Performance Trends for Marking Technologies in Copiers and Printers

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This article examines trends over the last three decades of selected attributes for copier and printer products using xerography and thermal ink jet marking technologies. Relationships are identified between attributes that consolidate data and reveal underlying trends. An engineering performance metric is examined, useful for interpreting the trends. The analysis forms a foundation that could possibly be extended to develop projections of key performance attributes for the near future.

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Introduction

Many advances have occurred during the last 30 years in marking and manufacturing technologies used for copiers and printers. Some of these have been implemented by equipment manufacturers to enable a steady stream of product improvements, such as higher throughput speed, lower cost, the transition from light-lens to digital, better print quality, and color. This article presents an analysis of three decades of progress for selected performance attributes of copier and printer products. Information on the speed, weight, price, and type of marking technology of several hundred products was gathered from product brochures, trade shows, company records, and publications that follow the industry.[1,2]

Speed and Price Trends

The pace of product progress is illustrated by examining the fastest throughput speed of copiers and printers offered by various manufacturers. Figure 1 shows this for machines that used xerography and thermal ink jet (TIJ) marking technologies, beginning in 1959 with the launch of the Xerox 914. For both technologies, the throughput speed, measured in prints per minute (ppm), has increased by more than an order of magnitude. For color xerography, this improvement has occurred in only 15 years. Xerographic color began with the Xerox 6500 in 1973, which used a single photoreceptor that rotates four times, once for each color (multi-pass[3] color xerography). In the 1990s, xerographic machines were introduced with four photoreceptors (tandem[3] color xerography) that enabled a 4X speed enhancement. Thermal ink jet began with the Hewlett Packard ThinkJet in 1984, a monochrome machine, soon followed by machines that offered color.

Simultaneously, the price has decreased markedly, illustrated for color machines in Fig. 2. This plot shows the <price/ppm> ratio has decreased by almost 2 orders of magnitude during the last 15 years. Other attributes, such as print quality, reliability, and cost per page have also improved markedly during this period.

Monochrome Machines

We first review relationships that are well known for monochrome, light-lens xerographic machines. Both machine price and unit manufacturing cost (UMC), based on cost engineering estimates, provide a measure of value. For monochrome light-lens xerographic machines, both are approximately proportional to the throughput speed, measured by the number of prints per minute (ppm). The UMC for machines with the same speed have been decreasing over time, driven by many technology

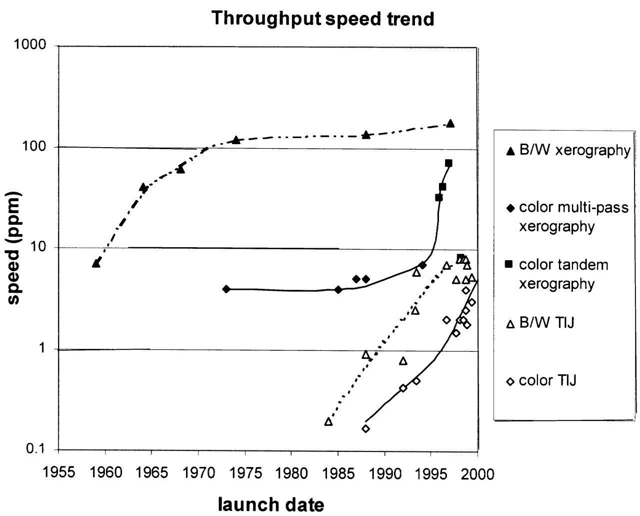

Figure 1. Trend in the throughput speed of the fastest printers and copiers. Manufacturers represented in this chart include Canon, Hewlett Packard, Xeikon, and Xerox.

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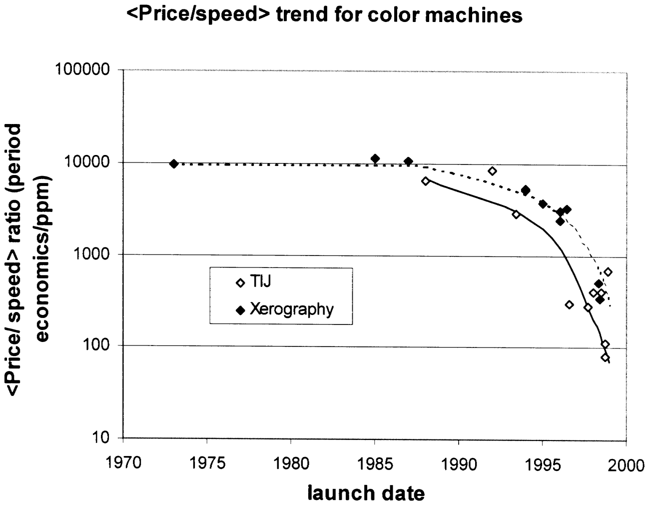

Figure 2. Trend of the ratio <price/speed> for color printers and copiers. Manufacturers represented in this chart include Canon, Hewlett Packard and Xerox.

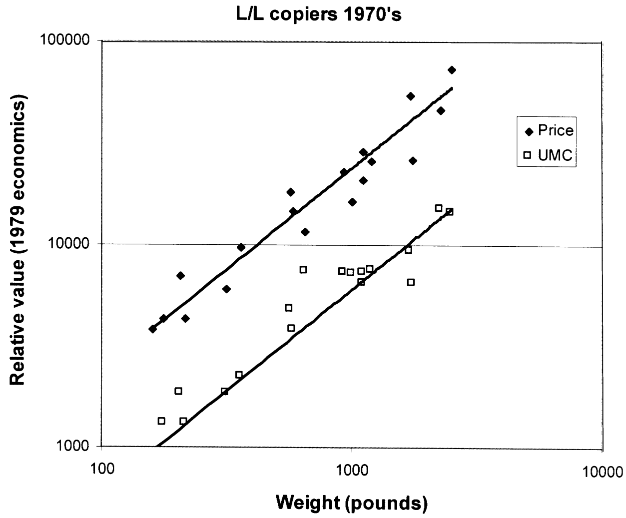

Figure 4. Correlation between weight and price and UMC for light-lens copiers launched during the 1970's. Manufacturers represented include Eastman Kodak, IBM, Savin, and Xerox

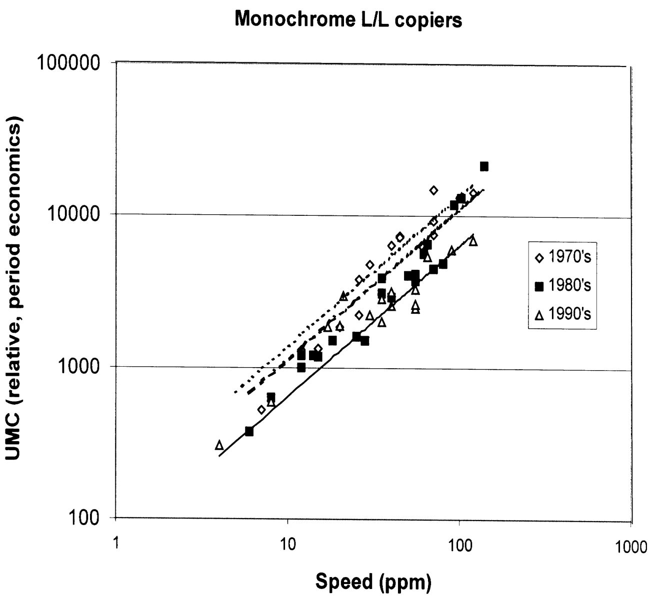

Figure 3. Relationship between the UMC and speed of monochrome copiers and printers. Manufacturers represented include Canon, Eastman Kodak, IBM, Lexmark, Ricoh, Savin, and Xerox.

and engineering innovations introduced over the years by manufacturers. Consequently, the correlation between UMC and speed must be examined as a function of product launch date.

Figure 3 illustrates the correlation between UMC and speed. The data has been grouped by decade—products introduced during the 1970s, 1980s and 1990s, respectively. The correlation between UMC and speed is good, though no effort was made to adjust the UMC to correspond to exactly the same set of features in all machines. The slopes of the linear regression lines, which represent the average ratio of UMC and speed, <UMC/ ppm>, have been decreasing over time. The values are <$137/ppm>, <$112/ppm>, and <$64/ppm> for the 1970s, 1980s, and 1990s, respectively. The square of the regression coefficients R^2 are 0.83, 0.82, and 0.83, respectively.

Figure 3 illustrates two points. First, looking at the trend, machine cost tends to increase in proportion to the throughput speed. One reason for this is that the size of many xerographic subsystems must increase as the photoreceptor speed increases, to keep the process dwell time approximately constant. Second, for a fixed speed, the cost has decreased over two decades by the ratio of the slopes, e.g. by a factor of about 2.1. Presumably, this is the result of continued improvements in both marking and manufacturing technologies.

Dependence of Price and Cost on Machine Weight

The relationships shown in Fig. 3 motivate us to look more closely at the drivers of cost. The correlation of cost with speed is intriguing and would seem to be connected with how the marking technology cost scales with process speed. But it is also known that machine cost tends to scale with weight of the machine. Price also scales with machine weight. These points are illustrated in Figs. 4, 5, and 6, where the data is again grouped by decade. The figures refer to the base machine, without peripheral equipment such as high capacity feeders or finishing equipment associated with high-speed machines. Digital machines include electronics that are normally packaged with the machine, but exclude specialized digital image processors, as required for higher speed color machines.

In all three decades, there is a strong correlation of both price and UMC with machine weight. This is true even though three major technological transitions are underway during this time. During the 1970s, all of the machines in Fig. 4 are monochrome, and use light-lens xerographic marking technology. During the 1980s (Fig. 5) a number of machines employed digital rather than light-lens technology; four in the figure offered color marking, and several used TIJ technology instead of xerography. By the 1990s (Fig. 6) the majority of the machines are digital and many offer color capability. The majority of the lower speed machines use TIJ technology. Even though there is a mix of color and monochrome machines using either xerographic or thermal ink jet

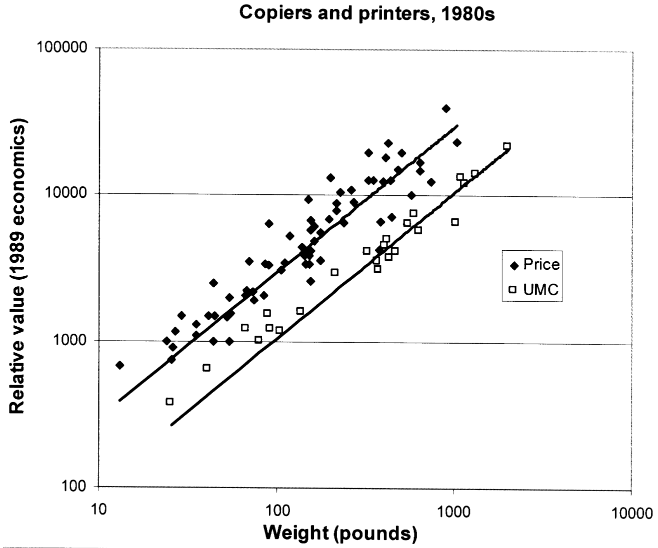

Figure 5. Correlation between weight and price and UMC for light-lens copiers and a few digital machines, launched during the 1980's. Speed and price values are restricted to <90 ppm and <$40,000. Four full-color xerographic machines are included in this chart - two digital and two analog. Manufacturers represented include Canon, Ricoh, Sharp, and Xerox.

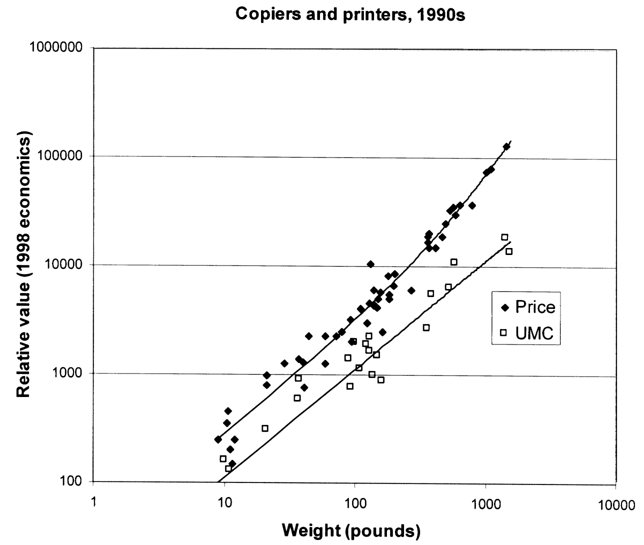

Figure 6. Correlation of price and UMC with weight for copiers and printers launched during the 1990's. Most of the machines are digital, and many offer full-color. Manufacturers represented include Canon, Epson, Fujitsu, Hewlett Packard, Lexmark, Okidata, Ricoh, and Xerox.

TABLE I. Summary of Parameters Presented In Figs. 4, 5, and 6. Value is Expressed in Period Economics.

	1970s	1980s	1990s
<Price/pound> R^2	$23.8/lb	$29.6/lb	$28.0/lb
	0.86	0.73	0.99
<UMC/pound> R^2	$6.0/lb	$10.4/lb	$11.2/lb
	0.87	0.95	0.92
<Price/UMC ratio>	4.0	2.8	2.5
Producer price index:			
finished goods &	77.5	118.8	139
capital equipment.	(1979)	(1989)	(1998)

technology, nevertheless all of the data cluster along the regression line, and the correlation with machine weight is quite good (see R^2 values in Table I).

Several trends can be deduced from Figs. 4, 5, and 6. The slopes of the linear regression lines summarized in Table 1 give the average ratio <price/pound> and <UMC/pound>. These ratios are expressed in period dollars. They are converted to 1998 dollars using the producer price index for finished goods and capital equipment, and plotted in Fig. 7. This figure shows that the average <price/pound> ratio has decreased somewhat during the last two decades, but the average <UMC/pound> ratio has remained essentially constant. At the same time, the average <price/UMC> ratio has decreased from 4.0 to 2.5.

A striking finding in Fig. 7 is that the average <UMC/pound> ratio from each decade, expressed in constant dollars, has remained essentially constant for over two decades, at a value of about $11/pound. As mentioned before, the data from which the correlation plots were plotted contains a variety of product capabilities and technologies—including light-lens and digital products, monochrome and color products, and products that use xerography and TIJ marking technologies.

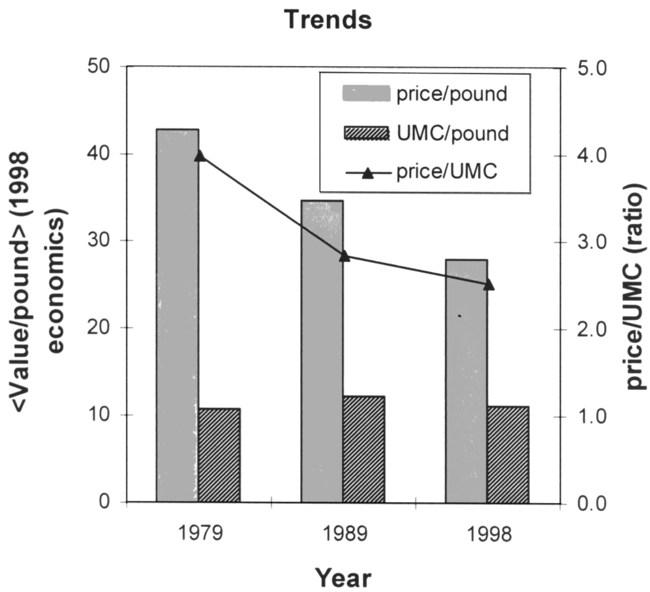

Figure 7. <Price/pound> and <cost/pound> trend, expressed in 1998 economics. The <UMC/pound> ratio has remained approximately constant. Meanwhile, the <price/pound> and <price/UMC> ratios have declined.

A second conclusion is that the average <price/UMC> ratio from each decade has decreased only slightly, from 4.0 to 2.5. This illustrates the extent to which margins have been squeezed by competitive pressures through these years.

If the average <UMC/pound> ratio for well-engineered products is constant, what distinguishes one marking technology from another? There may be print quality differences, but over time, print quality is improving and the difference between various marking technologies is gradually narrowing. Another key differentiating product attribute is speed. Consequently we return to the topic of speed and its cost-performance role.

Figure 3 showed that cost scaled with speed for xerographic light-lens machines, e.g. the average ratio <UMC/ppm> was constant in each decade. If the average ratio <UMC/pound> is constant during this period, what is improving over time? Our hypothesis is that technology and engineering improvements are driving up the performance per pound of machine weight, that is, they are driving the ratio <ppm/pound>. Typically, a customer is interested in getting the most performance (in this case speed) per price dollar. The relation between machine speed and price can be expressed as

$$<ppm> = <price> \frac{<UMC/price><ppm/pound>}{<UMC/pound>} \quad (1)$$

Earlier we showed that over two decades, the ratio <UMC/price> has decreased only slightly, and the ratio <UMC/pound> has remained essentially constant (expressed in 1998 dollars). Our hypothesis is that the ratio <ppm/pound> provides a key measure of progress from advances arising in marking technology, engineering, and manufacturing.

The ratio <UMC/ppm>, the slope of the line in Fig. 3, provides another way to determine this engineering performance metric:

$$<UMC/ppm> = \frac{<UMC/pound>}{<ppm/pound>} \quad (2)$$

Consequently, the ratio <UMC/ppm> is inversely proportional to the engineering performance metric, <ppm/pound>, and proportional to <UMC/pound>, which is approximately constant.

Engineering Performance Metric

The <speed/weight> ratio quantifies the impact of technology and engineering improvements on product performance. In this section, we determine the trend for this ratio for products using each type of marking technology. We suggest that this is an appropriate metric for preparation of technology S-curves, which are a useful way of characterizing incremental progress within an existing technological approach, and for helping to identify potentially disruptive technologies.[4] The <speed/weight> ratio can be improved by a variety of technology and engineering approaches, including engineering discipline to identify design limits and optimize the design near them, use of technologies that enable miniaturization of components, and substitution of materials to enable increased performance with less weight.

We now examine the trend in the <speed/weight> ratio over time. A much larger sample of data can now be examined, because unlike the analysis in previous sections which depends on knowing the UMC, this ratio involves only speed, weight, and launch date, information which is readily accessible from many sources.[1,2]

Figures 8, 9, and 10 present the <speed/weight> or equivalently, the <ppm/pound> trends for various technologies. On all three figures, a trend line has been drawn through the locus of machines with the largest values of the <ppm/pound> ratio. The intent of these curves is to indicate the best performance achieved up to that time. The charts do not display nor refer to the upper and lower throughput speeds possible for each marking technology.

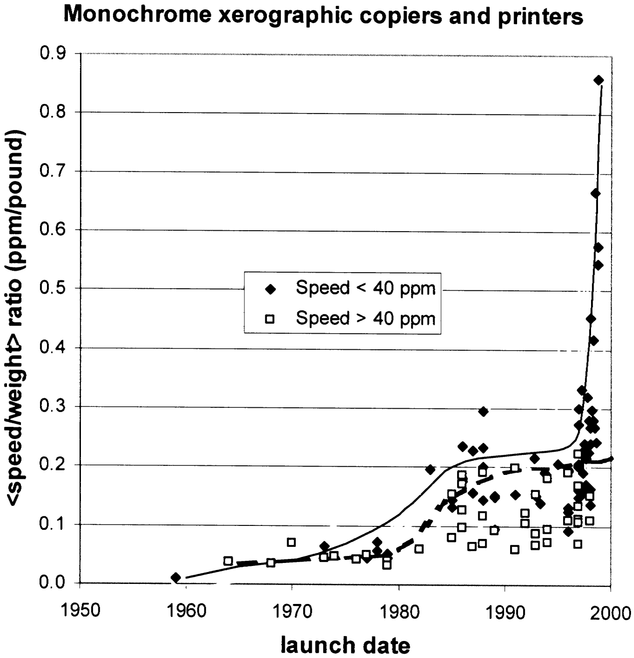

Figure 8. <Speed/weight> ratio for B/W copiers and printers that use xerography. Both light-lens and digital machines are included. The data is clustered into groups below and above 40 ppm. Manufacturers represented include Canon, Eastman Kodak, Hewlett Packard, IBM, NEC, Okidata, QMS, Ricoh, Samsung, Sharp, and Xerox.

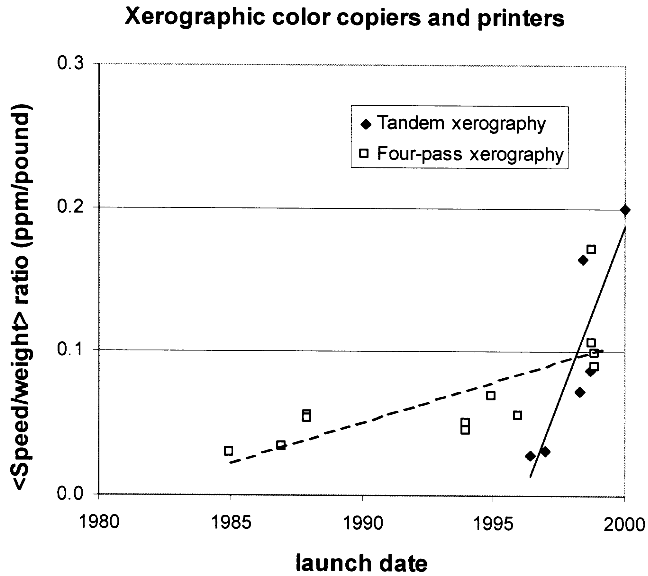

Figure 9. <Speed/weight> ratio for color copiers and printers that use xerography. Speed refers to the monochrome throughput rate. Manufacturers represented include Canon, Fujitsu, Hewlett Packard, Lexmark, Okidata, Tektronixs, and Xerox.

Figure 8 shows monochrome machines using xerography. The data was segregated into two domains: less than 40 ppm, and greater than 40 ppm. For speeds < 40 ppm, monochrome xerographic performance has improved almost two orders of magnitude from 0.01 to almost 1.0 ppm/pound. Two features stand out – the surge of progress in the early 1980s, and a second surge in

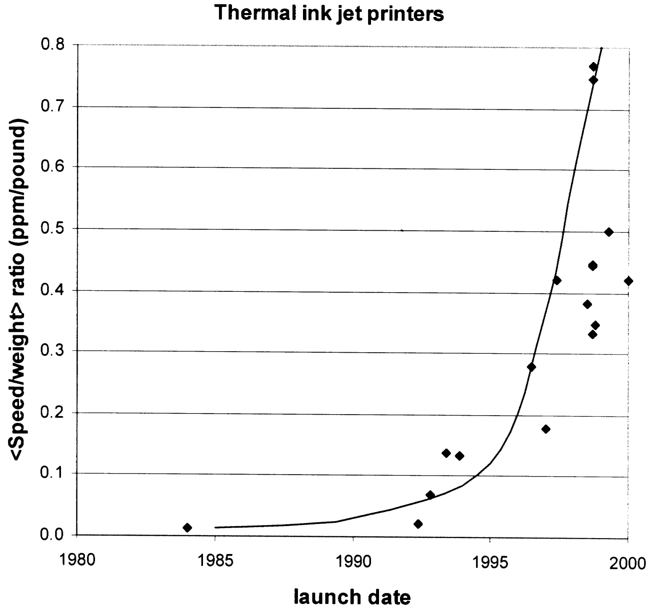

Figure 10. <Speed/weight> ratio for printers using thermal ink jet technology. Manufacturers represented include Epson, Hewlett Packard, Lexmark, and Xerox.

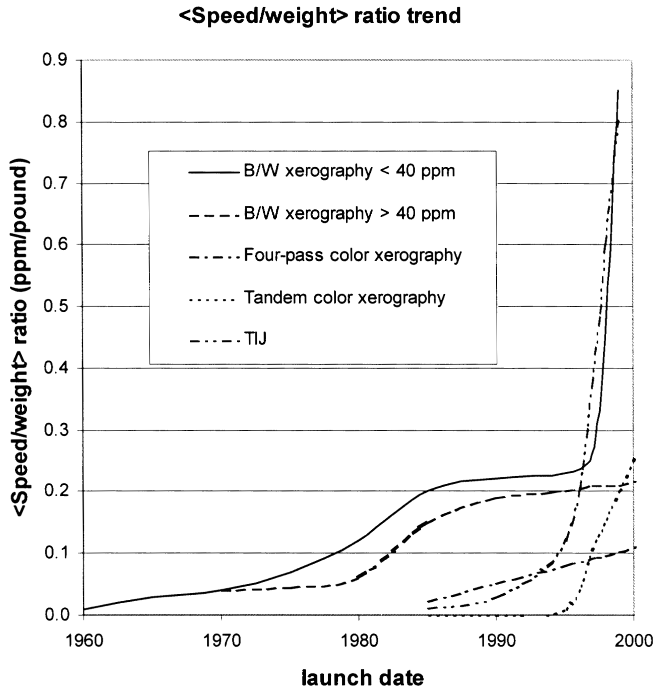

Figure 11. Comparison of trends for xerographic and TIJ marking technologies

the late 1990s. We associate the first surge with the entry of many new manufacturers into the market, many of them Japanese firms. We speculate that the second surge is a response of xerographic machine designers to rapid advances in TIJ technology, which began offering machines in the early 1990s.

For speeds > 40 ppm, the trend in the <ppm/pound> ratio plotted in Fig. 8 shows a similar surge during the early 1980s, which we also attribute to the entry of many new, highly competitive, low cost manufacturers into the market.

Figure 9 shows color machines that use xerography. In this case, the <ppm/pound> ratio was calculated using the monochrome speed. The machines are identified by technology configuration – those based on multi-pass xerography (one photoreceptor), and those using tandem xerography (four photoreceptors and associated subsystems). For the multi-pass configuration, the rate of progress has been ~9% per year, doubling every 8 years. For the tandem configuration, although the history is short, the rate of progress has been phenomenal, doubling in only 2 years. We believe that this is driven in part by rapid transfer and adaptation of miniaturized technologies developed for low-speed monochrome xerography.

Figure 10 shows the trend for machines that use TIJ technology. Again the <ppm/pound> ratio is calculated using the monochrome print speed. In 15 years, the performance metric has improved 50X. This has been driven by several factors, including a 10X increase in channel pulse rate, and 30X increase in the number of channels per print-head, while at the same time the resolution has increased by 6X.

The trend lines from Figs. 8, 9, and 10 are compared in Fig. 11. These can be regarded as technology S-curves[4] for each marking technology. An anonymous referee suggested that it would be constructive to offer speculations on future trends regarding the <ppm/pound> ratio. In principle, an engineering model for products using various marking technologies could be developed to predict the ultimate speed and minimum weight for each marking technology. This challenging task is not addressed in this article. For the moment, we provide the following three speculations.

We speculate that the S-curve for tandem color xerographic products will continue to trend upward, driven by rapid transfer and adaptation of miniaturized technologies for low-speed monochrome xerographic products, which has already reached a value of 0.9. Accordingly, we anticipate that the <ppm/pound> ratio for tandem color xerographic products will continue to increase in the near future, however, ultimately it will not exceed the value for monochrome machines, which sets an upper bound.

Regarding monochrome xerography above ~ 40 ppm, we speculate that the same technologies that have enabled improvements in the <ppm/pound> ratio of low-speed monochrome xerography will eventually be applied to this domain. When this happens, the S-curve for this class of products will again trend upward, similar to what is now being observed for low-speed products. This would create a second dramatic wave of improvement in the <ppm/pound> ratio, similar to what happened during the early 1980s.

Regarding TIJ, higher printing speed will be achieved relatively easily, for example by using wider print-head arrays, but a paper drying limitation is now being encountered. This will require the addition of a major new subsystem with associated power supplies, etc., which will add weight and cost to the product. In all likelihood, the <ppm/pound> ratio will be reduced - one could imagine a new S-curve evolving for TIJ products having drying capability.

Conclusions

Analysis of information about several hundred copiers and printers launched over a 30 year interval shows that the average value of the ratio <UMC/pound>, expressed in 1998 dollars, has not changed appreciably, and has a value of ~ $11/pound. This is true (on the average) for a wide variety of color and monochrome machines that use various marking technologies, including TIJ, monochrome xerography, and multi-pass color xerography and tandem color xerography. Over this time interval, the average <price/UMC> ratio has decreased from about 4.0 in 1979 to about 2.5 in 1999.

The analysis shows that a key measure of machine performance is the ratio of speed to weight, <ppm/pound>. An implication of this is that competitive advantage can be gained through technology & engineering advances that reduce weight without compromising product performance, specifically throughput speed. Examples of such advances include technologies that enable miniaturization of components, substitution of high performance materials, and ability to identify design limits and optimize the product design near these design limits.

The long-term trends of the <ppm/pound> ratio were presented for five types of marking technology: low-end B/W xerography, high-end B/W xerography, multi-pass color xerography, tandem color xerography, and TIJ. The "best performance" trend curves, or S-curves, were compared. Associated changes in the industry were briefly discussed.

The S-curves support three main observations. First, low-end B/W xerography is currently experiencing a period of extremely rapid growth in the <ppm/pound> ratio. Second, low-end monochrome xerography and TIJ both have improved rapidly in recent years, and have a similar S-curve and magnitude. We speculate that some of the rapid progress in monochrome xerography is the result of response by xerographic practitioners to competitive pressures from TIJ. Third, we anticipate that tandem color xerography may improve rapidly in the next few years, owing to continued transfer of technology and design rules from low-end monochrome xerography.

The linkage of price and performance involves the ratio <ppm/pound>, and also involves the ratios <price/UMC> and <UMC/pound>, as shown by Eqs.1 and 2. These last two factors have changed relatively slowly over the last 30 years. Starting with a specified price point or price-point range, Eq. 1 could be used to estimate machine speed possible for each price-point and time-frame. In principal, a physical model of the <ppm/pound> ratio could be developed for each marking technology. Such a model could be used to project future trends in the <ppm/pound> ratio. This in turn could be used to project what throughput speed will be achieved in the future as a function of the price point.

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