electricity rate, are between $ 15 and $ 21 per year, depending on the transaction rate. From this figure we can calculate what the capital cost of power management must be in order to meet a given pay-back period. For example, if a simple pay-back period of 3 years is required, any retrofit power management device for fax machines should cost no more than $ 45 to $ 60. A similar limitation should be applied to the incremental cost of building power management into new fax machines. Naturally, what is considered a reasonable pay-back period for energy-efficiency capital investment is another site specific parameter.[5]

Table 6. Annual on-time, energy and dollar savings for fax machines, by sub-sample, extrapolated from 12 week activity measurements.

Fax Machines	T_{saved} (hours)	P_{idle} (W)	Q_{saved} (kWh)	E_{energy} (¢/kWh)	C_{saved} ($)
sub-sample "A"	6097	25	152.4	10	15.24
sub-sample "B"	7698	25	192.5	10	19.25
sub-sample "C"	8284	25	207.1	10	20.71
Grand mean	7567	25	189.2	10	18.92

Fax machines with built-in power management are appearing on the market [Dandridge, 1994], and more will surely follow if Energy Star or similar guidelines are

[5] Note that a 15 minute switching criterion might be conservative. For the lower use machines it might be reasonable for the fax machine to enter a sleep mode almost as soon as a transaction is complete. In this case on-time would approach active time (Table 4) and the savings potential of power management would be greater than that shown in Table 6.

extended to encompass fax machines. In addition, at least one retrofit power management device for stand-alone fax machines already exists [Zemos, 1993]. However, its cost of U.S. $ 100 suggests its pay-back in energy savings may be a little too long for most applications. Feedback [1994] describes a retrofit device to power manage fax modems, eliminating the need to leave a PC on 24 hours a day to receive faxes. Though its price seems high (U.K. £ 200) one should remember it controls a relatively high power PC rather than a low power fax machine.

4.2.2 Hourly profiles

Figure 7 (a) indicates that even for the highest use machines, fax transactions overnight were rare; mean activity rate in the middle of the night being around 1 minute per hour. However, there is significant transaction activity in the early morning and early evening, with activity picking up at around 5 am, and not reaching "background" levels again until 8 pm. Considerable on-time (and therefore energy) could be saved during the night with automatic power management with a 15 minute inactivity switching criterion. However, on-time during the day for these busy machines would remain at around 50 minutes per hour; because of the high transaction rate, there are relatively few extensive idle periods during the working day.

Figure 7 (b) shows the transaction activity in more detail. Differences between the hourly profiles of the transmission and reception activity are evident. Transmission activity clearly depends on the schedules of the occupants of the office in which the host fax machine is located. If the occupants work traditional office hours, then the transmission activity will be largely limited to these hours. Figure 7 (b) shows virtually no transmissions overnight, with transmission activity picking up around 7 am as some occupants arrive, and peaking in the morning around 10 am, by which time, presumably, all the occupants would have arrived. There is a dip in transmission activity with a minimum at 1 pm, indicating a decline in office activity over lunch. Transmission activity increases after lunch to a maximum at 3 pm, and then falls off again; some activity at 6 and 7 pm results from "after hours" work. This profile is very similar to that observed in studies of computer keyboard activity [Tiller & Newsham, 1993].

In contrast, the time at which faxes are received depends on the schedules of workers in the offices from which the faxes were sent ("remote offices"). If these offices are predominantly in the same time zone, the reception activity should have a profile similar to that of transmission activity. If, on the other hand, the remote offices are predominantly in different time zones, the reception profile might be quite different to the transmission profile, as it would super-impose schedules at various remote offices. Figure 7 (b) shows reception picking up as early at 5 am. This can be explained by the fact that of the 7 machines in sub-sample "A" 5 were on the west coast of the U.S. (the other 2 being in Ontario, Canada). The majority of the faxes received from other time zones would presumably come from U.S. cities further east, particularly cities in the Eastern U.S. time zone, which is three hours ahead of the west coast -- therefore, 5 am on the west coast is 8 am on the east coast, Figure 7 (b) shows that at 8 am (local time) transmission activity is already half-way to its morning peak. Reception activity peaks at 1 pm, 1 pm on the west coast is 4 pm on the east coast, and 4 pm is when we observe close to peak transmission activity.

Figure 8 (a) indicates that, amongst sub-sample "B", fax transactions overnight were rare. Compared to sub-sample "A", transaction activity in the early morning and early evening was also curtailed, with activity not picking up until 8 am. Considerable on-time (and therefore energy) could be saved during the night and day with automatic power management with a 15 minute inactivity switching criterion, on-time during the day being reduced to less than 30 minutes per hour.

Figure 8 (b) shows no differences in the form of the hourly transmission and reception activity profiles. The reception profile follows the same traditional office schedule as the transmission profile. This likely indicates that for the intermediate transaction activity machines of sub-sample "B", most of the remote fax machines were in the same time zone as the receiver. If the remote machines were in many different time zones, the reception activity profile would have been "smoothed out" over the day, with a less evident dip at lunchtime, and activity in early morning and early evening. However, since we did not collect specific data on the locations of remote machines, we cannot answer this question unequivocally.

Figure 9 (a) indicates that, amongst sub-sample "C", fax transactions overnight were rare. Compared to sub-samples "A" and "B", transaction activity in the early morning and early evening was also curtailed, with activity not picking up until 9 am, and dropping to almost zero by 6 pm. Considerable on-time (and therefore energy) could be saved during both night and day with automatic power management with a 15 minute inactivity switching criterion, on-time during the day being reduced to less than 15 minutes per hour.

Figure 9 (b) shows no differences in the form of the hourly transmission and reception activity profiles. As with sub-sample "B", the reception profile follows the same traditional office schedule as the transmission profile. This likely indicates that for the lowest transaction activity machines of sub-sample "C", most of the remote fax machines were in the same time zone as the receiver.

4.2.3 Transmission to reception ratio

An indicator of the representativeness of the sample of 32 machines to the worldwide population of fax machines is the ratio of the number of transmitted pages to received pages. If we had a closed sample of fax machines, where all the machine transactions were with other machines in the sample, then the number of transmitted pages would be equal to the number of pages received. Therefore, if we were able to monitor all the fax machines in the world, the number of transmitted pages would be equal to the number of pages received. It follows that any sample of machines which seeks to be representative of the world population should approach the ideal of equal numbers of transmitted and received pages. For the sample of 32 machines in this study the total number of pages transmitted on all days of the 12 week period was 89,205, and the total number received was 94,281. This amounts to a discrepancy from equality of only 2.8 %:

$$(94{,}281 - 89{,}205) / (94{,}281 + 89{,}205) = 2.8\ \%$$

Therefore, our sample of 32 machines would appear to be representative of the general population of machines, at least for the this rough indicator of representativeness.

Interestingly, we might expect the number of receptions to exceed the number of transmissions, even in a closed system. This is due to the use of fax modems, likely to displace stand-alone fax machine transmissions in preference to receptions.

4.2.4 Pages/transaction

A further, stronger, indicator of representativeness is the frequency distribution of pages/transaction in the transmit and receive mode. For the world population, the distributions in transmit and receive modes should be identical. Figure 10 shows the distributions for our sample of 32 machines. The distributions are indeed observed to be very similar. This further, though still rudimentary, indicator of representativeness indicates that our sample of 32 machines is representative of the general population of machines.

The data on pages/transaction can be presented by sub-sample to investigate differences across sub-samples. Figure 11 (a) demonstrates that the normalized frequency distribution of the number of pages/reception is very similar across sub-samples. The normalized frequency distribution of the number of pages/transmission is also similar across sub-samples, as shown in Figure 11 (b). There is a tendency toward shorter transmissions in the highest use sub-sample ("A"), though overall there is little evidence that more frequent faxing means shorter length faxes.

4.2.5 Error rate and cover pages

If we assume that a zero ("0") page transaction indicates a transaction error, then Figure 10 provides information on error rates during faxing. Of a total of 55,355 observed transactions, there were 5,169 zero page transactions, or an error rate of 9.3 %. This is significant since transaction errors can waste employee time, boost telephone charges, and increase paper and electricity consumption. Errors can be due to the operator or the function of the machine. While it was not within the scope of this project to identify the causes of faxing errors in any greater detail, this may be an area worthy of further investigation.

The data of Figure 10 also allow us to speculate on the implications of the use of cover sheets for fax messages. If we assume that every transaction of 2 or more pages used a cover sheet, then we can estimate the maximum potential for savings through replacing cover sheets with stick-on labels. We observed 43,498 transactions of 2 or more pages, therefore, up to 43,498 cover sheets could have been saved. There were a total of 183,486 observed faxed pages, meaning that up to 23.8 % of faxed pages are cover sheets. In other words, almost one-quarter of transaction time, with its attendant electricity and telephone costs, could be saved by eliminating the cover page and replacing it with a stick-on label; almost one-quarter of the paper consumed by fax operations could also be saved. This potential source of savings was recognized by Haggett [1993].[6] The figure of 23.8 % is clearly an upper estiimate since some users in our sample might already be in the habit of using stick-on labels. Although more detailed investigation of cover sheet use was outside the scope of this study, it clearly warrants further investigation.

5. Conclusions

The main conclusions drawn from this study are:

- Fax machines, like other electronic office equipment, draw considerably less power than their nameplate rating, and exhibit poor power quality. Our measurements on a small sample of machines showed that when idle, they drew between 7 and 30 % of nameplate rated power, with power factors around 0.5 and total harmonic distortion in the current of over 150 %.

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[6] Another option, which saves only the paper consumed by cover sheets, is a re-usable, plastic laminate cover sheet [Picton, 1994].

- Fax machines are generally active for only a small fraction of the time they are switched on. Thirty-two machines over a 12 week period were active for an average of only 3.7 % of the time they were switched on. However, there was considerable variation about this mean; active time ranged between 18.2 % and 0.2 % of on-time.

- The above result suggests the potential for energy savings through power management: an average of 86.4 % of on-time could be eliminated by automatically switching the fax machine into a sleep mode after 15 minutes of inactivity.

- The dollar value of such power management depends on a number of site-specific parameters. Assuming an electricity rate of 10 ¢/kWh and a fax machine power draw of 25 W, power management could realize savings of around $ 19 per fax machine per year.

- Given a three year pay-back criterion for energy-efficient retrofit, an add-on device for power managing fax machines should cost no more than $ 60.

- Around 9.3 % of fax transactions failed due to transaction errors. Reducing this error rate could save employee time, telephone charges, paper, and energy consumption.

- Up to 23.8 % of faxed pages may have been cover sheets. Efforts to reduce the use of cover sheets, perhaps by replacing them with a stick-on label, could realize additional energy and paper savings, and reduce telephone charges.

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ACTIVITY REPORT

DATE/TIME 7-13-94 10:14AM
LOCAL TERMINAL ID.
LOCAL NAME
COMPANY LOGO Building Performance

*** SEND ***

No.	REMOTE STATION	START TIME	DURATION	#PAGES	MODE	RESULTS
1		7- 6-94 2:50PM	4'08"	6/ 6	EC	COMPLETED 9600
2		3:08PM	0'38"	1/ 1	EC	COMPLETED 14400
3		3:17PM	0'00"	0/ 6		CALL UNSUCCESSFUL 0P67 002C
4		3:36PM	0'00"	0/ 6		
5		3:41PM	2'19"	3/ 3		COMPLETED 9600
6		3:44PM	2'43"	6/ 6	EC	COMPLETED 14400
7		3:51PM	2'34"	6/ 6	EC	COMPLETED 14400
8		3:56PM	2'39"	6/ 6	EC	COMPLETED 14400
9		4:01PM	3'39"	6/ 6	EC	COMPLETED 9600
10		4:16PM	0'00"	0/ 6		
11		4:17PM	2'34"	6/ 6	EC	COMPLETED 14400
12		4:20PM	4'35"	7/ 7	EC	COMPLETED 9600
13		4:32PM	2'53"	6/ 6	EC	COMPLETED 14400
14		7- 7-94 10:02AM	0'40"	1/ 1	EC	COMPLETED 9600
15		11:43AM	4'30"	6/ 6	EC	COMPLETED 9600
16		12:01PM	0'53"	1/ 1		COMPLETED 9600
17		2:59PM	0'00"	0/ 7		
18		3:01PM	3'48"	7/ 7	EC	COMPLETED 9600
19		3:11PM	0'00"	0/ 7		TERMINAL FAULT 0P66 002D
20		4:03PM	0'54"	1/ 1		COMPLETED 9600
21		4:52PM	0'50"	1/ 1		COMPLETED 9600
22		5:23PM	0'40"	1/ 1	EC	COMPLETED 9600
23		5:56PM	0'58"	2/ 2	EC	COMPLETED 12000
24		7- 8-94 8:45AM	1'49"	3/ 3	EC	COMPLETED 14400
25		9:40AM	4'58"	10/ 10	EC	COMPLETED 9600
26		11:04AM	0'29"	1/ 1	EC	COMPLETED 14400
27		3:41PM	2'14"	3/ 3		COMPLETED 9600
28		4:07PM	1'30"	2/ 2		COMPLETED 9600
29		5:04PM	0'00"	0/ 2		
30		5:06PM	1'14"	2/ 2	EC	COMPLETED 9600
31		8:28PM	1'11"	2/ 2	EC	COMPLETED 9600
32		7-10-94 2:38PM	2'19"	3/ 5	EC	COMMUNICATION ERROR E204

Figure 1. An example fax machine activity report.

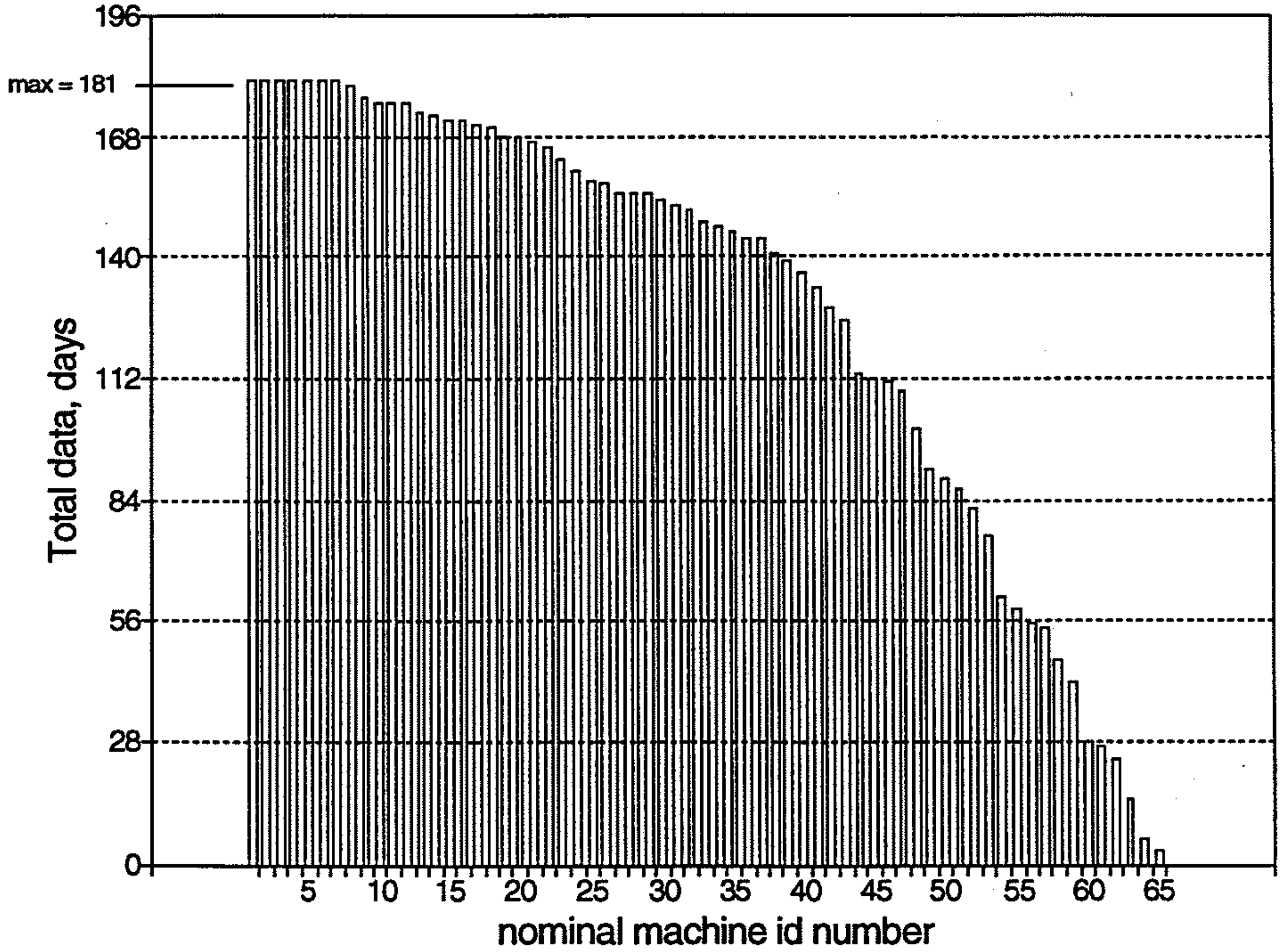

Figure 2. The number of days of data received for each fax machine; the machines are ordered according to the number of days of data supplied.

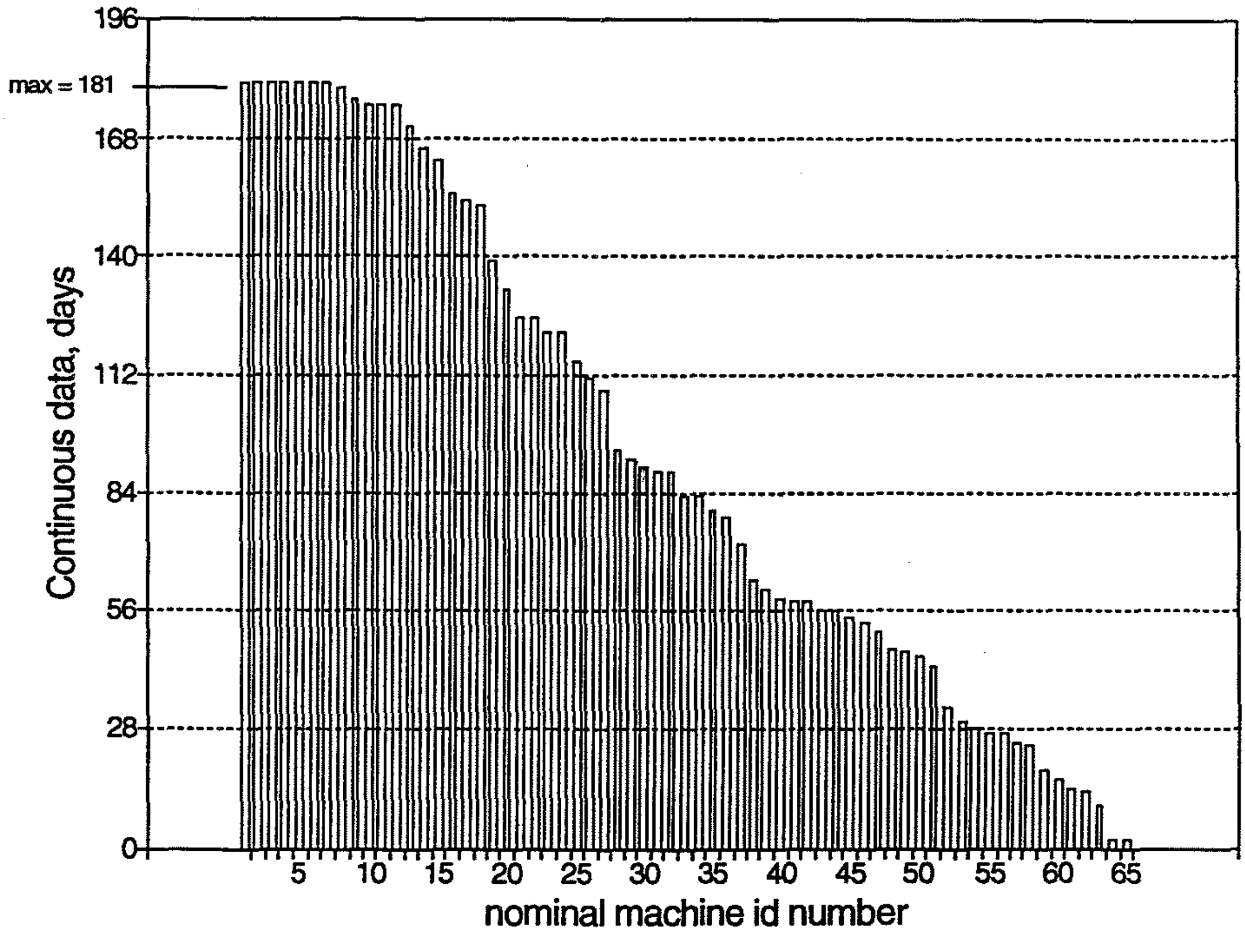

Figure 3. The longest string of continuous days of data for each fax machine; the machines are ordered according to the number of days of continuous data available.

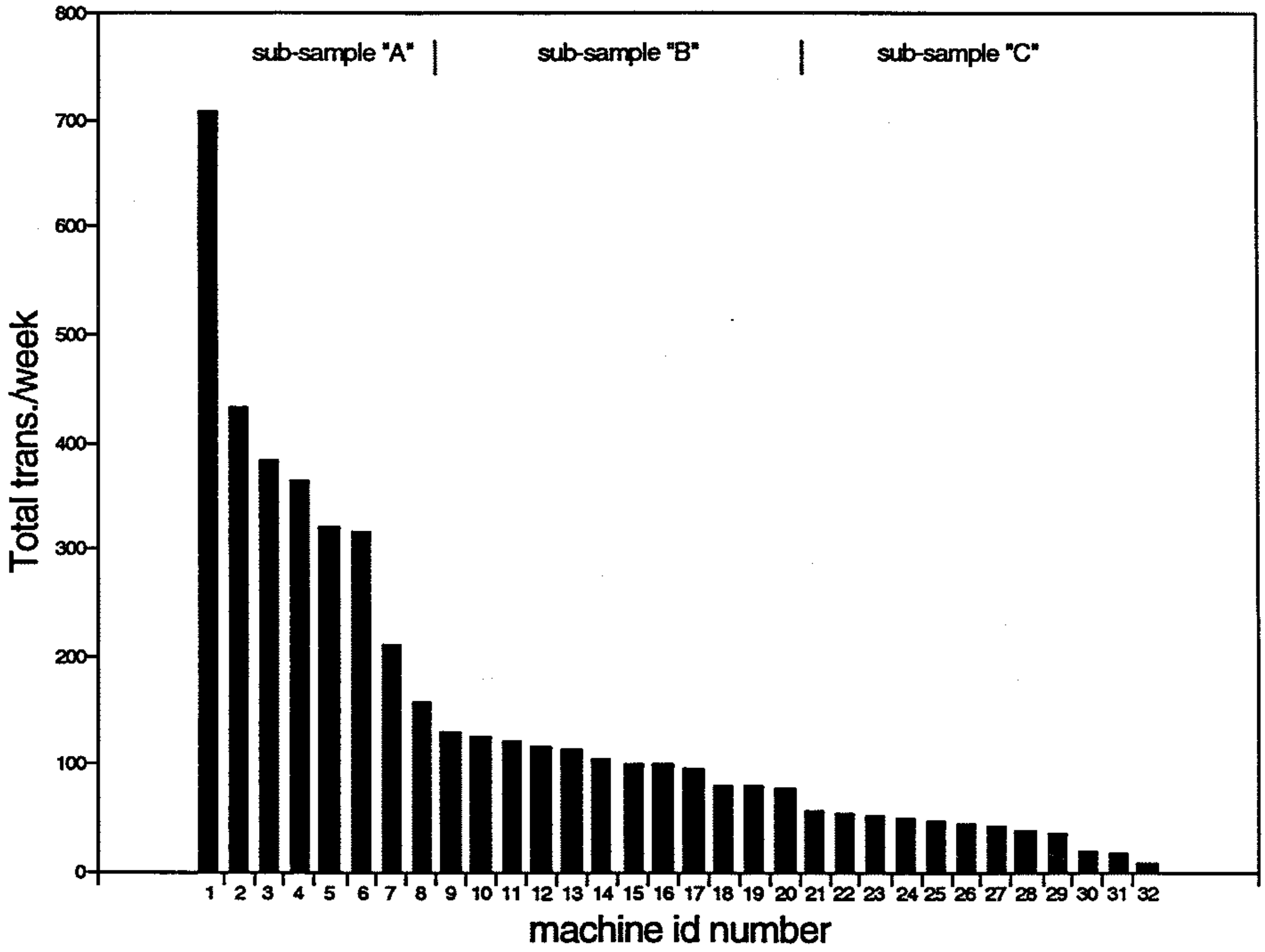

Figure 4. The measured distribution of transactions/week over the full 12 week period for the sample of 32 machines; the machines are ordered according to transaction rate.

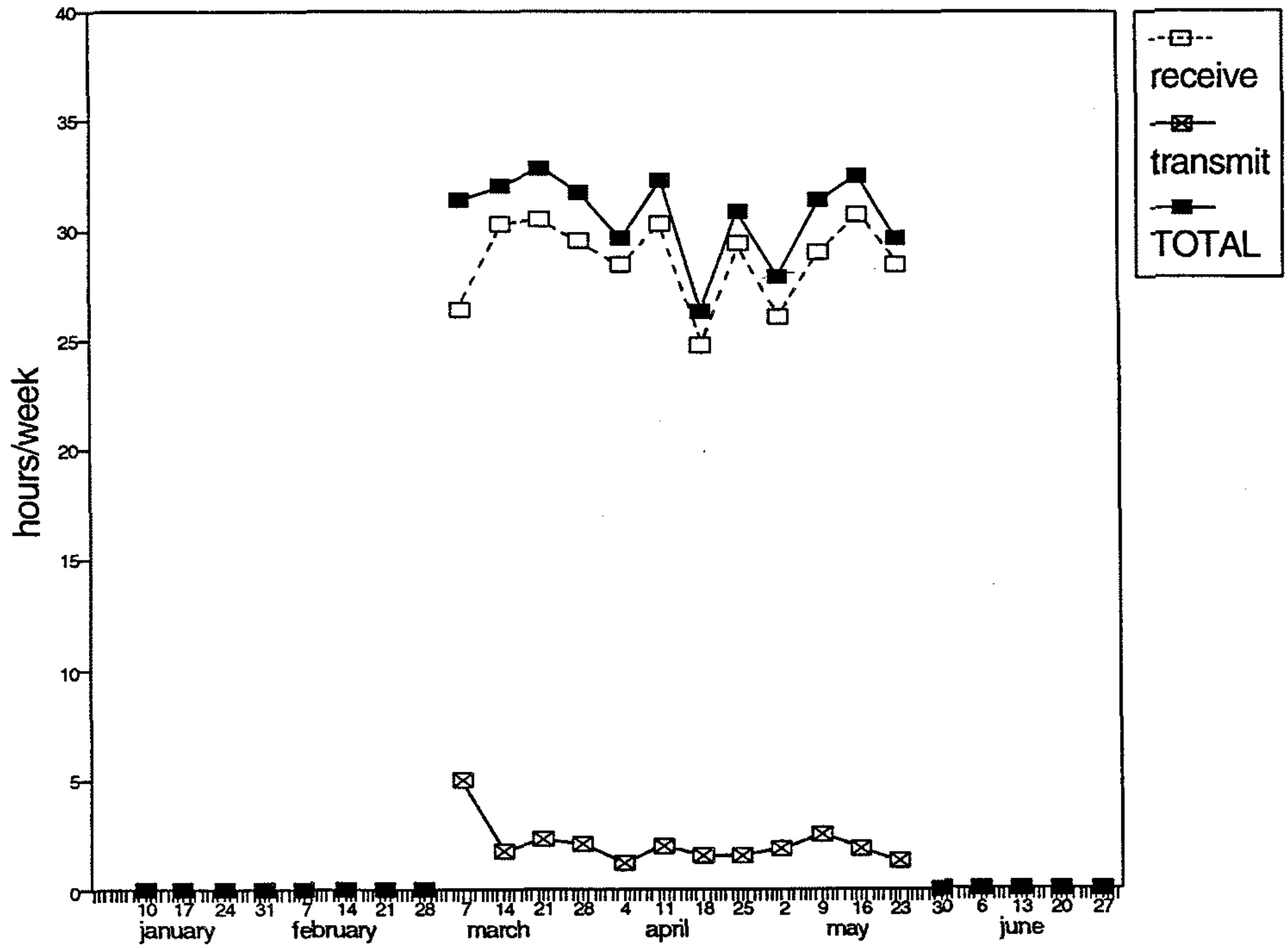

Figure 5 (a). Weekly transaction activity for fax machine 1. Each point represents mean activity over the previous week; points on the x-axis represent weeks with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

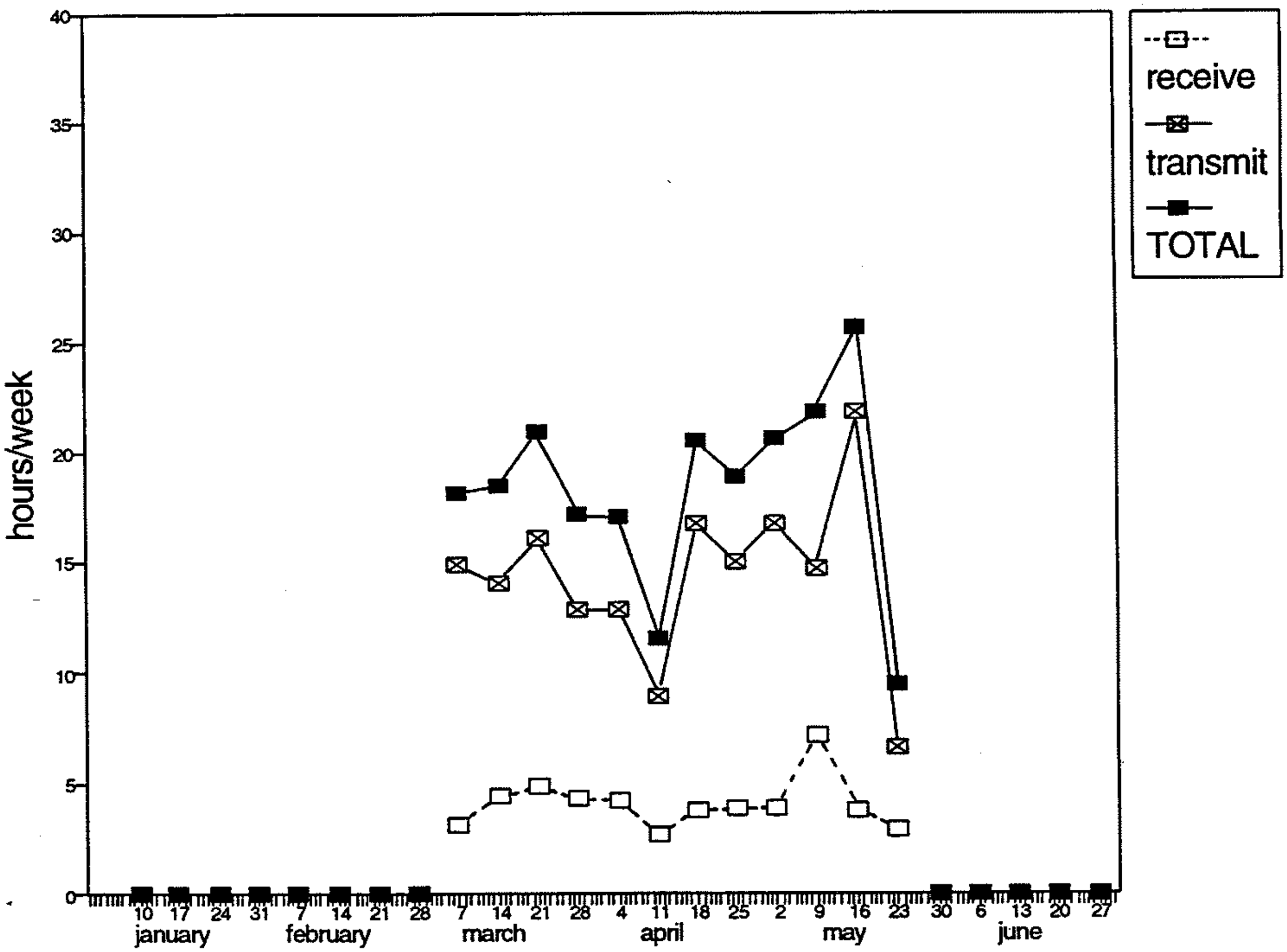

Figure 5 (b). Weekly transaction activity for fax machine 4. Each point represents mean activity over the previous week; points on the x-axis represent weeks with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

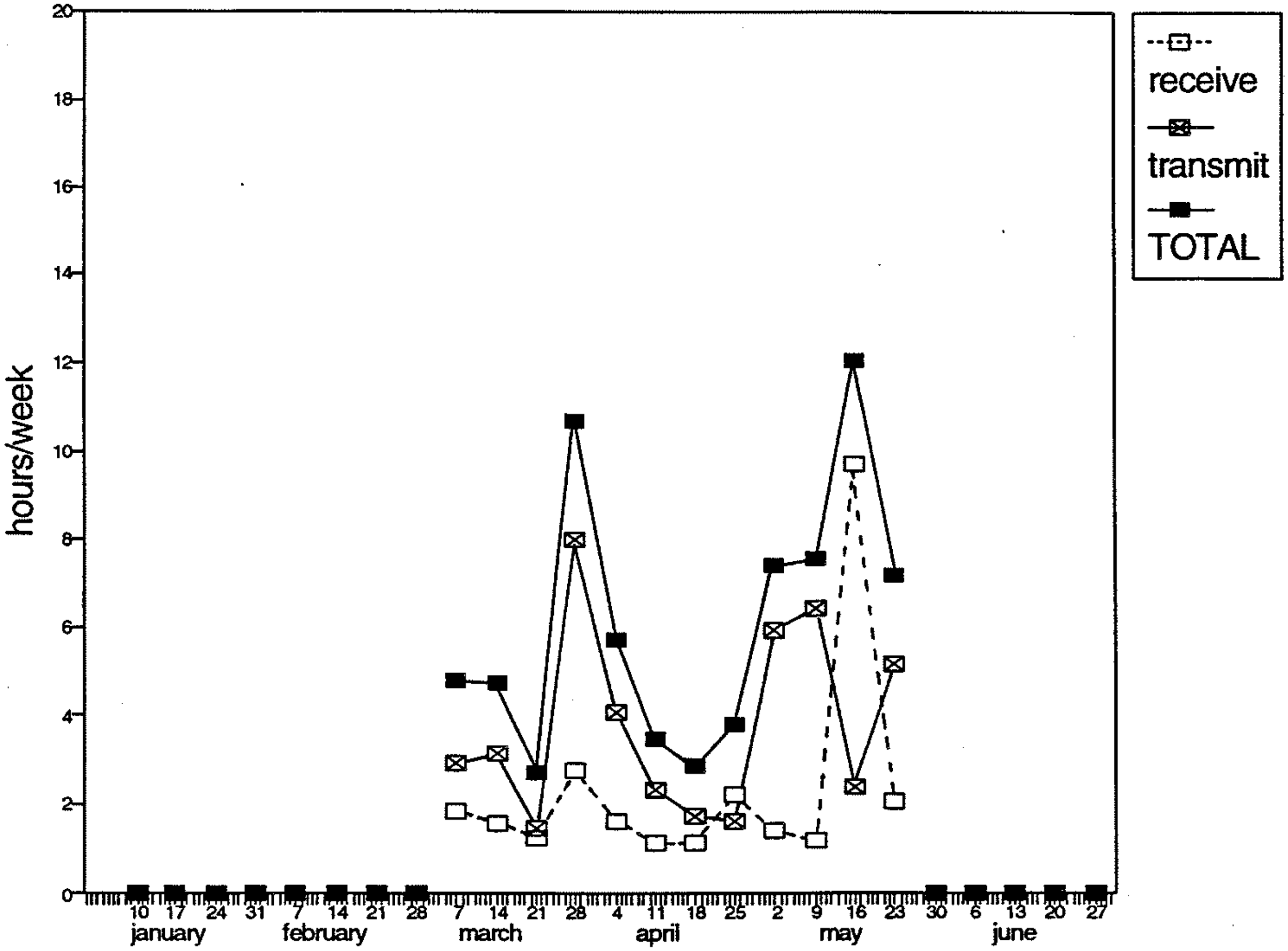

Figure 5 (c). Weekly transaction activity for fax machine 9. Each point represents mean activity over the previous week; points on the x-axis represent weeks for with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

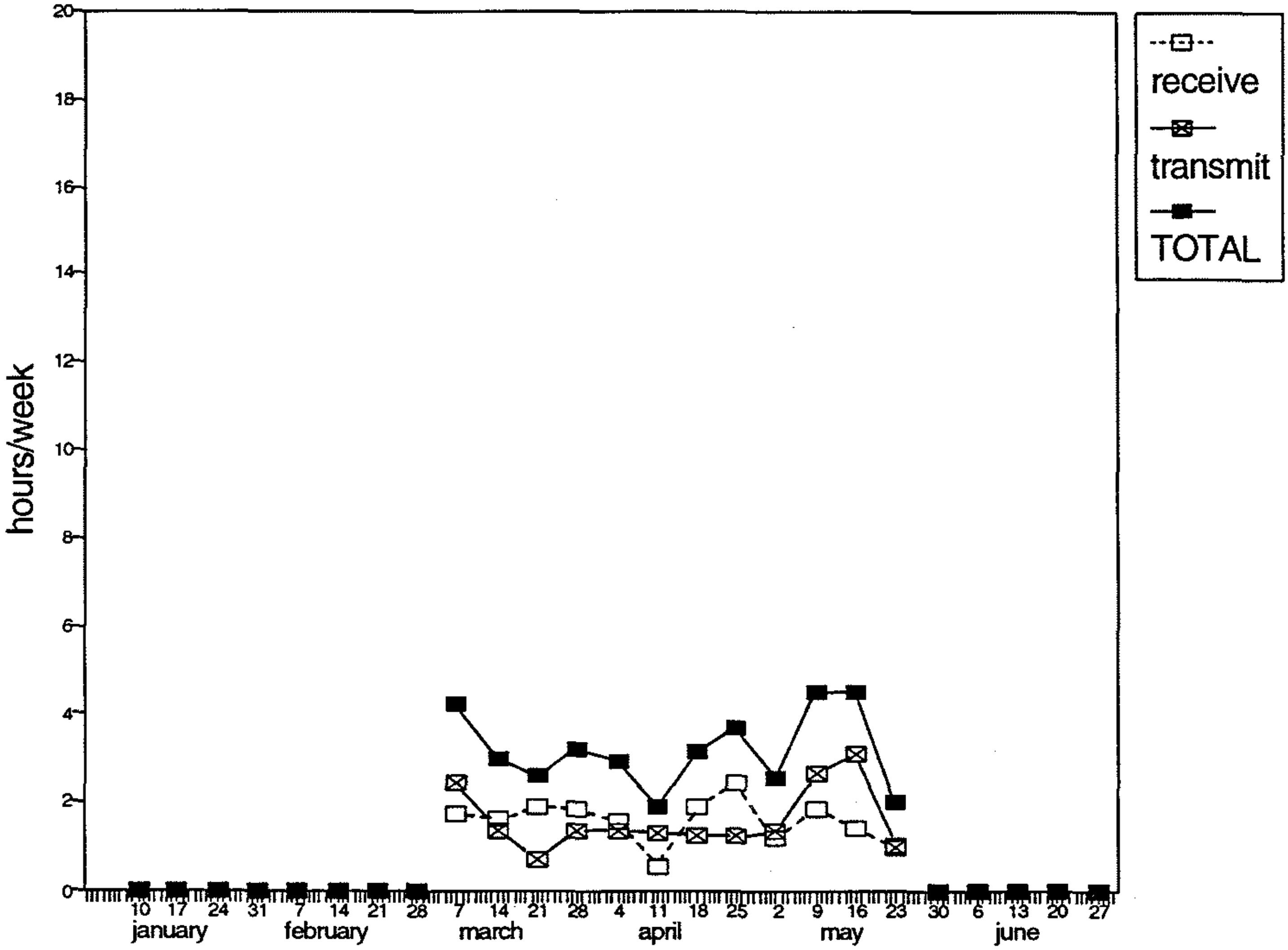

Figure 5 (d). Weekly transaction activity for fax machine 17. Each point represents mean activity over the previous week; points on the x-axis represent weeks with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

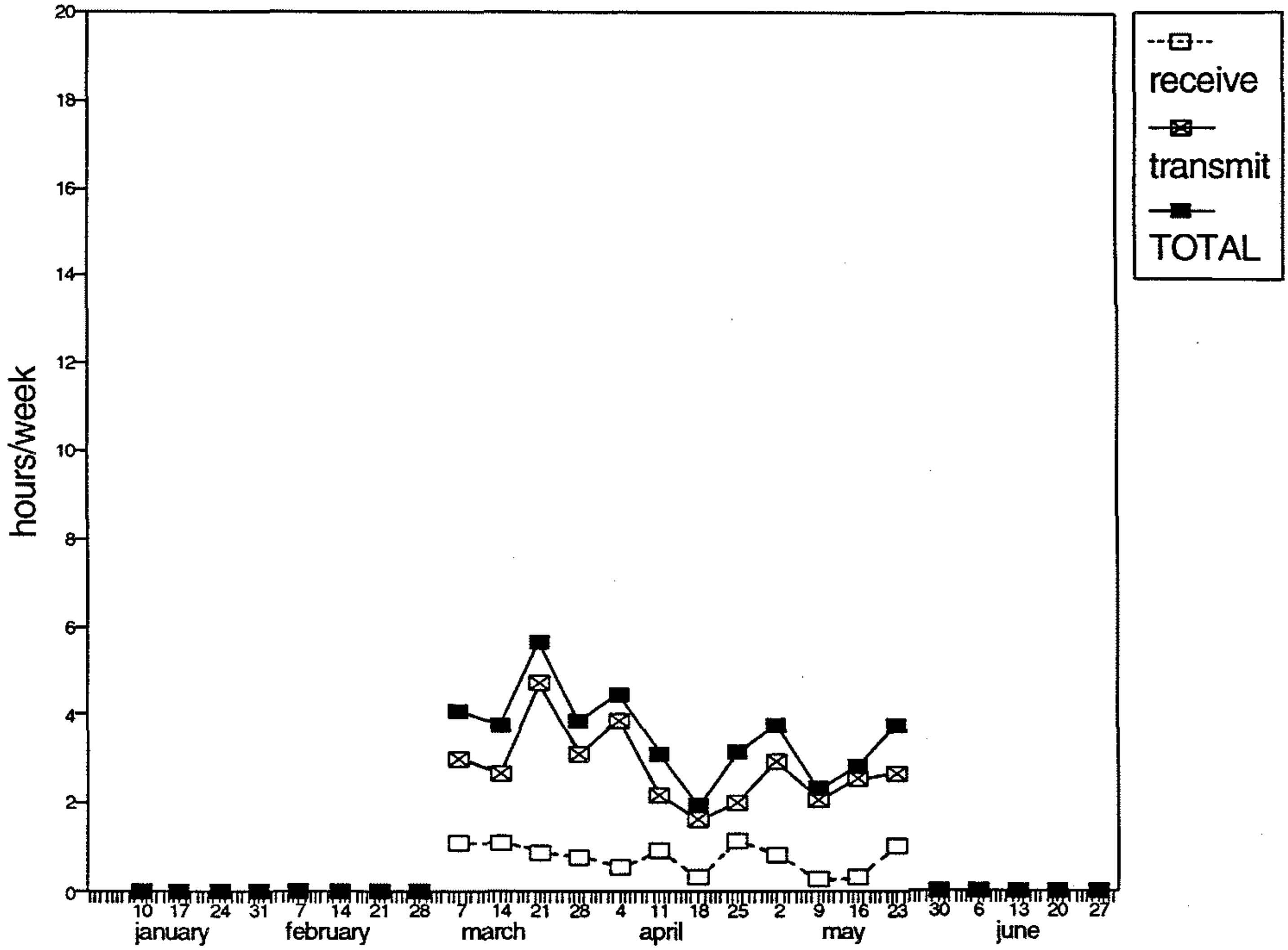

Figure 5 (e). Weekly transaction activity for fax machine 20. Each point represents mean activity over the previous week; points on the x-axis represent weeks with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

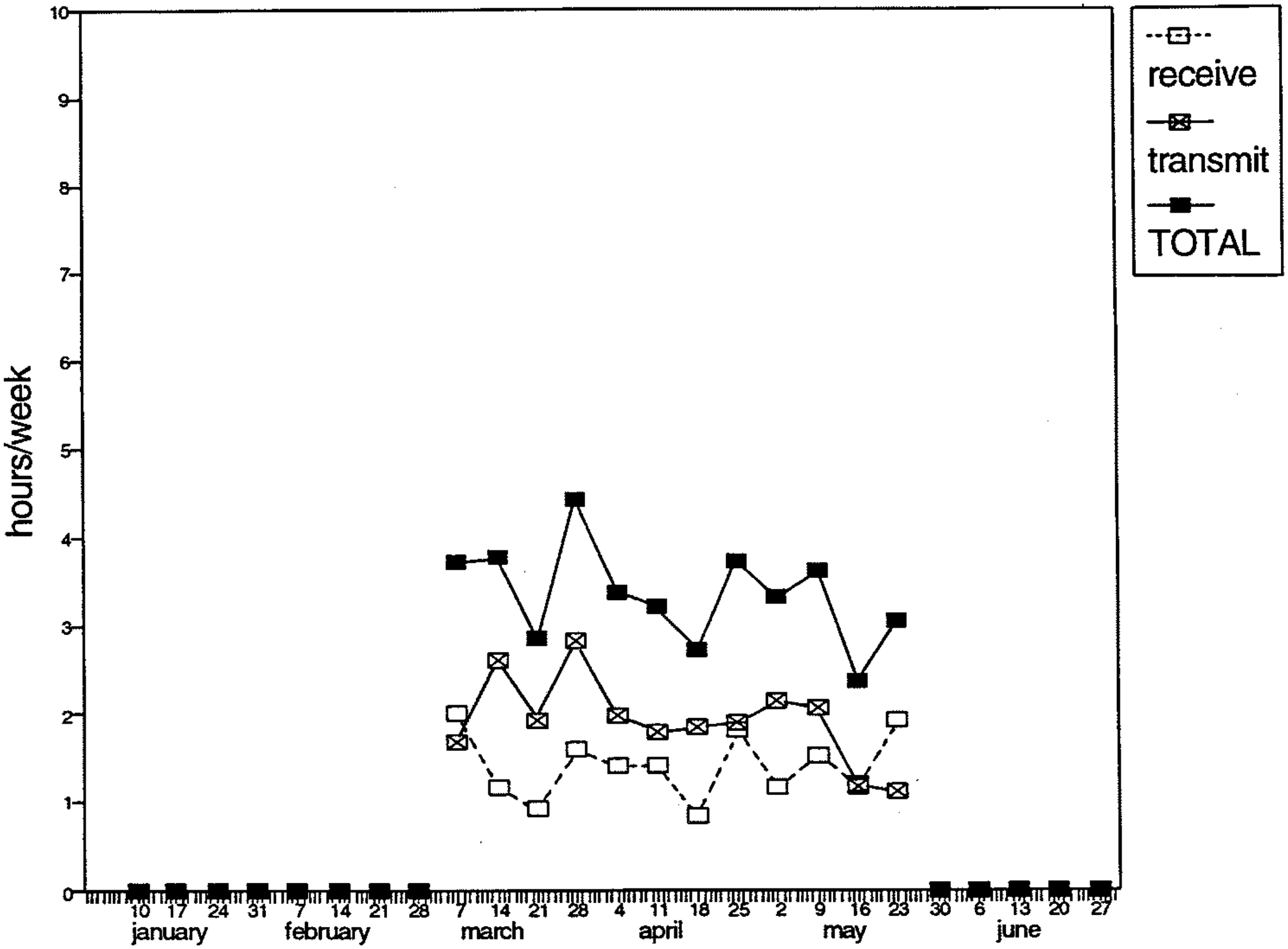

Figure 5 (f). Weekly transaction activity for fax machine 21. Each point represents mean activity over the previous week; points on the x-axis represent weeks with no data. The upper curve is the total transaction activity, and is the sum of the two curves below it, which plot weekly transmission and reception activity separately.

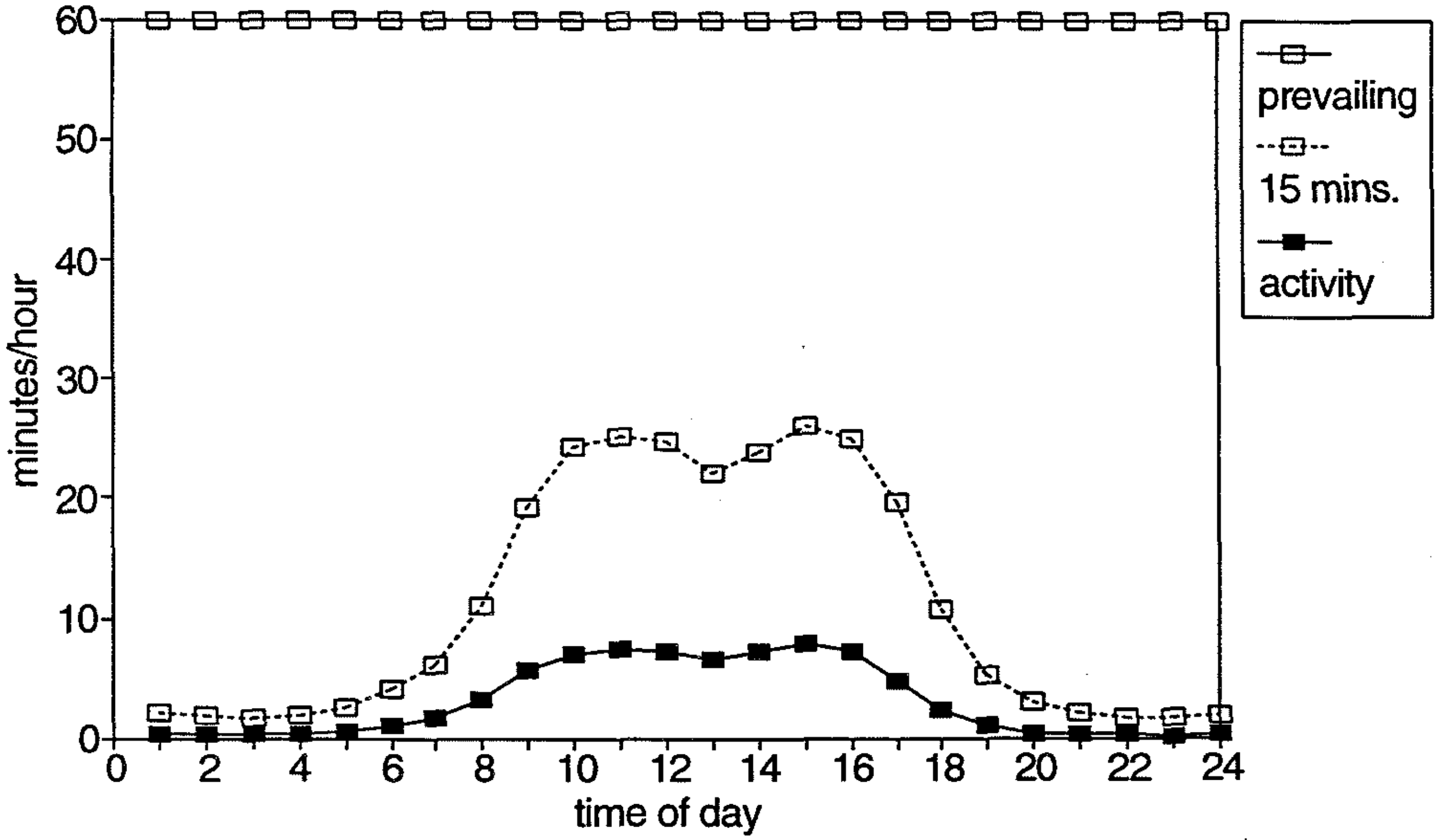

Figure 6 (a). Mean hourly fax use profile over all 32 machines and 60 weekdays in the 12 week period. The upper curve is the assumed prevailing on-time, in minutes per hour. The lower curve shows the mean minutes per hour for which there was activity. The middle curve shows the predicted mean on-time if power management automatically switched off fax machines after 15 minutes of inactivity.

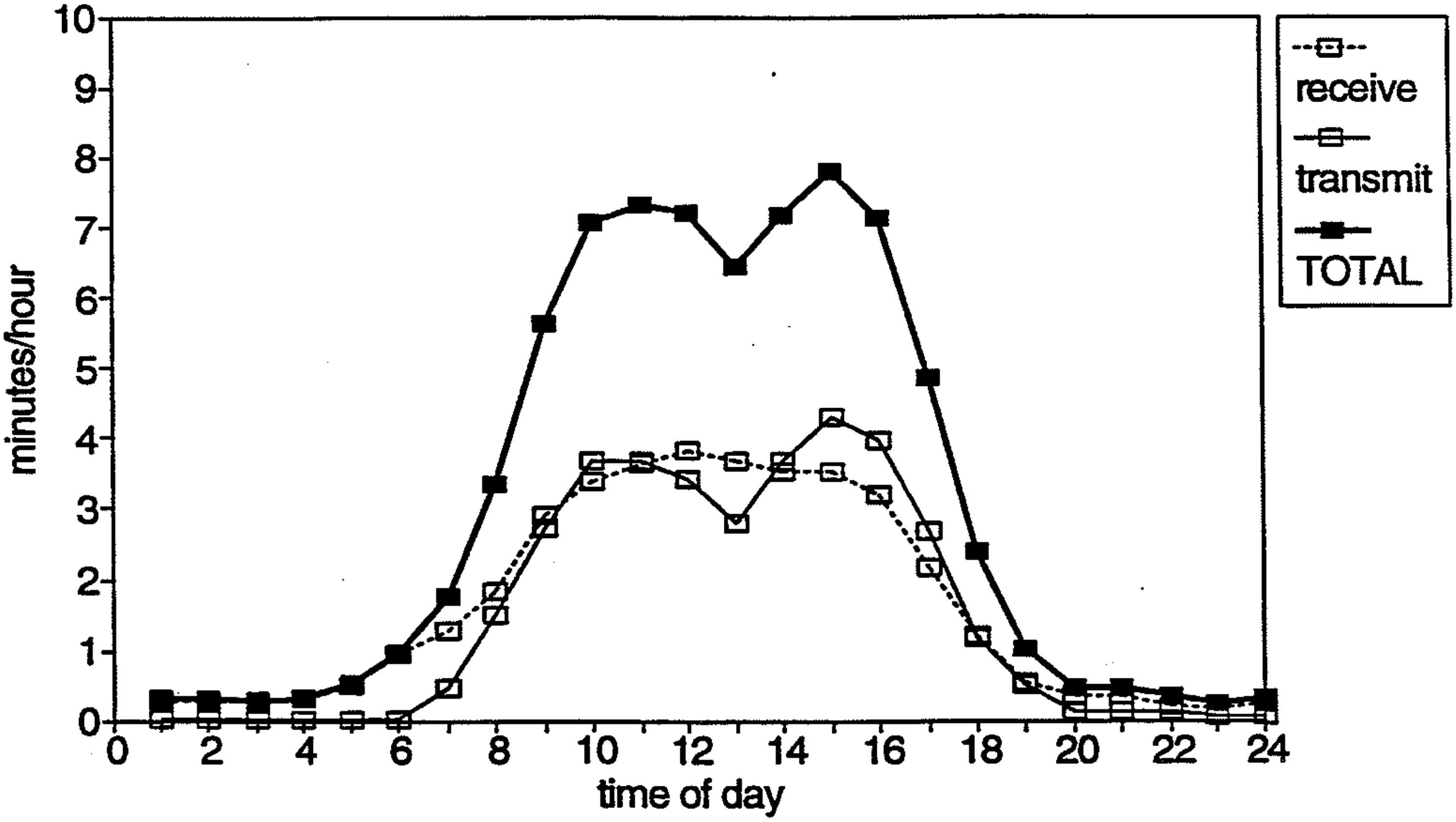

Figure 6 (b). Mean hourly transaction activity over all 32 machines and 60 weekdays in the 12 week period. The upper curve represents mean transaction activity, and is the sum of the two curves below it, which plot mean hourly transmission and reception activity separately.

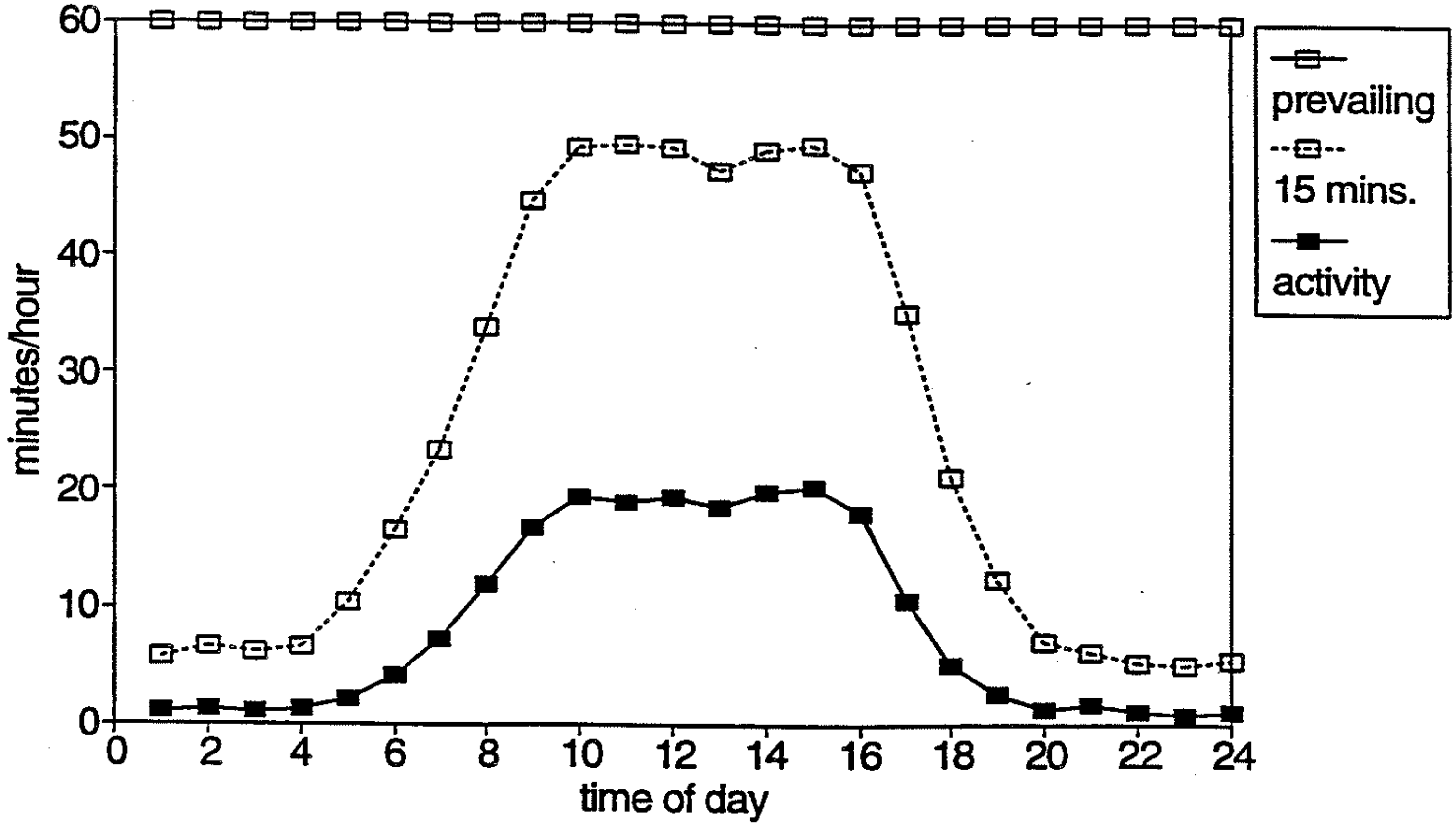

Figure 7 (a). Mean hourly fax use profile for sub-sample "A" over all 60 weekdays in the 12 week period. The upper curve is the assumed prevailing on-time, in minutes per hour. The lower curve shows the mean minutes per hour for which there was activity. The middle curve shows the predicted mean on-time if power management automatically switched off fax machines after 15 minutes of inactivity.

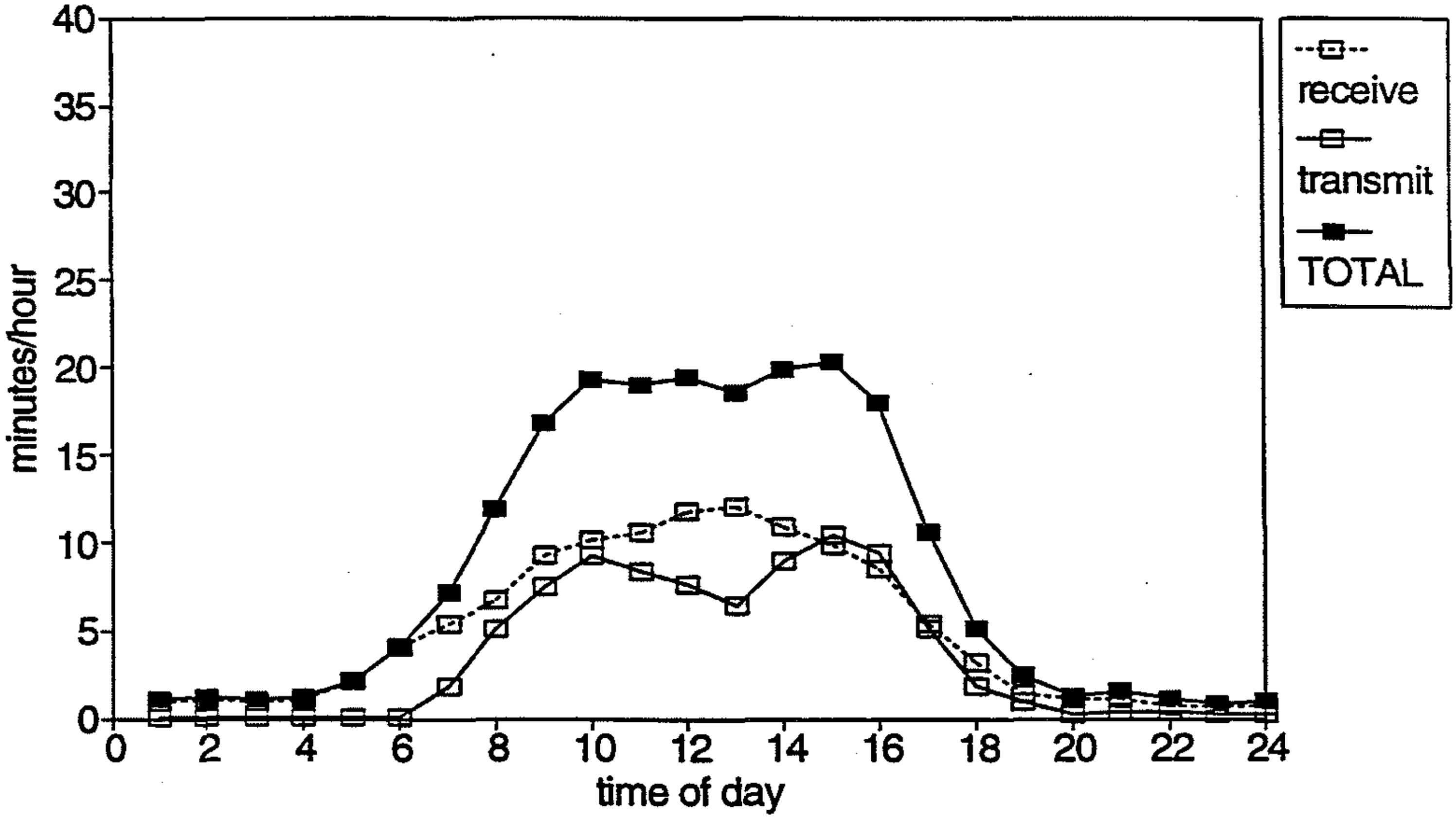

Figure 7 (b). Mean hourly transaction activity for sub-sample "A" over all 60 weekdays in the 12 week period. The upper curve represents mean transaction activity, and is the sum of the two curves below it, which plot mean hourly transmission and reception activity separately.

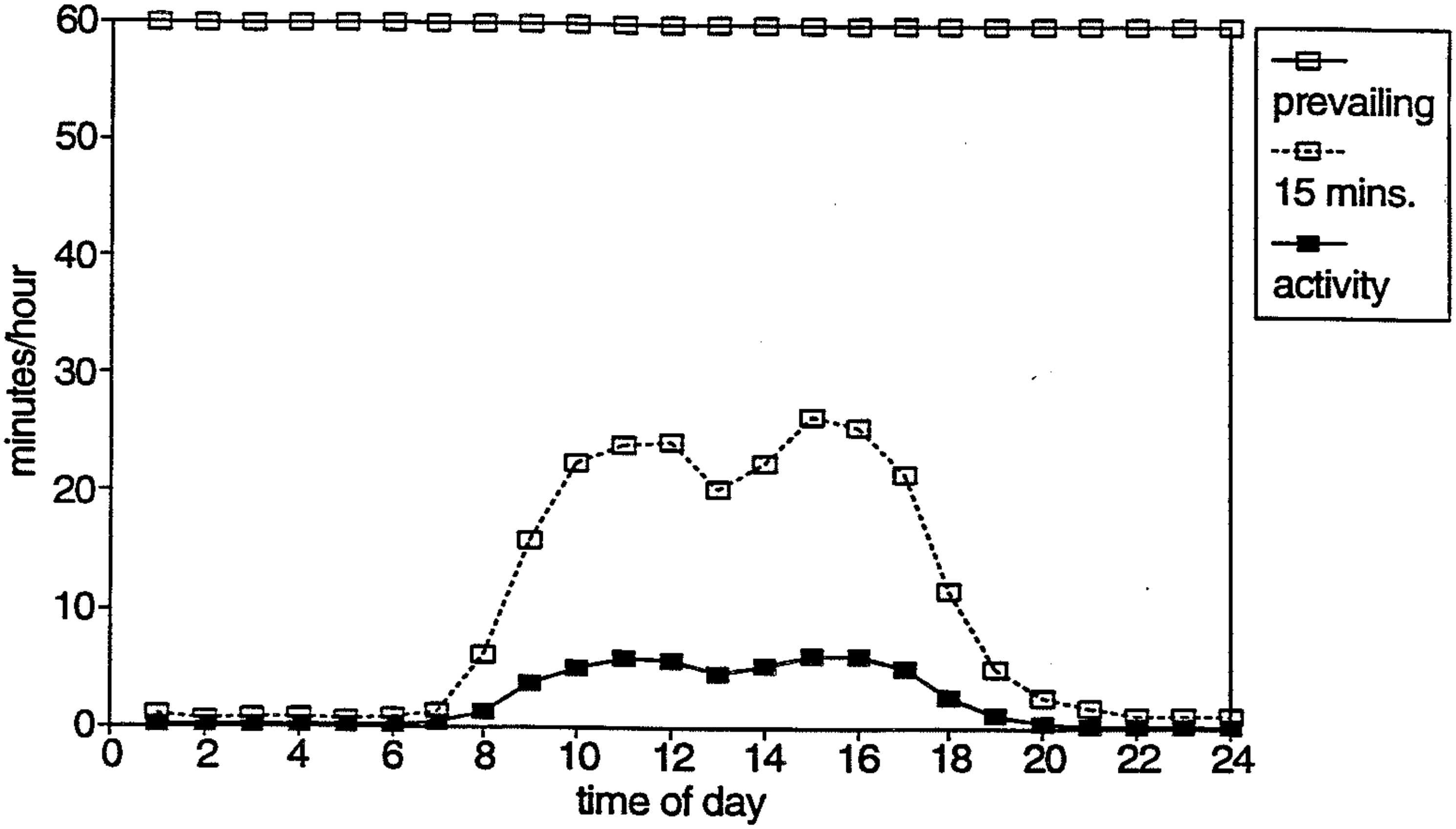

Figure 8 (a). Mean hourly fax use profile for sub-sample "B" over all 60 weekdays in the 12 week period. The upper curve is the assumed prevailing on-time, in minutes per hour. The lower curve shows the mean minutes per hour for which there was activity. The middle curve shows the predicted mean on-time if power management automatically switched off fax machines after 15 minutes of inactivity.

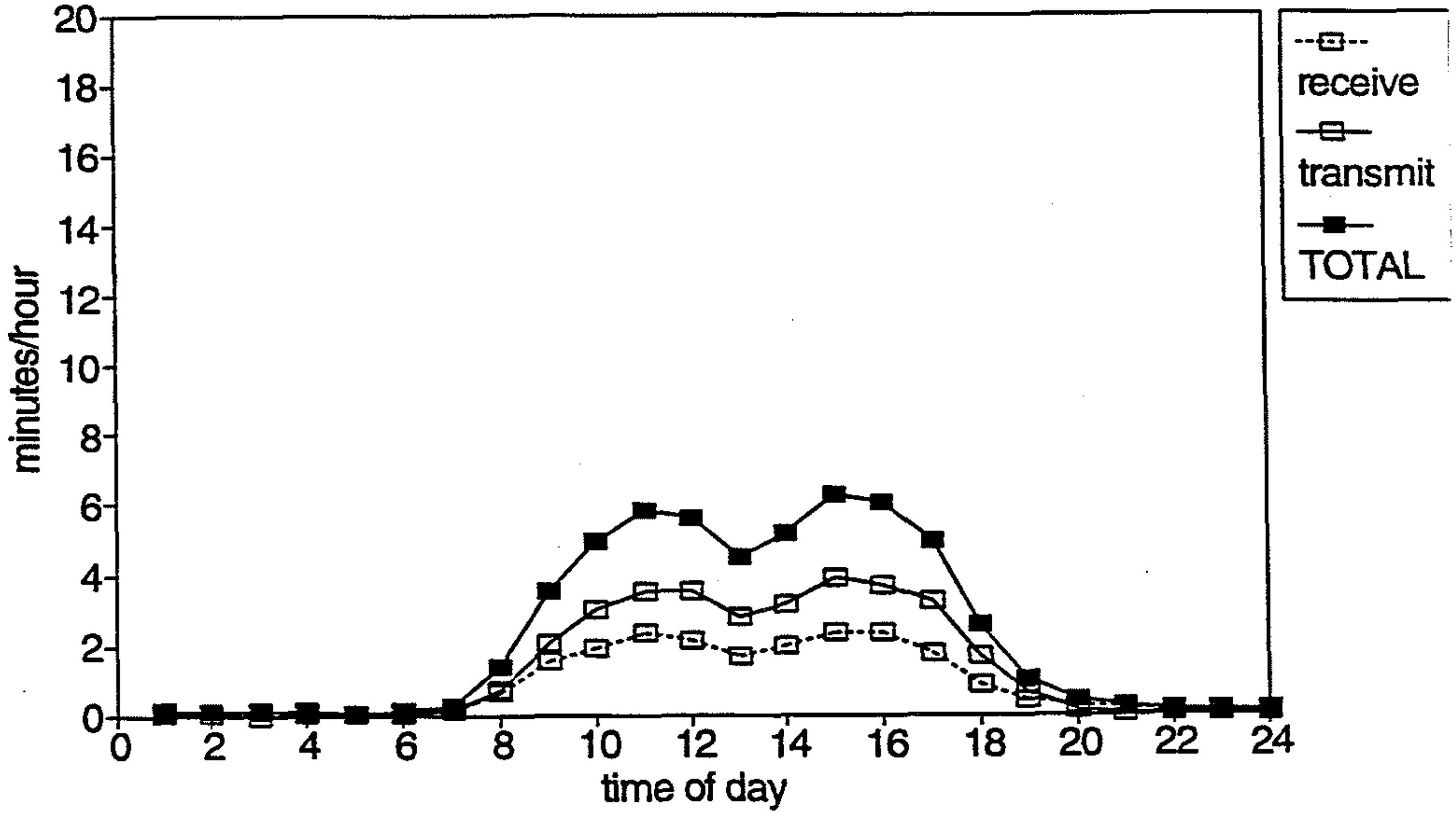

Figure 8 (b). Mean hourly transaction activity for sub-sample "B" over all 60 weekdays in the 12 week period. The upper curve represents mean transaction activity, and is the sum of the two curves below it, which plot mean hourly transmission and reception activity separately.

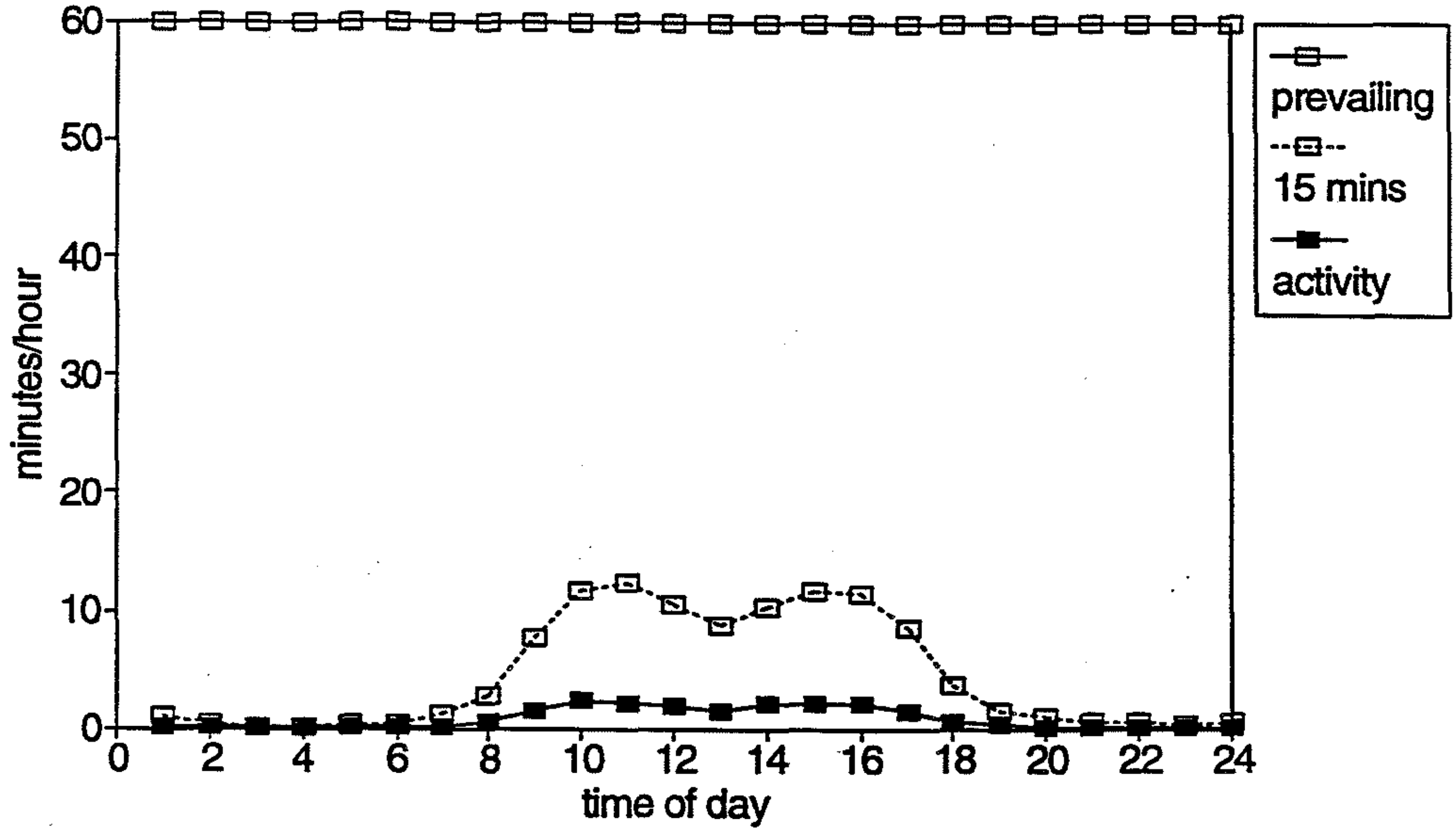

Figure 9 (a). Mean hourly fax use profile for sub-sample "C" over all 60 weekdays in the 12 week period. The upper curve is the assumed prevailing on-time, in minutes per hour. The lower curve shows the mean minutes per hour for which there was activity. The middle curve shows the predicted mean on-time if power management automatically switched off fax machines after 15 minutes of inactivity.

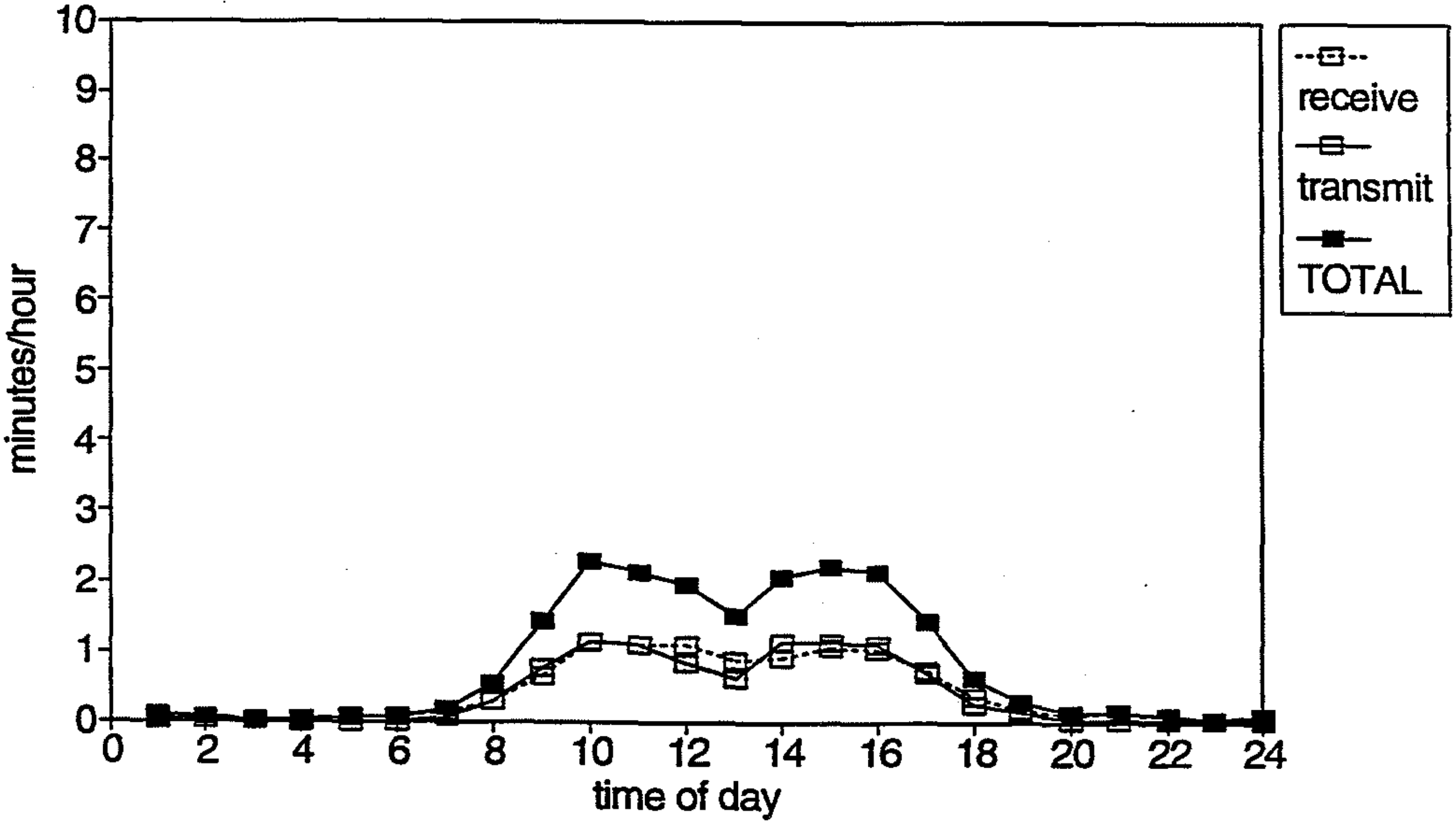

Figure 9 (b). Mean hourly transaction activity for sub-sample "C" over all 60 weekdays in the 12 week period. The upper curve represents mean transaction activity, and is the sum of the two curves below it, which plot mean hourly transmission and reception activity separately.

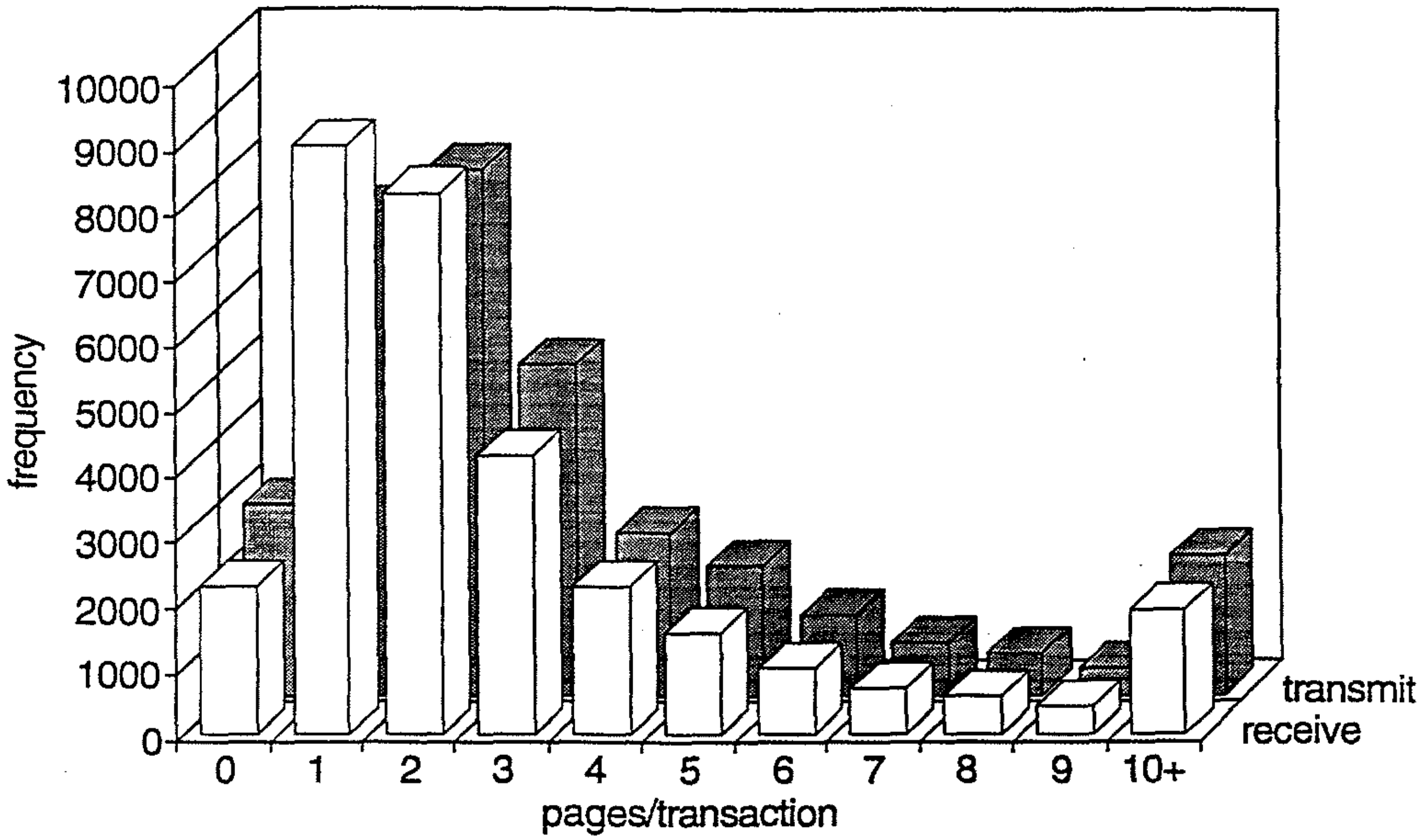

Figure 10. The frequency, over all 32 machines and 12 weeks, of transactions of a given number of pages; the data are sub-divided into transmissions and receptions. Zero ("0") pages/transaction indicates a transaction error.

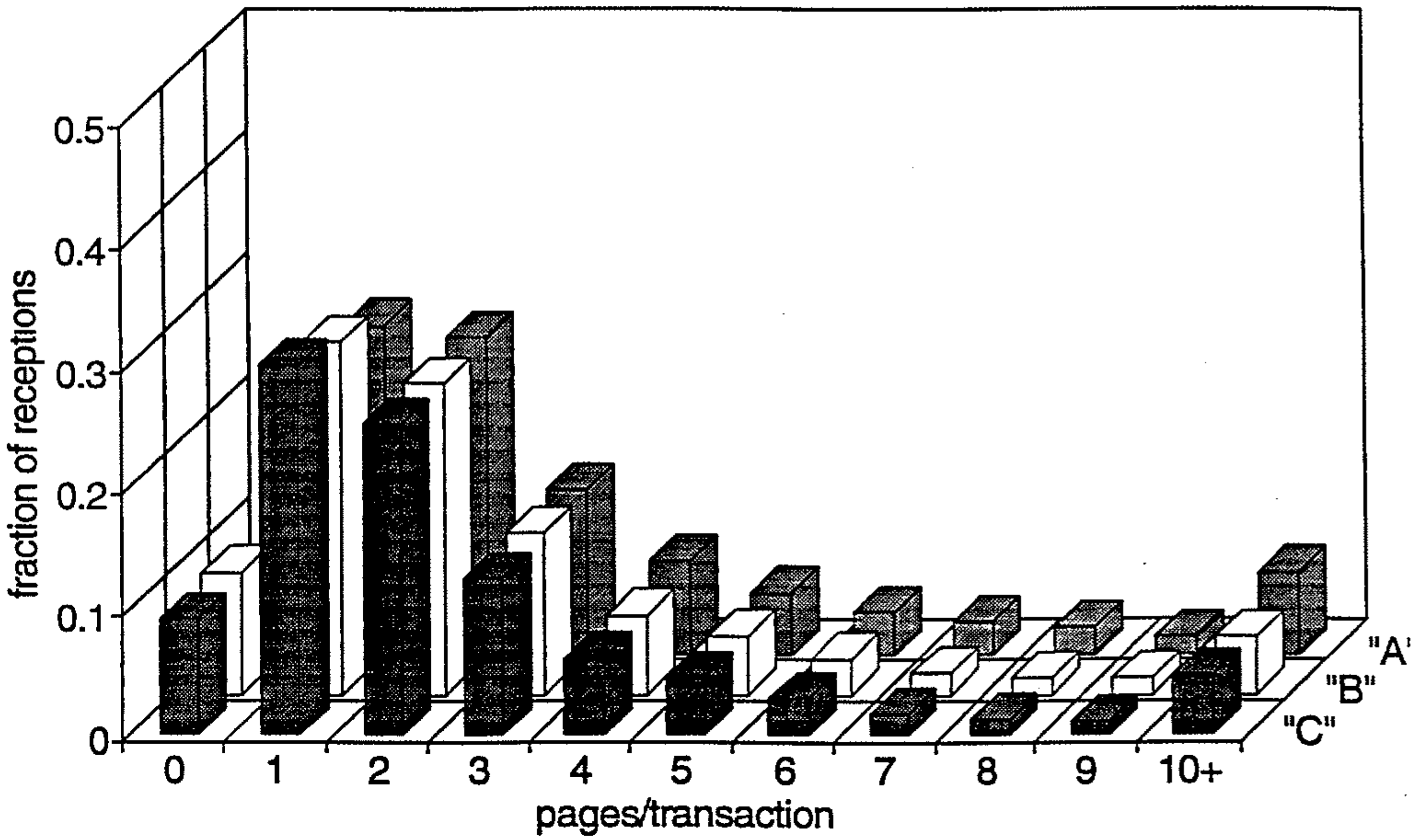

Figure 11 (a). The normalized frequency distribution over the 12 week period, of receptions of a given number of pages; the data are sub-divided by sub-sample.

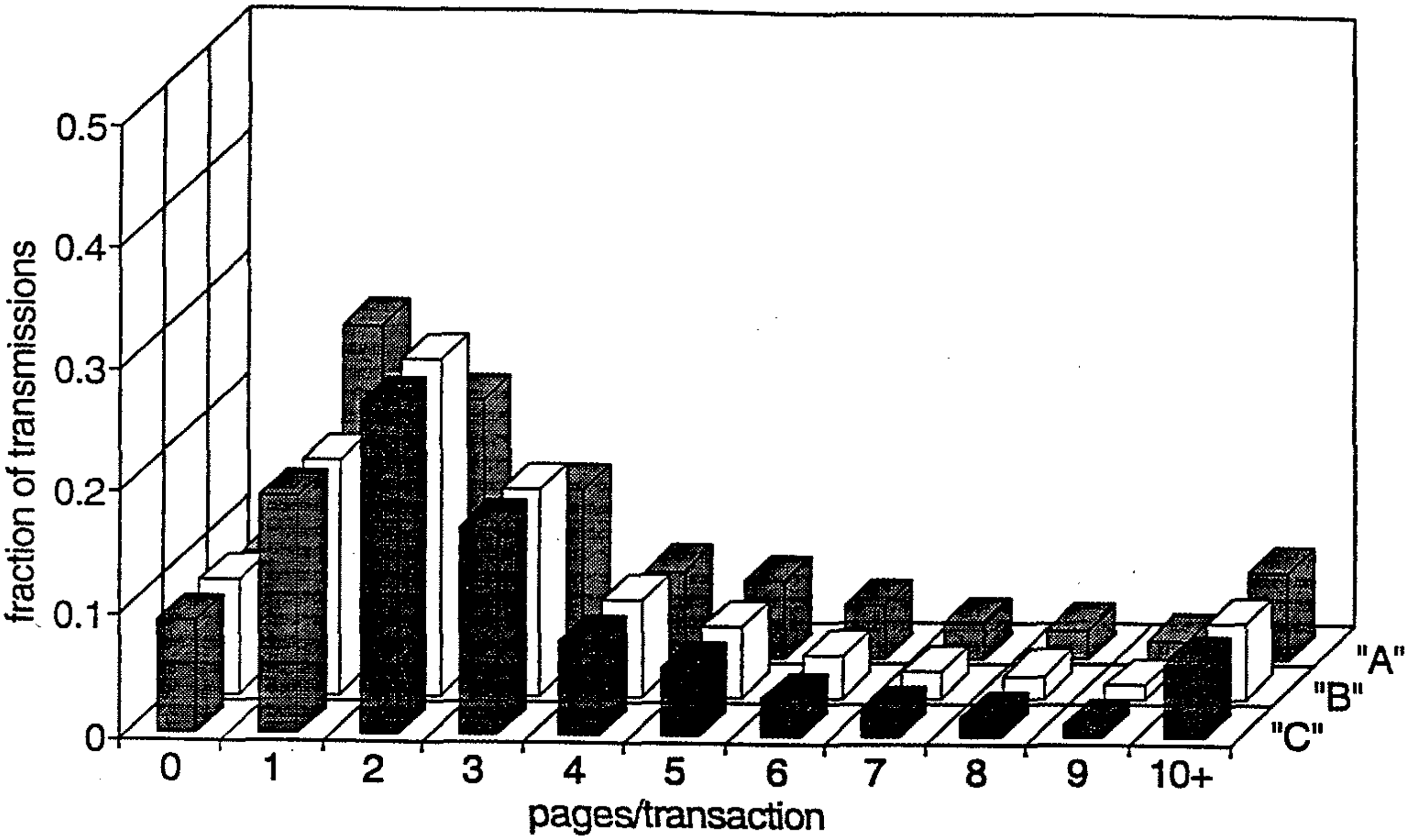

Figure 11 (b). The normalized frequency distribution over the 12 week period, of transmissions of a given number of pages; the data are sub-divided by sub-sample.