

Promises and Pitfalls of Architectural Strategy in the Printer Industry

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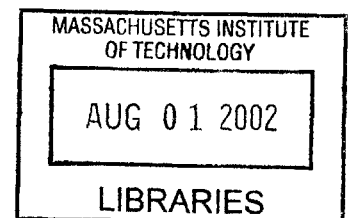
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Abstract

The xerographic printing and copying industry has become extremely competitive. Xerox market share has gradually declined since the 1960s as the market share of corporations like Canon, Hewlett Packard and Ricoh has increased. In response to rising competition, various product architecture strategies are heralded as the means to gaining, or regaining, competitive advantage in this environment. Among the most popular of these strategies are *platform strategy, product families and parts commonality, and outsourcing*. The objective of this thesis is not to dispute the value of these strategies in the present context. Obviously, platform strategies and parts reuse enable firms to develop products faster and with less cost by leveraging previous investments. Likewise, in order to remain competitive in this environment, a firm can no longer afford to vertically integrate its products—clearly, firms can no longer afford to do everything themselves. Horizontal integration through outsourcing, or what Xerox calls extended enterprise, is therefore one source of competitive advantage.

Platform strategy, parts reuse, and extended enterprise all make good sense *but each of these strategies can easily backfire*. In this paper we will examine these strategies and see how they relate to central themes in product architecture, such as, architectural modularity. Then we shall see how these strategies can, if not applied carefully, cause more problems than they attempt to resolve. Finally, in light of these problems, revised and more robust versions of these strategies are presented.

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Table of Contents

INTRODUCTION	7
SECTION 1: CONCEPTS AND FRAMEWORKS.....	13
OVERVIEW	13
PLATFORM MOTIVATION AND DEFINITION.....	14
<i>Platform Motivation</i>	14
<i>Platform Architecture</i>	17
MODULAR ARCHITECTURE AND ITS MOTIVATION.....	24
SECTION 2: PRODUCT FAMILIES AND PART COMMONALITY	28
A CANON PRODUCT FAMILY AND PARTS COMMONALITY.....	28
BEYOND PARTS COMMONALITY.....	31
WHEN PART COMMONALITY SHOULD DRIVE DESIGN.....	33
SECTION 3: PLATFORM STRATEGIES-- PROCEED WITH CAUTION.....	37
PLATFORM STRATEGY GONE AWRY.....	39
REDUCING THE RISK IN PLATFORM STRATEGY	46
SECTION 4: PLATFORM ARCHITECTURE AND WEAK MODULARITY	50
IMPORTANCE OF ARCHITECTURAL MODULARITY TO PRODUCT DEVELOPMENT.....	50
IMAGE ON IMAGE AND INTERMEDIATE BELT TRANSFER MODULARITY	51
MODULARITY AND ITS ADVANTAGES.....	57
SECTION 5: OUTSOURCING AND MISTAKEN MODULARITY.....	59
FROM VERTICAL TO HORIZONTAL INTEGRATION	59
POTENTIAL PITFALL OF AN OUTSOURCING STRATEGY	60
CONCLUSIONS.....	65
APPENDIX A: XEROGRAPHIC PROCESS OVERVIEW	67
APPENDIX B: COMPETITIVE LANDSCAPE.....	69
BIBLIOGRAPHY.....	70

Table of Figures

FIGURE 1 HIGH-LEVEL MARKET SEGMENTATION GRID FOR PRINTING	8
FIGURE 2 MODULARITY AS CENTRAL TO BOTH PLATFORM AND OUTSOURCING STRATEGIES.....	13
FIGURE 3 MEYER, LEHNERD MARKET SEGMENTATION GRID FOR INK JET PRINTING.....	21
FIGURE 4 MARKET SEGMENTATION GRID FOR XEROGRAPHIC PRINTING SHOWING VERTICAL AND HORIZONTAL PLATFORM STRATEGIES	22
FIGURE 5 MIXED PLATFORM STRATEGIES WITH VARIANTS BASED ON SCALING AND MODULAR ADDITION, SUBSTITUTION AND REMOVAL	23
FIGURE 6 SUB-SYSTEM COMPARISONS FOR HP-4L, HP-4, HP-4Si AND CANON GP-55	29
FIGURE 7 ESTIMATED COST OF 30 MM DRUM VERSUS VOLUME IN MILLIONS.....	34
FIGURE 8 MARKET SEGMENTATION GRID FOR XEROGRAPHIC PRINTING SHOWING VERTICAL AND HORIZONTAL PLATFORM STRATEGIES	38
FIGURE 9 IMAGE ON IMAGE COLOR PRINTING ARCHITECTURE.....	41
FIGURE 10 PLATFORM VERSUS NON-PLATFORM COMPROMISE MATRIX.....	45
FIGURE 11 GRAPHICAL ILLUSTRATION OF PLATFORM PRUNING PROCESS.....	46
FIGURE 12 DECISION TREE FOR PLATFORM STRATEGY	48
FIGURE 13 IMAGE ON IMAGE ARCHITECTURE FOR COLOR XEROGRAPHY	51
FIGURE 14 DESIGN STRUCTURE MATRIX FOR IMAGE ON IMAGE COLOR XEROGRAPHY	53
FIGURE 15 COLOR XEROGRAPHIC ARCHITECTURE BASED ON INTERMEDIATE BELT TRANSFER (IBT).....	55
FIGURE 16 DESIGN STRUCTURE MATRIX FOR INTERMEDIATE BELT TRANSFER (IBT) COLOR ARCHITECTURE WITH HIGHLIGHTED MARKING MODULES	56
FIGURE 17 ARCHITECTURE FOR BLACK AND WHITE XEROGRAPHIC SYSTEM.....	61
FIGURE 18 DESIGN STRUCTURE MATRIX FOR BLACK AND WHITE XEROGRAPHIC MARKING ENGINE	62

Introduction

Over time, the copying and printing industry has become increasingly competitive. Many companies, including Canon, Hewlett Packard, and Ricoh now share market segments that were once dominated by Xerox. As is generally the case, as markets get more competitive the focus on sources of competitive advantage becomes more intense. No longer in a dominant market position, Xerox, like other firms in the industry, must now find and develop sources of competitive advantage.

Some of these sources of competitive advantage relate to product development strategies. Three themes that are frequently repeated in this context are—*platform strategy, product families and parts reuse, and outsourcing*.

The first theme is that competitive advantage requires leveraging platforms so that a product family can be generated with minimal development cost. The second theme is that parts must be reused in order to minimize costs and bring products to market rapidly. The third theme is that in a highly competitive environment, a firm may no longer be able to afford to design and develop everything. To remain competitive, a firm must outsource pieces of the design and manufacturing to other firms. Vertical product integration typically gives way to horizontal product integration as competition increases. These three themes characterize the product development battle cry in response to the invading competition. And though I too emphasize the importance of these strategies, to a large extent, *this thesis is an exercise in caution. If not applied correctly, these three strategies can backfire and cause more problems than they resolve.*

Xerox and corporations like Canon compete in a variety of market segments. Figure 1 provides a coarse overview of these market segments. A more detailed segmentation map would show various gradations, for instance, in the black and white office market, but this map will serve our purposes. One dimension of the table is

printer speed, rated in terms of prints per minute.¹ Generally speaking, higher speed machines are larger and cost more. Printers in the Small Office and Home Office (SOHO) market tend to be desktop printers or smaller console printers. The cost of these printers ranges from a few hundred dollars to several thousand dollars. On the other hand, printers in the office environment tend to sit in company hallways and have speeds ranging in the 35 to 100 print per minute range. Finally, printers in the production market segments, unlike those in the office and SOHO markets, typically have dedicated operators and are placed in the special reprographic rooms of large corporations.

Production > 100 ppm				
Office 35 to 100 ppm				
SOHO 1 to 35 ppm				
	MICR	B&W	Spot Color	Full Color

Figure 1 High-level market segmentation grid for printing

The second dimension in the printing market segmentation grid is based on the type of image the printer generates. A MICR image is made with a special type of toner that contains magnetite and special types of magnetic readers can automatically read its characters at high speeds. MICR printers are commonly used in banking applications in which special magnetic characters are printed on checks. Black and white printing requires no explanation. Spot color, sometimes called highlight color, implies black and white printing plus one or perhaps two colors for emphasis. And

¹ A printer is not the same as a copier. A printer is a device that is interfaced to a computer or a computer network. A printer receives electronic files that are converted to binary data before printing. On the other hand, copiers have scanners that scan “hard copy” documents that are then converted into electronic files for printing. The focus of this paper is the xerographic system that converts these electronic files into fused images on paper. The same xerographic system can support both copying and printing, the only difference is in the origin of the electronic file sent to the xerographic system’s imaging sub-system.

finally, in full color printing, prints are made with the primary additive colors of cyan, magenta and yellow, as well as black, thereby enabling the full gamut of colors.²

If the battleground in printing is captured by Figure 1, then some of the strategic arsenal is in the form of product development strategies. As mentioned earlier, we will focus on three of these strategies—parts reuse in product families, platform strategies, and outsourcing. In section two, we consider the strategy of developing product families whose members have many parts in common. Parts and technology reuse is currently seen as a sign of an effective product family. Products can be developed faster and with less cost if parts from previous products are reused. Many companies, including Xerox, have specific requirements regarding parts reuse that must be met if a product family is to move past certain phase gates and into the next product development phase. In section two, however, we will see that an extremely successful product family, the HP LaserJet 4 family, is composed of products that share surprisingly few parts. In fact, if a high part commonality requirement had been imposed on this family, then these products would never have been developed.

This suggests that the parts commonality requirement may need some modification. In particular, the notion of commonality needs to be broadened so as to include sub-system technology commonality, architectural commonality, as well as commonality in manufacturing and assembly processes. In the end, what may be leveraged is not common parts, but knowledge and processes.

Nonetheless, it will be argued that *in certain critical areas*, part commonality is extremely important to the printing business model. In printers, toner and photoreceptors are replaced frequently and are sometimes referred to as “consumables” for this reason. These items are critical to the printing business model, much like razor blades are to the shaver business model. Therefore, commonality in these areas may be more important than in other areas because of the number of times these materials and parts are replaced and the effect of volumes on cost per unit, e.g., economies of scale. If this is right, then it may make sense to design non-commonality into sub-systems that interact with the toner and photoreceptor if, as a result, toner and photoreceptor

² Appendix A provides an overview of xerographic technology that is designed for those with little or no background in the field.

commonality is maintained across the product family. For example, use non-common charging and imaging systems if this enables common photoreceptors across the product family. In summary, blind application of a parts commonality metric overlooks these more subtle points and may not necessarily be a good indicator of a strong product family.

In section three, we consider a second product development strategy that is prevalent in the literature today, namely, developing products on the basis of platforms. Corporations can no longer afford long development cycles. Platform strategy is generally recognized as one key towards developing products in less time. Although a platform may require significant development efforts, the variants of the platform will require less time to develop because they are enabled by the platform. The general theory is that through the use of platforms a firm can leverage its investments and develop a family of products with minimal cost and time. One sign of an effective platform strategy might be parts reuse, but we shall see that this is not necessarily the case.

As with the parts commonality criterion, platform strategies must be applied with great care. What is often overlooked in the literature on platform strategy is the fact that *platforms often compromise one product for the sake of another*. Product A may be compromised in the platform architecture so that product B can be derived from the platform. The problem is further compounded if for some reason product B never goes to market—then product A is compromised for no good reason. When evaluating alternative platform strategies, it is imperative that all compromises to individual products be clearly identified. Likewise, a risk factor should be associated with each product, for example, a probability that the product will actually go to market. Combining risk factors with an outlooked NPV provides an expected NPV for each product variant from which the expected NPV of a platform strategy can be computed. Through this use of this type of method, a company can make a more informed decision in selecting one platform strategy versus another.

In section four, platform architectures are examined in terms of modular design. In particular, two alternative architectures for color printing are discussed—image on image (IOI) color printing and intermediate belt transfer (IBT) color printing. Both

architectures can function as platforms supporting black and white, spot color, and full color printing. But an analysis based on design structure matrices (DSM) indicates that, of the two choices, the IBT architecture is more modular. Though there are advantages to an IOI design, such as fewer photoconductors and no intermediate belt, the weak modularity of IOI introduces system engineering and time to market issues. Non-modular architectures that introduce iterative feedback loops typically require more time to development and are more difficult to plan whereas modular architectures enable rapid, independent, and asynchronous product development and, therefore, outsourcing.

Finally, in section five, we turn to the strategy of outsourcing in the printer industry. As competition increases, advantage often shifts to firms that develop modular, horizontally integrated designs. Standardization and off the shelf modules are the result of product commoditization and this tends to devalue the expertise of a vertically integrated corporation like Xerox that, over the years, developed the skills needed to virtually “do everything”. Hewlett Packard, for instance, outsourced the entire xerographic system in its highly successful LaserJet 4 series to Canon. Likewise, raster output scanning (ROS) laser imaging systems, once a source of competency differentiation for Xerox, are now more or less commodities that can be purchased from firms like Fuji Photo Optical. Xerographic development sub-systems can now be outsourced to Chinese companies and toner can be outsourced to Japanese firms specializing in toner development. The xerographic printing world has changed dramatically in the last thirty years and competitive advantage may now be found in modular architectures that enable outsourced components.

Nonetheless, as was our theme when it came to parts commonality and platform strategies, outsourcing must be applied with great care. This is not simply because a firm might select an incompetent partner. That point is obvious. Rather, the point developed in section five is that outsourcing strategies can run into real *problems if the outsourcing strategy does not mirror the true modularity of the system*. We shall see that with an integral architecture many sub-systems are developed as a single unit whereas in a modular architecture, modules can be developed independently. The distinction between integral and modular designs has important consequences for

outsourcing. In general, components of an integral architecture are difficult to outsource because they are designed in conjunction with other components in the system. Managing product development in this context is very difficult if the development of sub-systems is outsourced to different companies. The framework of Design Structure Matrices (DSM) is useful for evaluating the modularity of a given design. This technique shows that outsourcing components within an integral architecture has the effect of *outsourcing tasks that must take place in the context of iterative feedback loops*. These loops are very difficult to manage when they involve more than one firm. To avoid problems in outsourcing, Design Structure Matrices should be constructed and subsystems should be ranked in terms of modularity. Modularity rank should then be used as a criterion for deciding whether a given subsystem should be outsourced. Outsourcing without these precautions can create more problems than it solves.

In summary, each of the strategies considered above is aimed at increasing competitive advantage. But without careful thought, each of these strategies can backfire, and a firm can jump from the frying pan to the fire. Before turning to a detailed examination of each of these strategies, it will be useful to begin with a general conceptual framework for thinking about platforms, parts reuse, modularity, and outsourcing—this is the topic of section 1.

Section 1: Concepts and Frameworks

Overview

It will be helpful to begin with a conceptual framework that can then be used to structure subsequent discussion. For that reason, we begin with an overview of some key concepts and arguments. First, the motivation for product platforms is discussed, followed by a discussion of what we mean by a product platform. With these concepts in mind, we then turn to a discussion of the ways in which products are derived from platforms. Here, it is argued that, in general, there are two methods for deriving variants from platforms, namely, derivation through scaling and through modularity. In the first case, certain critical parameters in a platform are scaled so as to generate a product that addresses another market segment. For example, by scaling certain parameters in a black and white printer the speed of the printer can be increased, thereby producing another variant in the product family. In the second case, certain modules in the platform are replaced, or, certain modules are added onto the module. For example, a color printer might be derived by adding certain modules to a base black and white printer.

Modular design is therefore a key enabler to platform design. Modular design lends itself to a “mix and match” architecture with which a variety of products can be derived by replacing and adding modules. Because of the centrality of the notion of modularity, at this point we turn to an overview of modular versus integral designs. In modular designs complex interactions are contained within module boundaries so that interfaces between modules are well defined and stable. The concept of modularity, we shall then see, can be made more precise with Design Structure Matrices.



Figure 2 Modularity as central to both platform and outsourcing strategies

Just as modular design is a key enabler to platform design, so too, modular design is essential to an outsourcing strategy. As Figure 2 illustrates, design modularity is central to both platform and outsourcing strategy. Serious problems can result from outsourcing components within an integral design. As Fine and Whitney conclude, “the best candidates for outsourcing are those most easily decomposed [into modules]”.³ Furthermore, a modular design may simultaneously enable both a platform design and an outsourced design. This is the case when modules within the base platform, sometimes called platform elements, are outsourced. In the extreme, all of the elements of a platform might be outsourced and a company’s added value might lie in the system engineering competencies required in decomposing the system into distinct modules.

Today, the concepts of platform and outsourced design are championed as keys to gaining competitive advantage and modular design is generally recognized as a critical enabler to both platform and outsourced design. These are powerful tools, but they must be applied carefully because, without significant care, they can create more problems than they attempt to solve. Before turning to a detailed examination of how these strategies can go awry, a conceptual framework for the discussion will be developed.

Platform Motivation and Definition

In this section, we examine the motivation for product platforms. Why are platforms important? What benefits do they offer that are not found in a strategy that focuses on single products as opposed to product families? Having examined the motivation for platforms, we then turn to the concept of a platform. What exactly is a platform and how do they differ from products?

Platform Motivation

A platform strategy provides an alternative to the more traditional strategy of developing new products *one product at a time*. The argument for product platforms is

³ Fine and Whitney (1996).

based on various factors, ranging from development costs, to manufacturing costs, to field support and maintenance costs.

Perhaps the most fundamental argument for platforms is that they enable a firm to leverage its development costs. Product platforms that can accommodate new component technologies and variations make it possible for companies to economically create derivative products. Since the costs associated with the platform are essentially sunk costs, only the incremental costs of creating variation are incurred by the derivative products. These incremental costs are typically a small fraction of the cost of developing the original product platform. The resulting economic leveraging is what Meyer and Lehnerd call “platform efficiency” and it can be represented mathematically as the ratio of development cost of a derivative product to the development cost of the base platform.⁴ A variant with a platform efficiency on the order of, for instance, 0.05, implies that the variants was nearly fully enabled by the development of the platform. If several derivative products are generated from a single platform, then the average platform efficiency of the platform is defined as:

$$\text{Average Platform Efficiency} = \frac{\text{Average}(\text{Derivative Products Engineering Costs})}{\text{Platform Engineering Costs}}$$

Meyer and Lehnerd’s study of the electronics industry indicates that benchmark values for platform efficiencies are on the order of 0.10, but of course, benchmarks values will tend to be industry-specific.

Through the use of product platforms, derivative products are not only developed at fractions of the cost of developing the base platform—they are also developed in fractions of the time required to develop the base platform. This suggests a similar metric to platform efficiency, which Meyer and Lehnerd call cycle time efficiency. For a single derivative product, the cycle time efficiency is simply the ratio of the time to develop the derivative product to the time to develop the base platform. If several derivative products are generated from a single platform, then the average cycle time efficiency of the platform is defined as:

⁴ Meyer, Lehnerd (1997, p. 153)

$$\text{Average Cycle Time Efficiency} = \frac{\text{Average}(\text{Time to Develop Derivative Products})}{\text{Time to Develop Product Platform}}$$

In addition to reducing development costs and time, platforms can also reduce manufacturing costs and time. A platform approach to product development dramatically reduces manufacturing costs and provides significant economies of scale in the procurement of components and materials, because so many of these are shared among individual products. When products are developed one product at a time, products tend to use different materials for the same purpose, for example, many different types of switches and motors to achieve similar purposes. But when products are developed in coherent families, part commonality is increased and inventory levels are decreased. The benefit to manufacturing extends beyond part commonality, reduced inventory, and greater economies of scale because when products are developed in families, production line changeovers are faster because most or all of products in a family can be built on the same production line. If production line changeovers are faster, then shorter production runs become more economically feasible which in turn means smaller finished goods inventories.

This suggests that some of the benefits attributed to platform strategies are due to parts commonality. Kota and Sethuraman introduced a commonality index for benchmarking product families based on the level of part commonality in the family.⁵ Simpson offers the following simple metric for evaluating product families in terms of part commonality:⁶

$$\% \text{ Commonality}_x = \frac{100 * \text{Common}_x}{\text{Common}_x + \text{Unique}_x}$$

In the above expression, the subscript “x” is used as a variable such that percent part commonality can be computed for any sub-system or component in the product family. For example, x might represent the imaging sub-system in a printer, in which

⁵ Kota, Sethuraman (1998)

⁶ Definition of percent commonality from Simpson lecture to MIT SDM class.

case a % commonality_{imaging} would represent the percent of common parts in all imaging sub-systems in the product family.

Finally, another advantage of a platform strategy is market coverage. Because development costs of derivative products are relatively low, platforms make it economically possible to produce products for small niche markets. Niche markets may be addressed by making small changes in the base platform and thereby leveraging sunk costs. MICR and custom color provide clear examples in the printing industry.⁷ Because these markets are relatively small, it would not be economically feasible to develop new products aimed at these markets from scratch; hence, platform strategies open the door to growth through niche markets.

Platform Architecture

Having reviewed the motivation for product platforms, let us now turn to platforms themselves. What are they and how are derivative products created from platforms? First, consider the definition offered by Michael McGrath in his book *Product Strategy for High-Technology Companies*:

A product platform is not a product. It is a collection of the common elements, especially the underlying core technology, implemented across a range of products. In general, a platform is the lowest level of relevant common technology within a set of products or a product line. These common elements are not necessarily complete in the sense that they are something that could be sold to a customer. A product platform is primarily a definition for planning, development, and strategic decision making.⁸

In their book *The Power of Product Platforms*, Meyer and Lehnerd offer the following definition of a platform:

Product families do not have to emerge one at a time. In fact, they are planned so that a number of derivative products can be efficiently created from the foundation of common core technology. We call this foundation of core technology the “product platform,” which is a set of subsystems and interfaces

⁷ The MICR market is relatively small and would not be economically viable if MICR products had to be designed from scratch. Likewise, in custom color, a specific version of spot color, a color toner is designed specifically for a given company, for instance, IBM blue; hence, given the limited market, custom color would not be viable if not based on an existing platform.

⁸ McGrath (1995, p. 39).

that form a common structure from which a stream of derivative products can be efficiently developed and produced.⁹

These two definitions are similar. McGrath emphasizes product lines with *common elements*. He then draws attention to a *common underlying core technology*, where the notion of a *core* technology is based on “the lowest level of relevant common technology”. Likewise, Meyer and Lehnerd characterize platforms in terms of a *common core technology* that underlies a product family. The emphasis on *common core technology*, as opposed to *common technology*, is designed to draw attention to commonality at a deep level, or in the words of McGrath, at the *lowest level of relevant common technology*. The implication here is that products based on a common platform may not have common technologies at a high level of detail. For example, the sub-systems and their individual parts may differ from one product to the next. Nonetheless, the sub-system technologies are common at a lower level. For example, although two printers in the same family may use different parts, they may be said to share a common platform if they are based on a common technology set. While McGrath, Meyer and Lehnerd appear to be shifting the focus of commonality from parts to a higher level notion of common technology, we shall find some motivation for *further broadening* the notion of commonality assumed in defining product platforms. In this broader concept, commonality is linked with both knowledge and process reuse as well as parts reuse.

What constitutes the right level of commonality within a product family is a delicate issue. Obviously, if everything were common then there would be no differentiation amongst the individual products and, in the limit, the product family would collapse into a single product. At the other extreme, low levels of commonality may provide significant product differentiation, but, in the limit, the product family collapses into a set of distinct products that do not leverage a common platform. *The dilemma of platform strategy is essentially providing as much variety for the market as possible with as little variety between products as possible.*

With this concept of platforms in mind, we now turn to the question of how are products derived from platforms? Tim Simpson describes two ways in which

⁹ Meyer, Lehnerd, (1997, xi).

derivative products are generated from a base platform.¹⁰ In the one case, the technologies of the base platform are *stretched* or *scaled* in order to create derivative products. One of the clearest examples of this strategy is found in Black and Decker's motor strategy.¹¹ In this case, a team of engineers designed a universal motor that could serve a broad range of products, such as, drills, sanders, saws, and grinders. Because the motor design they created was fixed in its axial diameter, the designers could create a standardized motor housing diameter for all power tools in the product family. Power scalability was achieved by simply adjusting the length of the motor. By stacking and wrapping more copper and steel around the backbone of the motor, a range of 60 watts to 650 watts could be achieved. Motor design standardization had breakthrough benefits in manufacturing. Variations in length, and hence, in power, could be produced "untouched by human hands", as the backbone of the motor "could be placed at the head of as mechanical assembly line and then stacked, welded, insulated, wound, varnished, terminated, and tested automatically".¹² Material, labor, and overhead costs were 31 cents per unit in the new design versus 51 cents in the old design. All motors could be produced on the same line because of the fixed axial dimension. Labor costs were therefore the same for the 65-watt and the 650-watt motor and the only variable cost was due to the amount of steel and copper required in each motor.

As the terms suggest, when derivative products are generated through *scaling* and *stretching*, some critical parameters within the base platform are simply scaled or stretched to new values, e.g., the length of the Black and Decker is scaled in proportion to power requirements. Printing platforms can be scaled in similar ways to create products at different printing speeds. Faster printing speeds are obtained by increasing the speed of the photoconductor and scaling the speeds of other elements in the system by the same ratio, e.g., paper path, development and fusing motors. Sometimes, however, performance at higher speeds can only be obtained by scaling elements in size as well as in speed. For example, it may be necessary to scale charging devices and development and fusing rolls in size in order to meet product specifications at higher

¹⁰ Simpson (1999, p.2)

¹¹ Meyer, Lehnerd (1997, p. 3-15)

¹² Meyer, Lehnerd (1997, p. 12)

speeds. Nonetheless, whether through speed, size, or some other scalable dimension, derivative products in these cases are obtained through the scaling or stretching of some critical parameters.

Scaling is one method for generating derivative products. A second method is based on *addition, substitution, or removal* of one or more modules. The Swiss Army Knife provides a simple example of how a single platform, through the addition, substitution, and removal of modules can serve as the base for a variety of products. A “knife platform” can be thought of as a metal case, covered in red plastic that bears the Swiss Army Knife logo. Within the case are spaces reserved for various types of modules, namely, knives, saws, scissors and screwdrivers. It is easy to imagine how a wide array of derivative products is easily obtained with this base platform. Through *addition, substitution, or removal* of these modules, a large number of product variants can be created. A similar type of platform strategy can be found in the printer industry. A printer platform, for instance, might support black and white, highlight color, and full color products. The black and white printer is the simplest product variant and has the smallest number of modules. A highlight color printer might then be generated by adding modules to the base black and white printer, and perhaps, substituting a different fuser for the black and white fuser. Adding the additional sub-systems needed to support cyan, magenta and yellow printing might then create a full color product.

In the first case, product variants are derived through scaling or stretching the critical parameters within some sub-systems. Let us call this method for generating variants, *product derivation through scaling*. In the second case, product variants are derived through adding, substituting, or removing modules. Let us call this method for generating variants, *product derivation through modularity*, since this method emphasizes the need for a “plug and play” modular design. Let us now examine a market segmentation matrix and illustrate how these two methods might be used to cover the market. Simpson and Meyer and Lehnerd discuss three types of platform strategies, namely, horizontal, vertical and beachhead platform strategies. Given the market segmentation grid for the printing industry (Figure 1), we shall see that vertical platform strategies tend to be based on product derivation through scaling, and horizontal platform strategies tend to be based on product derivation through

modularity. A combination of the two results in a platform strategy that spans the segmentation grid in both directions.

Meyer and Lehnerd introduced the concept of a “market segmentation grid” to provide a framework for evaluating alternative platform strategies.¹³ Major market segments are arrayed horizontally whereas the vertical axis is intended to distinguish price and performance characteristics, that is, a sort of good, better, best indicator. Figure 3 illustrates the market segmentation grid for ink jet printers as described by Meyer and Lehnerd.

Best			
Better			
Good			
	Desktop PC User	Portable Computer User	Home Office Small Business

Figure 3 Meyer, Lehnerd market segmentation grid for ink jet printing

In developing a suitable segmentation grid for xerographic printing it is necessary to capture two important dimensions that segment the market. The first dimension is printer speed. Printers in production environments must operate at very high speeds whereas those that operate in home offices may run at much lower speeds, i.e., prints per minute. The second dimension is *image type*, a phrase that is intended to distinguish black and white, MICR, highlight color, and full color imaging.

¹³ Meyer, Lehnerd, (1997, p.53)

Production > 100 ppm				
Office 35 to 100 ppm	←			→
SOHO 1 to 35 ppm				
	MICR	B&W	Spot Color	Full Color

Figure 4 Market segmentation grid for xerographic printing showing vertical and horizontal platform strategies

Figure 4 depicts a market segmentation grid for the xerographic printing market. Where production printing starts and office printing ends in terms of prints per minute (ppm) is debatable, nonetheless, the grid captures the essence of the market segments and can also be used to characterize the concepts of horizontal and vertical platform strategies. A vertical platform strategy in printing attempts *to span a range of speeds within a given imaging segment*. For example, one such strategy might be based on a black and white printing platform whose variants span a range of speeds from 50 to 100 prints per minute. A similar strategy might be used with the full color column. Here, a color platform might support variants ranging in speed from, for instance, 100 to 160 prints per minute. Whatever the exact range of speeds supported by the platform, the key attribute of a vertical platform strategy in printing is confinement to a single column, that is, a single type of imaging. We have seen that changes in speed are generally enabled through scaling and stretching, or what was previously labeled product derivation through scaling. Black and white speed variants, for example, are typically generated by increasing certain drive speeds, roll diameters, and so forth. Therefore, given the market segmentation grid illustrated in Figure 4, *vertical platform strategies are typically enabled by product derivation through scaling*.

Horizontal platform strategies, on the other hand, assume variants that differ in terms of image type but are constant in terms of speed. A hypothetical horizontal platform strategy is based on a platform whose variants are all at 60 ppm but of

different image type, namely, black and white, MICR, highlight color, and full process color. In general, horizontal change in the printing segmentation grid is not based on scaling, but on *addition, substitution, or removal* of one or more modules. Adding additional subsystems to black and white printer creates highlight color variants. Adding additional modules that can support cyan, magenta and yellow printing creates full color variants. MICR may require the replacement of one or more subsystems in the base black and white product. Therefore, whereas vertical platform strategies tend to be supported through scaling, *horizontal platform strategies typically require product derivation through modularity.*

In reality, platform strategies in printing tend to span both directions, requiring both scaling and “mix and match” modularity. At some point however, scaling typically gives way to replacement or addition of modules. While it may be possible to scale a platform across some range of speeds, at some point the sub-system technologies will not be extensible. In this case, vertical platform strategies may also rely on adding and substituting modules.

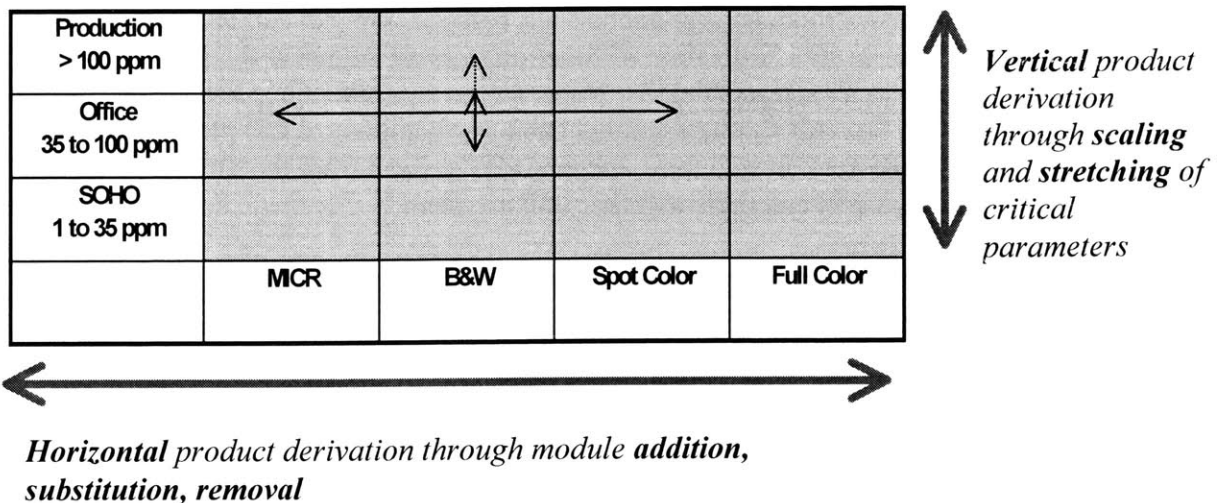


Figure 5 Mixed platform strategies with variants based on scaling and modular addition, substitution and removal¹⁴

¹⁴ A third dimension to the printer market segmentation grid is process width. This dimension can be imagined as extending into the paper, thus turning our grid into a three dimensional rectangle. Extensions of a platform in this direction are typically based on scaling parameters, e.g., width of frames, photoconductor and sub-systems. An 8 ½ inch process width supports 8 ½ x 11 inch paper short edge feed. An 11 inch process width supports 8 ½ x 11 inch paper short edge feed. For the same

Figure 5 illustrates a mixed platform strategy that spans the market segmentation grid both horizontally and vertically. Two types of vertical platform development are shown. The solid arrow depicts extension through scaling whereas the dotted arrow indicates additional extension, not through scaling, but by module replacement. For example, at some speed it may make sense to simply replace the development or fusing sub-system instead of trying to scale them. For this reason modular design may also be a key enabler *to vertical* as well as horizontal platform strategies. Because of the importance of the concept of modularity, let us now turn to a brief discussion of modularity and the distinction between modular and integral designs.

Modular Architecture and its Motivation

Modular design is critical to platform development, and we shall see, is also a key enabler to a product or platform design in which elements are outsourced. Fine and Whitney provide the following characterization of a modular architecture:

A product with a modular architecture has components that can be “mixed and matched” due to standardization of function to *some* degree and standardization of interfaces to an *extreme* degree. Home stereo equipment has a modular architecture; one can choose speakers from one company, a CD player from another, a tape deck from a third, etc, and all the parts from the different manufacturers will assemble together into a system.¹⁵

Clark and Baldwin offer the following characterization of a module:

A module is a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units. Clearly, there are degrees of connection, thus there are gradations of modularity.¹⁶

photoconductor speed, the prints per minute of the printer with an 11 inch process width is effectively $(11)/(8\frac{1}{2})$ greater than that of the printer with an 8 $\frac{1}{2}$ inch process width. An 11 inch wide process width can also support 11 x17 inch paper short edge feed. A 17 inch wide process width can support 11x17 inch paper long edge feed, thus increasing the effective prints per minute using 11x17 paper. Finally, 11x17 inch paper can be cut or folded in order to create two 8 $\frac{1}{2}$ x 11 inch sheets, thereby, in effect, doubling the 8 $\frac{1}{2}$ x 11 inch paper printing speed.

¹⁵ Whitney, Fine (1996, p. 10)

¹⁶ From Kim Clark, Carliss Baldwin, *Design Rules: The Power of Modularity*, p. 62.

The system architect plays the crucial role of partitioning the system into modules. Various maxims guide the architect in finding the optimal partitioning of a system; these include:

- ✓ Elements of the system should be chosen that are as independent as possible.
- ✓ Elements should have low external complexity and high internal complexity.
- ✓ The system architect should partition the system such that complex interactions are kept within module boundaries.
- ✓ In partitioning a system, choose a configuration in which local activity is high speed and global activity is slow change.
- ✓ In partitioning a system into subsystems, choose a configuration with minimal communications between the subsystems.
- ✓ Do not partition by slicing through regions where high rates of information are required.

These maxims, though expressed in different terms, all basically emphasize the importance of dividing a system into modules that have well defined and stable interfaces. Some of these maxims, however, emphasize that there are low rates of information exchanged between modules. But modular designs can have modules with high rates of information exchange. *It is not the number of interfaces between modules that is critical, but the clarity and stability of these interfaces.* For example, a cable connecting two components of a computer system may have many wires. But if the signal along each wire is clearly defined, for example, that a high signal on wire seven from module one to module two means the motor on module two should turn on, then engineering development of both modules can proceed independently and unambiguously.

Good system partitioning results in a modular design, which in turn is critical to both platform and outsourcing strategies. In the first case, a product with a modular architecture has elements that can be “mixed and matched”. A modular platform architecture will therefore support derivative products that are obtained by adding, removing, and substituting modules. In the second case, because of standardization of interfaces, modular designs lend themselves to outsourcing strategies. A supplier can work independently as long as it adheres to these interface requirements.

But it is important to note that not all systems can be cleanly decomposed into modules. In these cases, adjustments in one subsystem are made to accommodate parameters within other sub-systems and as a result the system must be designed as a single unit. The architecture in this case is referred to as an integral architecture. Fine and Whitney describe an integral architecture as follows:

A product with an integral architecture, on the other hand, is not made up of off-the-shelf parts, but rather comprises a set of components and subsystems designed to fit with each other. Functions typically are shared by components, and components often display multiple functions. Airplanes are an example. One cannot take a wing off the shelf from one supplier, an engine from another, avionics from a third, and expect to end up with a viable (flyable) system.¹⁷

A similar example in the xerographic printing industry relates to toner and the development and fusing sub-systems. Often, these three sub-systems are developed as a single module and adjustments are made in toner to accommodate fusing and development. Or, conversely, adjustments are made in fusing and development to accommodate toner design. The resulting architecture is not modular at the individual level of the fusing and development subsystems and toner; rather, modularity is only achieved on a larger scale that includes all three.

Although an integral architecture has clear disadvantages in terms of platform development and outsourcing, there are clearly many outstanding products that are based on this type of architecture. Sometimes integral architectures are unavoidable. In these cases, the system architect needs to assess the modularity of the system. This maxim is particularly applicable when it comes to outsourcing. As Fine and Whitney point out, serious development problems can result if non-modular components are outsourced. If, for example, the development sub-system is outsourced to one supplier, and toner and fusing to another, then the product development process can become very difficult to integrate. It becomes more difficult to keep partners out of each others' way and to concisely explain their individual sub-system requirements as opposed to the requirements of the system.

The various concepts introduced so far will help guide the discussion in the following sections. Before proceeding to these sections, a summary of these concepts,

¹⁷ Whitney, Fine (1996, p. 10)

and the definitions we will assume, is in order. A market segmentation grid is a two-dimensional array that segments the market according to two critical customer requirements. In the case of the printer market, I have segmented the market in terms of printer speed (prints per minute) and image type. Other market segmentation grids for the printer industry can be imagined and three dimensional market segmentation grids can be conceived. Process width might be used as a third dimension. In fact, even higher dimension market segmentation grids might be constructed, but simplicity is important, and often the most critical segments of a market can be captured with two dimensions. A product platform consists of an architecture and set of core technologies that are common to two or more products. These individual core technologies may also be referred to as platform elements since, together, they make up the platform. A product family consists of two or more products that are based on a common architecture and set of core technologies; hence, a product platform is the basis for a product family. The products within a family may not have all technologies in common, i.e., they may only share some common platform elements. For this reason, platforms and product families are matters of degree. A modular system can be partitioned into distinct modules that have well-defined and stable interfaces. The greater the modularity of a given system, the greater the number of modules fitting the above description. An integral system can not be partitioned into distinct modules that have well-defined and stable interfaces, instead, the system is developed as a whole. Of course, there are many systems that are more or less modular, and therefore the modular-integral distinction should be seen in terms of a continuum of possibilities.

With these concepts in mind, let us now turn to a discussion of product families and part commonality, platform strategies, and outsourcing. In the present section we have found strong motivation for part commonality, for platforms that support many derivative products, and for outsourcing certain modules within an overall system. In the following sections we will find similar motivation, but in all cases, motivation for these strategies will be accompanied by warnings about how these strategies can backfire if not applied with caution.

Section 2: Product Families and Part Commonality

In the previous section we considered some metrics for evaluating product families and platform strategies. One such metric is part commonality. The general claim is that good product families reuse a large percentage of parts, thereby eliminating new design work, new tooling and part testing. Although it is difficult to dispute this conclusion, it may pay dividends to examine the importance of part commonality in greater detail. For example, are there examples of highly successful product families whose members have few parts in common? Are there certain areas where part commonality is most important? Should non-commonality be accepted in certain areas of the design so as to enable part commonality in more critical areas? And finally, should the notion of part commonality be broadened so as to include other types of commonality and reuse, such as technology reuse, knowledge reuse, and manufacturing and assembly reuse? In short, it may be too simplistic to evaluate product families with a parts commonality metric and a requirement, for instance, that they should have 80 % common parts.

A Canon Product Family and Parts Commonality

The above questions will be addressed through an examination of the highly successful HP LaserJet 4L, LaserJet 4, and LaserJet 4si product family. The xerographic system for the LaserJet family is in fact made by Canon. This reflects the fact that Hewlett Packard's expertise relates to electronics as opposed to xerographic printing systems. Hewlett Packard provides the electronic "front end" and Canon provides the xerographic system. In addition to the HP LaserJet 4L, LaserJet 4, and LaserJet 4si, the Canon GP-55 is added to the study because, with it, we can determine if there is product commonality at higher printing speeds. Figure 6 provides an overview of the print speeds and various technologies used in these four products:

	HP-4L	HP-4	HP-4Si	Canon GP-55
PPM	4	8	17	30
DPI	300x300	600x600	600x600	600x600
Charge	Resistive conformable bias charge rolls	Resistive conformable bias charge rolls	Resistive conformable bias charge rolls	Scorotron
ROS	Single beam IR Ball bearing motor Plastic lenses	Single beam IR Ball bearing motor Plastic and glass lenses	Single beam IR Ball bearing motor Glass lenses	Single beam IR Ball bearing motor Glass lenses
Development	AC bias assisted jumping development	AC bias assisted jumping development	AC bias assisted jumping development	AC bias assisted jumping development
Toner	7 um styrene based resin with 50% magnetite and wax	7 um styrene based resin with 50% magnetite and wax	7 um styrene based resin with 50% magnetite and wax	9 um styrene based resin with 50% magnetite and wax
Photoreceptor	24 mm OPC DRUM	30 mm OPC DRUM	30 mm OPC DRUM	30 mm OPC DRUM
Transfer	Bias transfer rolls	Bias transfer rolls	Bias transfer rolls	Corotron
Cleaning	Elastomer molded blade cleaning	Elastomer molded blade cleaning	Elastomer molded blade cleaning	Elastomer molded blade cleaning
Fusing	Belt fuser	CHOL	CHOL	CHOL

Figure 6 Sub-system comparisons for HP-4L, HP-4, HP-4Si and Canon GP-55¹⁸

Figure 6 suggests that, in this case, Canon was able to produce a product family based on many common technologies. In general, the same types of sub-systems are used throughout the product family. Nonetheless, a more detailed examination of these products by Xerox engineers revealed that they actually have surprisingly few parts in

¹⁸ PPM stands for prints per minute. DPI stands for dots per inch. ROS stands for raster output scanner. A ROS sub-system typically consists of a modulated laser diode that illuminates a rotating polygon mirror that in turn reflects light onto the photoconductor. The ROS in this case is an IR ROS, meaning an infrared laser diode. OPC stands for organic photoconductor. CHOL stands for core heated oil less.

common. These results are summarized as follows on a sub-system by sub-system basis:

- ✓ Charge: Canon uses resistive, conformable biased charge rolls for HP-4L, HP-4 and HP-4Si, and a scorotron charging device for GP-55. The biased charge rolls in the three HP products, however, have different sizes and electrical parameters. *In general, the parts are not common.*
- ✓ ROS: The raster output scanners in all four products share a common architecture and layout, but *all parts are dissimilar across the family.*
- ✓ Development: Canon uses the same development technology in all four products, namely, AC bias assisted jumping development. *But different parts and electrical parameters are used across the product line.*
- ✓ Transfer: Canon uses resistive, conformable biased transfer rolls (BTR) for the three HP products and a corotron for the CP-55. The biased transfer rolls in the three HP products, however, have different sizes and electrical parameters. *In general, the parts are not common.*
- ✓ Cleaning: The cleaning blades for all four products have a similar design, *but are all different when it comes to details such as size.*
- ✓ Fusing: Core heated oil less (CHOL) fuser technology is used in the HP-4, HP-4Si, and GP-55. *But almost all of the parts are different.* The HP-4L, however, uses a belt fuser that provides instant on warm up. Belt fusing constitutes a radical technology departure from CHOL fusing but it provides *instant on* (no warm up time) and zero standby power consumption. Apparently, Canon judged these to be critical requirements for the HP-4L market.
- ✓ CRUs (Customer Replaceable Units): Canon uses a common CRU strategy across the product family, but the shapes and parts of the CRUs have *been uniquely scaled to fit the requirements of each product.*

Let us now return to the percent part commonality metric and use it to evaluate the Canon product family:

$$\% \text{ Commonality}_x = \frac{100 * \text{Common}_x}{\text{Common}_x + \text{Unique}_x}$$

If percent commonality is used to measure the effectiveness of a product family strategy, then clearly the HP LaserJet 4L, LaserJet 4, LaserJet 4si and Canon GP55 are a very bad example of a product family. In general, although the products in many cases share a common type of technology, sub-system parameters have been scaled in order to provide performance at the product speed (ppm). As was noted in section one, what we find in this case is an example of a vertical platform strategy in which derivative products are obtained through scaling. In some cases, however, there are technology changes, for example, the highest speed product, the GP-55, uses different charging and transfer technologies than the other products in the family. Again, as pointed out in section one, at some product speed, derivation of variants through scaling must give to product derivation through replacement of one type of technology with another.

Beyond Parts Commonality

Nonetheless, although the product family gets a low rating using a simple percent commonality index, there is strong evidence that these products *do form a family, and a highly successful product family*. There is a strong intuition that, as with part commonality, each of these products *leverages* investments made in other products in the family.

These products form a strong family in terms of (1) shared technology and general architecture, and (2) shared manufacturing and assembly processes. With minor exception, the same basic technologies are used throughout the product family. For example, blade cleaners are used in all four products, although their size and shape varies from one product to the next. The same is true for jumping development, transfer based on biased transfer rolls, charging based on biased charge rolls, and fusing based on core heating without oil. In fact, there are many examples where Canon has used the same technology across even broader product families and over longer

timeframes. Canon jumping development, for instance, has been used in many Canon products besides those discussed in this study.

A common technology means that these products leverage existing engineering knowledge. The knowledge that is reused in this case has many facets, ranging from reuse of test plans, failure mode analysis and diagnostics, to reuse of design knowledge pertaining to subsystem critical parameters. In general, technologies typically evolve within an infrastructure that is specially suited to their development. Test equipment, test patterns, test plans, and so forth, are all tailored to a technology; hence, with technology reuse comes reuse and leveraging of these investments. Canon's engineers must have an excellent understanding of the technologies used in this case study. They must understand sub-system failure modes and critical parameters in order to configure and customize the subsystems to the needed shape, size, speed, or cost demanded by a given product in the family. Although sunk costs in *part* development are not significantly leveraged in this product family, sunk costs in *developing knowledge and engineering competencies* related to these technologies are clearly leveraged.

Equally important, the products within this family leverage common manufacturing processes and assembly procedures. Although the cleaning blades used in each product are different, they are all formed with the same elastomer molding process. Furthermore, analysis of these products reveals that there is very high commonality in terms of the materials used to fabricate the piece parts. Canon appears to have mastery of a few common materials, manufacturing processes, and assembly processes that they use to make piece parts of whatever shape or design that is required for a given product variant. In terms of common assembly processes, the fuser, CRU and ROS modules all appear to enable common assembly processes, thereby reducing the cost of assembly.

These results suggest that the simple metric of part commonality may be overly simplistic and may benefit from some modification. Good product families reuse engineering, architectural knowledge, and design paradigms. They reuse product development infrastructures that include test plans, test equipment, failure mode analyses, and so forth. A better, richer, metric for evaluating product families would go beyond part commonality and take account of technology and knowledge reuse as well

as commonality in other aspects of the product delivery process such as manufacturing material and processes, including assembly processes. In the extreme, effective concepts of commonality and reuse would cover the entire product delivery and support chain, ranging from research and development, to manufacturing, to distribution channels, to customer support and maintenance.

When Part Commonality Should Drive Design

Nevertheless, the traditional emphasis on parts commonality finds some support from our analysis of the Canon product family. Up to this point, we have avoided discussion of toner and the photoreceptor sub-system. There is good reason for this omission. In xerographic printing systems, both toner and photoreceptors are regarded as *consumables*, and, in general, consumables are critical to the printing business model. Unlike other sub-systems in a printing system, toner and photoreceptors are “consumed” and replaced many times during the life of the product. A toner bottle becomes empty every few thousand prints and a photoreceptor drum may last on the order of 100,000 prints. For this reason, the cost of these sub-systems is more critical to the business case than that of other sub-systems. And it is for this reason, I suspect, that the Canon product family exhibits not only *technology commonality when it comes to consumables, but also part commonality*. Through commonality of consumables, Canon is able to reduce cost in this critical area through economies of scale.

The 30 mm photoconductive drum is a good case in point. Canon has used the 30 mm aluminum core drum since 1984 and in a variety of products including the HP-1, HP-2, HP-IIP, HP-3Si, as well as the HP-4, HP-4Si and GP-55. Canon standardized on 30 mm drums until 1993 when the HP-4L was launched with a 24 mm drum. The use of a standard 30 mm drum enabled Canon to fully utilize the capacity of its photoreceptor plants and thus reduce drum unit manufacturing cost (UMC).

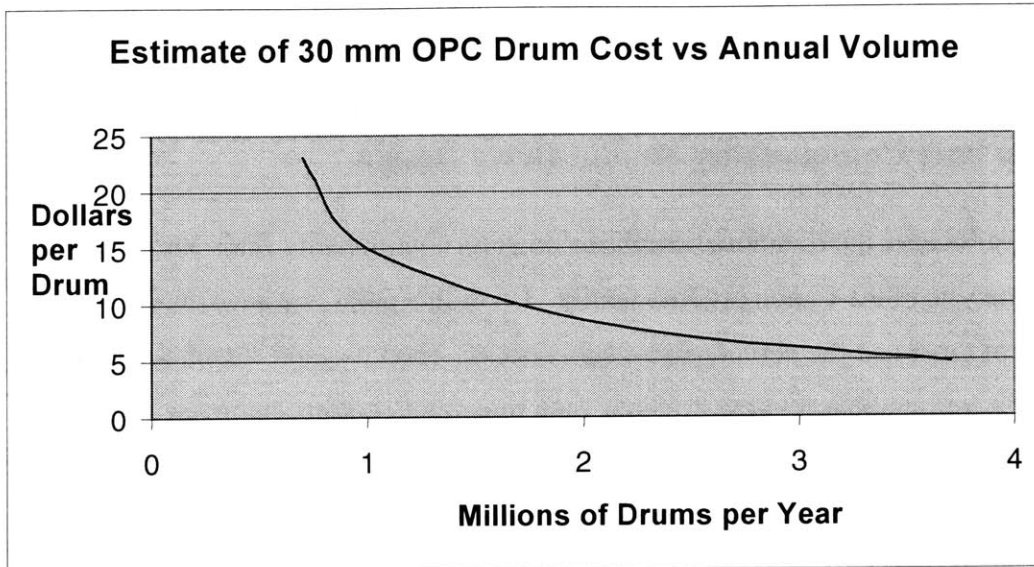


Figure 7 Estimated cost of 30 mm drum versus volume in millions

Figure 7 provides an estimate of the impact of drum volume per year on drum UMC.¹⁹ Imagine two cases. In the first case, the LaserJet 4, LaserJet 4si and the GP-55 all use a common 30 mm drum and the annual combined drum volume is three million. The total cost of these drums is about 18 million dollars. If, on the other hand, the LaserJet 4, LaserJet 4si and the GP-55 did not use a common 30 mm drum and we assume one million in annual volumes for each drum and fifteen dollars per drum, then the total drum cost would be on the order of 45 million dollars. Therefore, drum commonality in this case could save as much as 27 million dollars in manufacturing costs. Nonetheless, with the LaserJet 4L, Canon decided to break with the 30 mm drum standard and use a 24 mm drum; hence, for the LaserJet 4L, the benefit of a smaller sized drum outweighed the economies of scale due to large drum volumes. A smaller drum implies that either more components can be packed into the same volume or that the overall volume of the printer can be reduced. Marketing advantage, in terms of

¹⁹ Xerox internal report estimate of impact of drum volume on Canon drum cost.

fitting increased feature/function into the box, or decreasing overall printer “footprint”, appears to be the source of motivation for this change.²⁰

Toner is a second example of a xerographic consumable that will benefit from economies of scale. The HP LaserJet 4L, LaserJet 4, and LaserJet 4si use the same toner, a 7 um styrene based resin with 50% magnetite and wax.²¹ Economies of scale resulting from common toner can be quite significant. Toner manufacturing plants cost millions of dollars. The fixed overhead of the plant is amortized over the volume of toner produced; the greater the volume, the cheaper the toner.

Toner and photoconductors are to the xerographic industry as razor blades are to the shaving industry. A significant portion of total revenue comes from the repeated sales of these consumables. These results support the view that, while part commonality may not be critical in certain design areas, it may be imperative in other areas. Furthermore, these results suggest the following thesis—*part non-commonality is forced into certain design areas in order to preserve commonality in more cost critical areas*. Evidence for this thesis can be found in the Canon sub-system designs that impact toner and drum design.

In xerographic systems, the development and fusing sub-systems and the toner design are highly interactive. All three HP products discussed above, the HP-4, HP-4L and the HP-4Si, have jumping development and fusing sub-systems that have very few parts in common. Nonetheless, they all use identical 7 um, 50 % magnetic toners with wax. This suggests that that in order to adapt these printers to different requirements, such as prints per minute, Canon has forced part non-commonality into the development and fusing sub-systems in order to enable the use of a common toner. Alternatively, Canon might have changed toner formulation in order to adapt to higher speeds, but instead, they localized change in development and fusing so as to gain the economic advantage of a common toner for these products.

²⁰ Another possibility is that the smaller drum was needed in order to enable belt fusing as opposed to CHOL fusing. Note that the LaserJet 4L is the only product in the family with belt fusing. Belt fusing is important to the LaserJet 4L because it provides instant fusing warm-up and no waiting to make prints.

²¹ Wax is added to toner in order to eliminate the need for applying oil to the fusing roll for release purposes.

Likewise, the HP-4, HP-4Si and GP-55 use 30 mm photoconductive drums with the same under coating layer (UCL). On the other hand, the sub-systems that strongly interact with the drum have few or no parts in common, e.g., the biased charging roll sub-system, the biased transfer roll sub-system, and the laser imaging system. Again, this suggests an architectural principle that accepts non-commonality in certain sub-systems so as to preserve part commonality in the cost critical consumable area. This is not to say that the drums in the HP-4, HP-4Si and GP-55 are identical. Performance across this speed range could not be achieved without some modifications in drum design. Nonetheless, differences in drum design are localized to the top coatings that are applied to the core drum, thus preserving the economies of scale of the basic drum.

In summary, two arguments have been derived from the Canon product family case study. First, great product families may have members that have surprisingly few parts in common. This problem was addressed by characterizing a broader concept of commonality and reuse that includes knowledge, infrastructure, and manufacturing process reuse. The second argument essentially qualified the first argument and stated that, in certain critical cost areas, part commonality is key to the success of a product family. In printing, these areas tend to be what we call “consumable” parts and materials, and in order to maintain commonality in these areas, non-commonality in closely related areas may be increased.

Section 3: Platform Strategies-- Proceed with Caution

Vestige—a trace or visible sign left by something vanished or lost²²

Platform strategies can go awry. Leveraging a common set of core technologies in order to generate a variety of products is clearly an attractive proposition. Nonetheless, platform strategists need to proceed with caution, and, in particular, they need to clearly recognize any compromises involved in enabling several derivative products with a single platform. In order to understand these cautions about platforms, let us begin with an example of a platform in which these cautions are less applicable and then proceed to a more troublesome case in printing.

The Black and Decker electric motor platform that was discussed in the first section provides an example of a platform strategy that involves little or no compromise. In this case, a team of engineers designed a universal motor that could serve a broad range of products, such as, drills, sanders, saws, and grinders. Because the motor design they created was fixed in its axial diameter, the designers could create a standardized motor housing for all power tools in the product family. The power tool housing could be the same for drills, sanders, jigsaws and grinders. Power scalability was achieved by simply adjusting the length of the motor. By stacking and wrapping more copper and steel around the backbone of the motor, a range of 60 watts to 650 watts could be achieved.

The key question at this point is, did the motor platform strategy compromise certain products in order to enable other products? For example, did designing a motor platform that could support a higher power saw compromise the lower power drill? In other words, if platform considerations were not a factor, would some products have been more optimal with a different motor housing diameter? My suspicion is that there is very little compromise in this case. Greater power is achieved by simply adding length to the motor stack and adding more copper and steel windings. The 60-watt

²² Webster's New Collegiate Dictionary

motor is short in length and the 650-watt motor is long. Each product pays in proportion to its power requirements.

Unfortunately, however, platform strategies often require compromising one product for the sake of another. To see this point, let us return to the market segmentation grid for xerographic printing:

Production > 100 ppm				
Office 35 to 100 ppm				
SOHO 1 to 35 ppm				
	MICR	B&W	Spot Color	Full Color

Figure 8 Market segmentation grid for xerographic printing showing vertical and horizontal platform strategies

In section one, it was argued that whereas vertical product families have common subsystems that have been scaled to the appropriate speed, horizontal product families are based on a mix and match platform strategy that is enabled through modular design. A spot color printer, for instance, is derived from the black and white base architecture by adding modules needed for spot color charging, exposing and developing. The full color printer, on the other hand, is derived from the spot color printer by adding more sub-systems in order to enable black and white, cyan, magenta, and yellow image development.

Although the above “plug and play” characterization of how color products are derived from the base black and white platform seems very attractive, it overlooks required compromises to the black and white product. Expressed differently, a black and white product that must support color extensibility will be different from one that does not require color extensibility. Furthermore, the difference is not simply that one of these architectures will leave room for color sub-systems. Rather, the sub-systems

used for black and white will be different in the two cases and, in the case where color extension is enabled, the black and white sub-systems will be compromised.

In general, not enough attention has been paid to how platforms trade-off the performance of one product so as to enable another. An ideal decision tool for selecting between alternative platform strategies will take account of these compromises as well as the risk associated with developing each product, i.e., the probability that a product may never go to market.

Platform Strategy Gone Awry

A platform architecture that enables both black and white and color will typically do so at the expense of the performance of the black and white variants. The performance impact may be in the form of printer cost, consumable cost, reliability, or time to market and development costs. All of these factors must be considered before adopting a platform strategy. Furthermore, the situation may become much worse if the product variants (color) that forced the compromise in other products (black and white) *never make it to market*. In this case, the products that go to market are marked with the vestiges of products that never make it to market. The good intentions of the platform strategy have gone awry.

A typical path to this pitfall is as follows. Suppose that after marketing has identified the most important market segments, product planning decides that four products are needed to address these market segments. Let us call these products A, B, C and D. System architects then develop high level designs of a base platform that can support these products. Often, though not necessarily, a platform that enables one product compromises another product. For instance, enabling product D might disadvantage product A in terms of time to market, quality, reliability, or cost. Nonetheless, compromising product A is justified by the prospect of product D. Suppose development of the base platform and products A and D then proceeds in parallel. Now suppose that after a year of development it is determined that product D can not meet its objectives in terms of time to market, quality, reliability, or cost, and management cancels the product. Product A, on the other hand, is half way through its

development cycle and although product A is compromised by a base platform that was designed to enable product D, it is too late to turn back. Of course, it is possible to start over again and base product A on a different platform, one that isn't compromised by the requirements of product D. But getting to market in a timely manner often outweighs such considerations; hence, product A is brought to market compromised.

Some specific examples of this phenomenon may happen when platforms are designed to support both black and white and color printing. In such cases, product A is a black and white product and product D is a color product. I will use the example of an "image on image" architecture, such as that used by Konica in the early 1990s, to illustrate the point. Figure 9 shows a *generic* single-pass image on image color printing architecture and is not intended to represent any one product in particular:

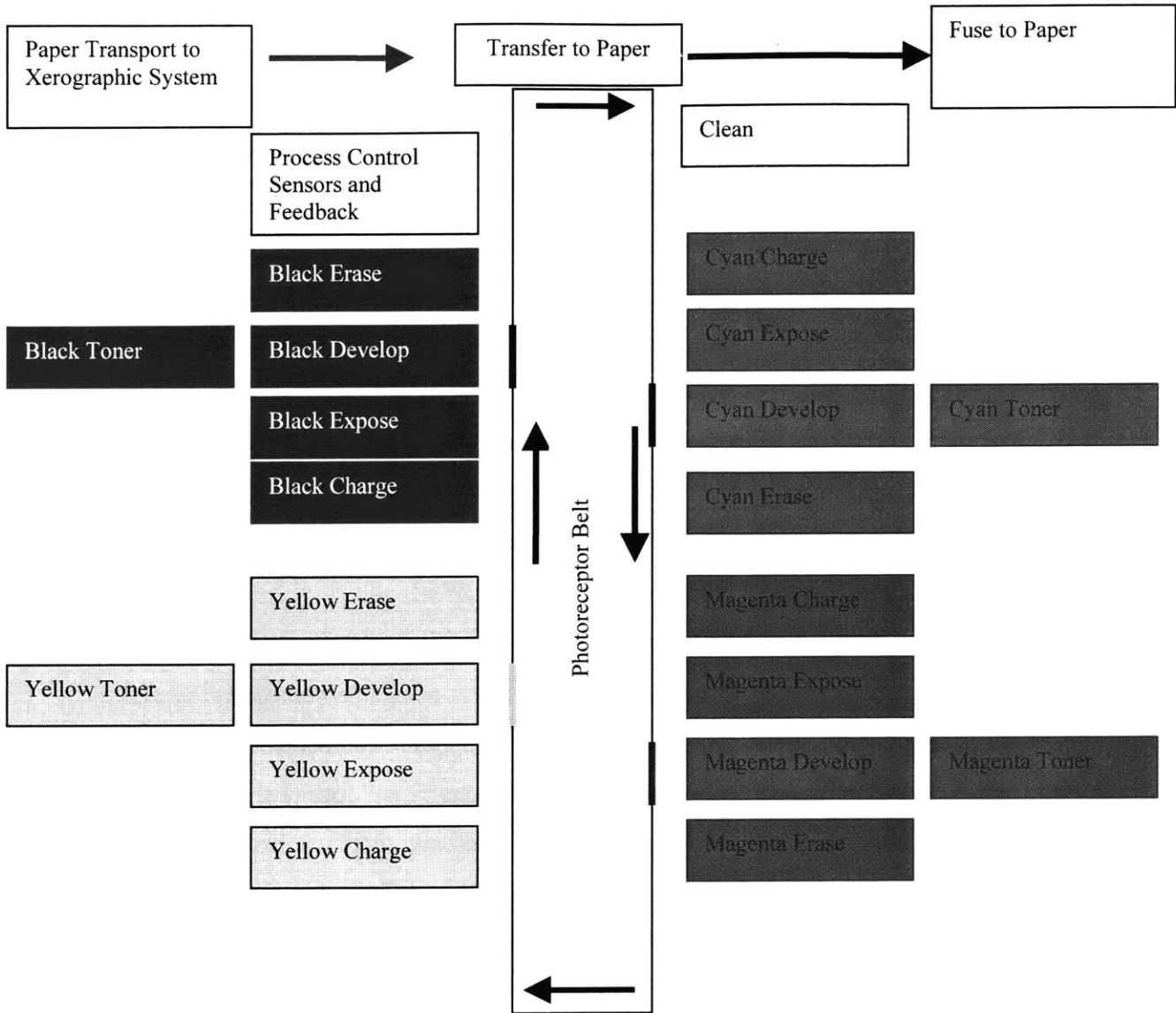


Figure 9 Image on image color printing architecture

Figure 9 essentially consists of the development of four images onto the photoreceptor. The resulting cyan, magenta, yellow, and black image is then transferred to paper and then fused to paper. First, the photoreceptor is charged and then, via the exposure sub-system, discharged in only those areas where we want to develop cyan toner. The same process is repeated development magenta, yellow, and black toner onto the photoreceptor, but in these cases, toner must be developed onto

existing toner, and the exposure sub-systems must expose through existing toner in order to discharge the photoreceptor.

There are various advantages to an image on image architecture including the ability to make a full color image in one revolution of the photoreceptor belt.²³ Furthermore, it is easy to see how the above platform supports black and white, spot color, and full color products. A black and white product can be derived by simply removing the sub-systems relating to cyan, magenta, and yellow imaging. Likewise, a spot color printer can be derived by removing all of these sub-systems except those needed to develop one color. With spot color, the toner color will most likely be blue or red, instead of one of the primary additive colors used in full color printing, e.g., cyan, magenta and yellow. In this respect, an image on image architecture clearly supports a “plug and play” strategy for developing several variants from a single base platform.

But these advantages are not gained without some cost, and the cost is in the form of compromising the black and white product. First, as can be seen from Figure 9, an image on image architecture requires a large photoreceptor circumference. The photoconductor circumference must provide enough “waterfront” for all of the cyan, magenta, yellow, and black sub-systems. Generally speaking, there are two types of photoconductors used in xerographic engines, namely, belts and drums. Belts are currently available in sizes that can provide the needed waterfront whereas drums are currently limited to smaller sizes. For example, the circumference of the belt used in the Xerox Docutech product is nearly seven feet. On the other hand, some of the larger drums available today have a diameter only on the order of 180 mm. Hence, the extensive waterfront requirements of an image on image architecture force a belt-based architecture. The black and white product may be compromised in the process because the running costs of drums tend to be less than the running costs of comparable belts. The photoreceptor running cost is essentially the photoconductor life (in copies) divided by the cost of the photoconductor. Small differences in running costs can have

²³ The advantages and disadvantages of image on image architecture will be discussed in the next section when this architecture is compared to an “intermediate belt transfer” architecture. Image on image, for instance, requires fewer photoconductors than “intermediate belt transfer” architectures and does not require an intermediate belt.

significant impact within a low-margins, commodity-like, black and white market. Although image quality, ease of use, and various features once differentiated black and white printers, today, there is little difference in these respects. Running costs have come to the forefront and in this respect an image on image color platform may compromise black and white competitiveness.

In addition, an image on image platform can increase black and white running costs by increasing black and white toner costs. Assuming the ordering of colors indicated in Figure 9, image on image printing requires developing the magenta image onto the cyan image, the yellow image onto the magenta and cyan image, and the black image onto a combined yellow, magenta and cyan image. Generally speaking, developing images *onto* images requires a special type of development system that is capable of developing images onto images without disturbing the quality of these images. Development systems of this type tend to be less robust and may require (1) more expensive toners in order to achieve the required latitude as well as (2) more time to optimize the system before going to market. As we saw in section two, consumables like toner and photoreceptors are critical to the printing business model. Toner running cost is equal to the cost of a pound of toner divided by the number of copies per pound and an increase on the order of five cents per thousand copies can introduce a significant disadvantage in the commodity black and white printing business.

Finally, the difficulty of developing image onto image may impose additional constraints on the process width of the printer. Image on image development is inherently difficult and this is typically reflected in narrow operating windows and insufficient latitude. Development latitude can only be further reduced if development width is increased. Therefore, selecting an image on image platform architecture so as to enable full color product variants (horizontal strategy) may compromise platform extensibility in the third dimension, namely, process width.

In summary, these examples show how a platform strategy can compromise individual products. But now suppose development of the color products encounters persistent problems and the color programs are cancelled. Development of the black and white variants, on the other hand, proceeds according to plan but with greater difficulty than if originally based on a black and white only platform, that is, a platform

optimized for black and white products only. Furthermore, the cost and reliability of the black and white products are compromised because of an overly aggressive platform strategy. It would, of course, be possible upon cancellation of the color products to turn back and base the black and white products on a platform customized to black and white only, i.e., use a drum, a different development system, and cheaper toner. But the resulting program setback may be unacceptable from a time to market perspective.

The above story would not be of general interest if it only told us something about a problem unique to a certain printing strategy. But undoubtedly, *the same sort of platform problems arises for products in other industries*. By their very nature, platform strategies drive compromises into certain products. The aim of a platform strategy is essentially to provide as much variety for the market as possible with as little variety between products as possible. Something must give and it is usually in the form of products that, driven by platform commonality constraints, are not ideally tailored to the requirements of their respective markets. Given a problem that is common to platforms in general, there is motivation for a general solution that is not specific to printing platforms. The following list of procedures may prove useful in this respect:

1. Create a market segmentation grid for your product line
2. Identify the most important market segments. Assign weights to market segments in terms of importance. Assign highest weights to areas where market growth and high margins are anticipated. If data is available, weights might be based on projected ROI or NPV.
3. Characterize a platform that can span these market segments. Identify the core sub-system technologies and general architecture of this platform.
4. Now, forget platforms and simply identify the optimal product for addressing the market segment with the highest weight. Characterize the architecture and sub-systems of each of this product.
5. Construct a table that compares the sub-system technologies and architecture used in the platform case (step 3) and in the non-platform case

(step 4). Identify sub-systems that are compromised and determine type of compromise, e.g., cost, reliability, time to market, etc.

Sub-system	Subsystem assumed in platform case	Subsystem assumed in non-platform case	Platform compromise
A	A1	A1	None
B	B1	B2	More costly
C	C1	C2	Lower reliability
D	D1	D2	Increased time to market
E	E1	E1	None
F	F1	F2	Lower quality
G	G1	G2	Lower productivity
H	H1	H1	None

Figure 10 Platform versus non-platform compromise matrix

6. If no significant compromises are made to products then platform strategy may be viable. Repeat steps 4 and 5 for product with next highest weight product, and then next highest weight product. Use resulting compromise matrices and judgement to decide viability of platform strategy. If little or no compromise is encountered until relatively low weight product, the platform strategy is attractive.
7. If significant compromises are made to products with relatively high weights then attempt to eliminate compromises by developing a platform strategy that does not support lowest weight product. Repeat step 5 and determine whether compromises are eliminated and were therefore driven by lowest weight product.
8. If compromises are eliminated, consider a platform strategy that does not support lowest weight product.
9. If compromises are not eliminated, repeat this step by developing a platform strategy that does not support the next to lowest weight product.
10. If compromise to highest weight product is not eliminated, repeat this process using a platform strategy that does not address the next to next lowest weight product, and so forth.

11. If significant compromises to the highest weight product are not eliminated until all other products are eliminated, then the highest weight product should be developed as a single point product. Examine platform strategies for remaining products.

Figure 11 illustrates the process of *pruning a product family* until compromises to the most valued products are eliminated. At the start, the proposed platform is intended to cover market segments A through H. Product F is the most valued product within the family and its is shaded in dark gray to indicate that significant compromises are made to product F in order to enable the family. Next, by eliminating products C and G (the least valued products), the compromise to product F is reduced (now shaded with light gray). Finally, by eliminating products A and B, product F is no longer compromised in any respects, i.e., it is essentially the same product as the firm would design if no platform considerations were taken into account.

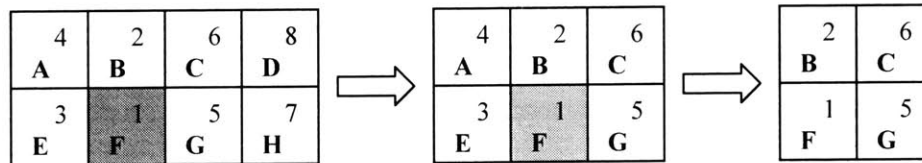


Figure 11 Graphical illustration of platform pruning process

Reducing the Risk in Platform Strategy

Another approach for evaluating platform strategies is based on NPV's and probabilities of success. Although these numbers might only be roughly estimated, even a coarse NPV risk analysis may provide significant guidance in developing a platform strategy. For example, suppose the platform choice is between developing a black and white only platform and a platform that supports both color and black and white products. Furthermore, suppose that there are several color and black and white variants, some of which are copiers, some printers, and some are multifunctional copiers and printers. In addition, suppose these variants are further distinguished in terms of speed, that is, the number of copies or prints they can generate per minute.

The resulting product family then consists of color and black and white printers, copiers and multifunction machines of various speeds. Alternative platform strategies can be analyzed with an NPV decision-tree like that shown in Figure 12:

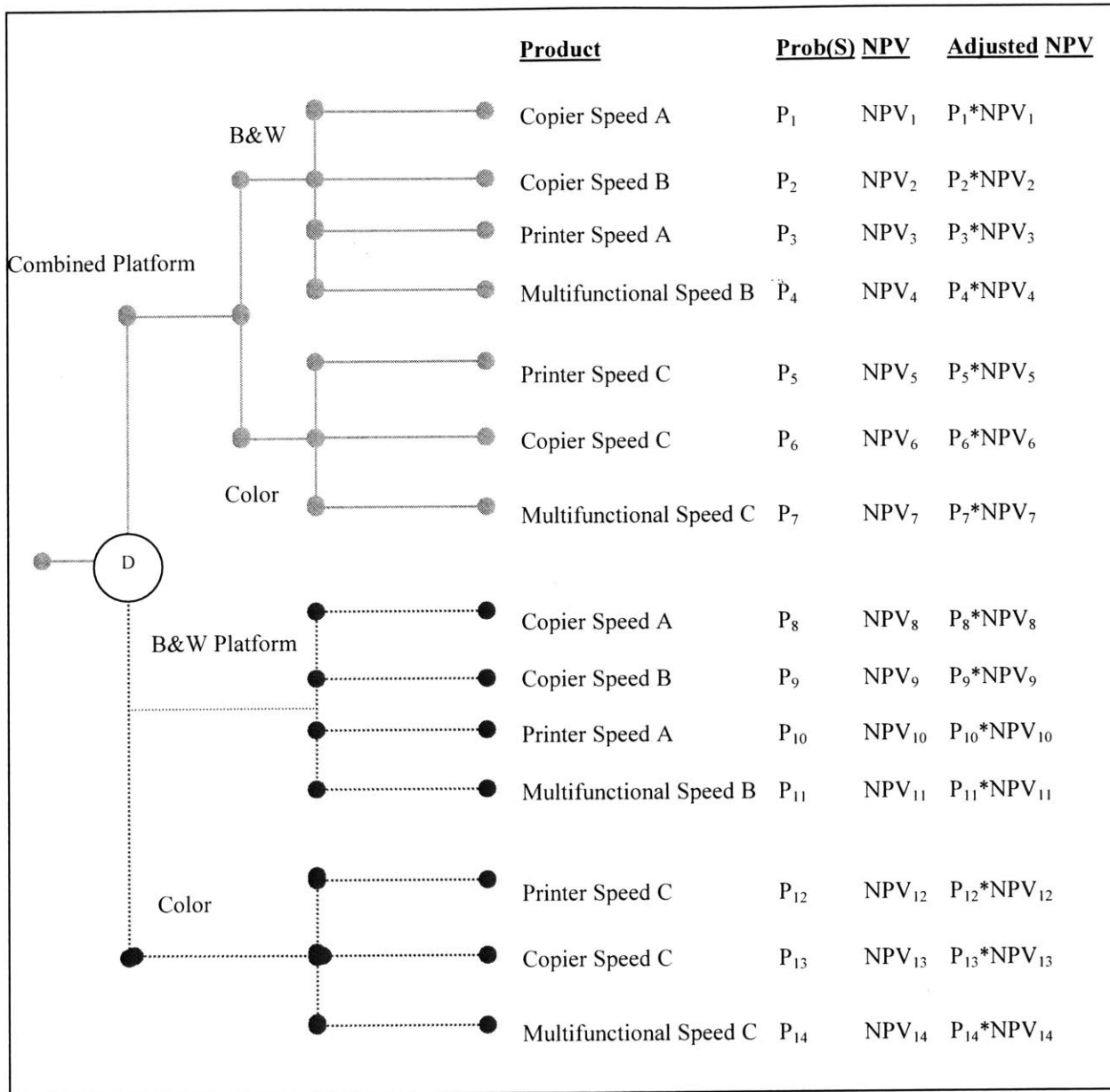


Figure 12 Decision tree for platform strategy

Figure 12 characterizes each product in terms of a projected NPV and a risk factor P that indicates the probability that the product will go to market. The decision tree is divided into two major branches following the decision node D . The top half of the diagram shows the seven color and black and white products as variants of a single

platform. The bottom half of the diagram shows an alternative strategy that bases the color products on a unique color platform and the black and white products on a unique black and white platform. The estimated total NPV for the products based on the combined color and black and white platform is:

$$NPV_{c,b\&w} = \sum_{n=1}^{n=7} P_n \times NPV_n$$

The estimated total NPV for the products based on the black and white only platform and the color only platform is:

$$NPV_{b\&w} = \sum_{n=8}^{n=14} P_n \times NPV_n$$

Given the previous discussion about how platforms compromise products, we would expect that the probabilities of going to market are higher in the case in which two separate platforms are used since the individual products are less constrained by platform considerations in this case. Mathematically, this is expressed by $P_1 < P_8$, $P_2 < P_9$, and so forth. Nonetheless, in leveraging a common platform, products P_1 to P_7 may have lower development costs and manufacturing costs than products P_8 to P_{14} . Hence, the decision as to whether to use a single platform or two platforms for black and white and color may not be obvious but this type of NPV analysis may be valuable when reviewing platform strategies *even if* the product development and marketing team is only making best guesses. Even best guesses may give some clear direction if the differences between the two strategies are large enough. Alternatively, this method might be used to calculate various *breakpoints*, such as the NPV that some product would need to have before we would prefer one platform strategy versus another. And finally, if nothing else, this type of exercise at least forces companies to become aware of tradeoffs that otherwise might be glossed over.

Section 4: Platform Architecture and Weak Modularity

Importance of Architectural Modularity to Product Development

In the previous section we focused on tradeoffs involved in overextending a platform strategy. In this section, we turn to platform architecture. An important attribute of both platform and product architecture is modularity. A better architecture allows partitioning of the system into modular units that can be developed independently and asynchronously of one another. A non-modular architecture cannot be partitioned into modules that allow for independent design and development. Everything depends on everything else. Tasks relating to subsystem A depend on tasks relating to subsystem B and tasks relating to subsystem B depend on tasks relating to subsystem A. As a result the whole system is developed within a sort of iterative feedback loop. With a more modular design, tasks can proceed more independently and, as we shall see in the following section, this is a key enabler to an outsourcing strategy.

Alternative product architectures are often evaluated in terms of cost, reliability, and quality. Modularity of design, however, is not always fully appreciated in this context. Non-modular designs present problems for outsourcing strategies and platform strategies based on product derivation through modularity. But for the moment, we will focus on the effect of non-modular design on the product development process. Given an integral architecture, tasks become iterative and depend on feedback from other tasks that in turn await feedback from other tasks. For these reasons engineering and planning become more difficult. In illustrating these points, we will examine two alternative architectures for color printing—image on image (IOI) and intermediate belt transfer architectures (IBT). We shall see that although there may be cost arguments in favor of the image on image architecture resulting from fewer subsystems, its architecture is less modular than an intermediate belt transfer architecture and this creates issues for product development. The end IOI product may be superior than an IBT product, but managing the product development process may be very challenging.

Image on Image and Intermediate Belt Transfer Modularity

Figure 13 illustrates a generic image on image architecture. The Konica 9028 used this type of architecture, although Figure 13 is not intended to represent any specific product:²⁴

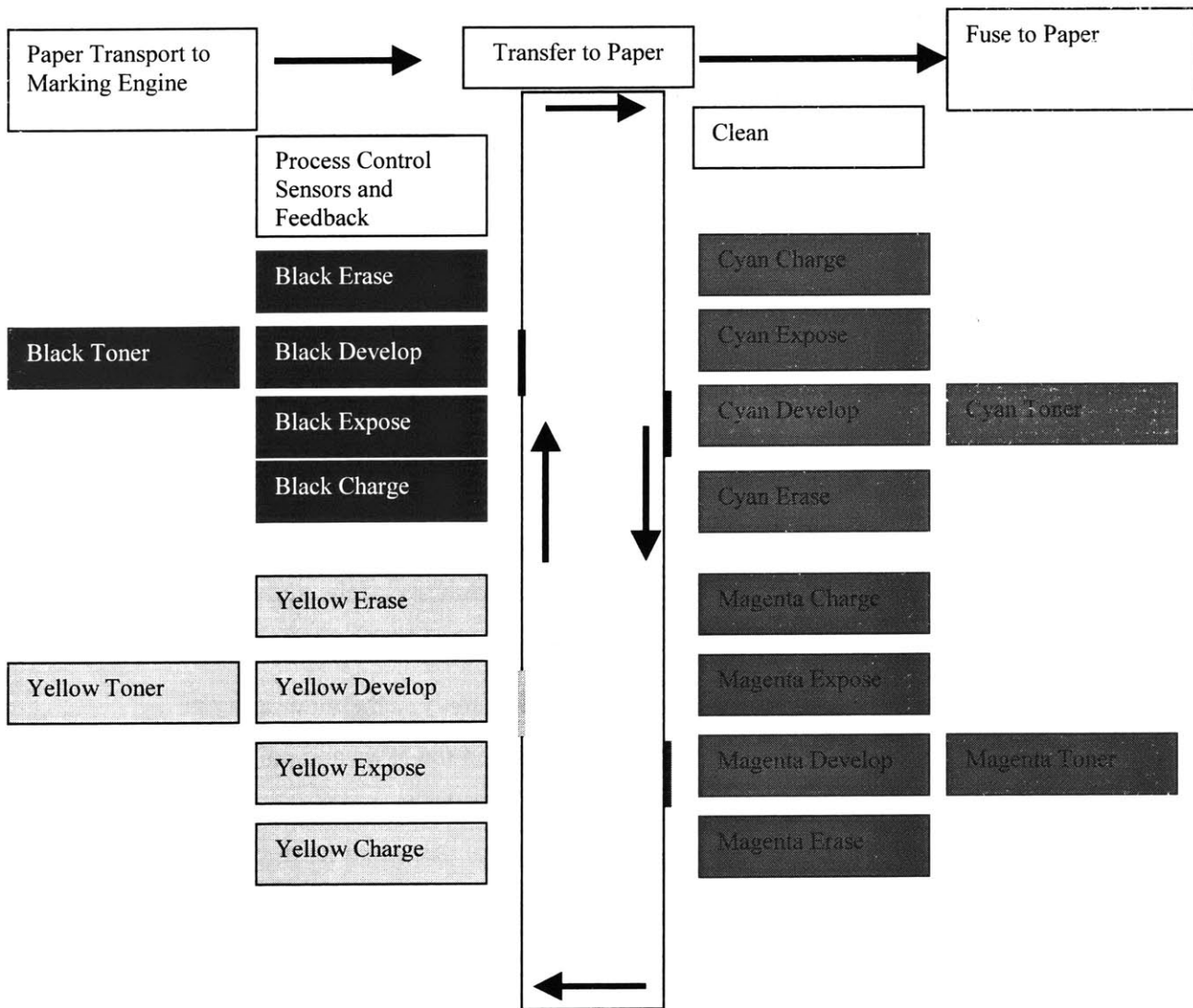


Figure 13 Image on image architecture for color xerography

²⁴ The Konica 9028 uses an image on image architecture but requires four passes to make a single print, one for each color. This means they need four development stations but can use the same imaging charging subsystems for all four colors; hence, productivity is traded off for cost and space. But whether

To examine the modularity of an image on image architecture, consider the process of developing a magenta image on the photoreceptor. The magenta exposure sub-system will have to expose *through* cyan toner in order to discharge the photoconductor; hence, the level of discharge will depend on the pile height of the cyan toner. Furthermore, the development of magenta toner will depend on the charge of the cyan toner on the photoconductor and other general problems associated with developing magenta toner on top of cyan toner. The problem is further compounded in the case of yellow since now cyan and magenta have already been developed. The exposure system for yellow must image through magenta and cyan toner and the development system for yellow must develop on top of magenta and cyan toner. Following this thought process, it is easy to see why the problem is even further compounded in the case of exposure and development for black.

The architecture for image on image printing is relatively non-modular because of several iterative feedback loops in the design process. Without these loops, the development of the individual modules for each color could proceed more independently and asynchronously. With these loops, the development of individual subsystems is linked to the completion of certain tasks related to other subsystems that in turn depend on the completion of other tasks. The modularity of the xerographic system is large scale since the system does not cleanly partition into smaller modules.

Design Structure Matrices (DSM) can be used to analyze the modularity of a system. By placing the various sub-systems of a system in the rows and columns of a matrix, dependencies between subsystem development can be shown by placing an X in the appropriate box. For example, placing an X in the box identified by the magenta development row and the cyan development column captures the fact that completing magenta development tasks depends on completing cyan development tasks. Conversely, placing an X in the box identified by the cyan development row and the magenta development column captures the fact that cyan development tasks depend on the completion of magenta development tasks.

an image on image architecture requires four or one pass to make a print, it still requires developing toner on top of toner.

	Cyan Charge	Cyan Expose	Cyan Development	Cyan Erase	Cyan Toner	Magenta Charge	Magenta Expose	Magenta Development	Magenta Erase	Magenta Toner	Yellow Charge	Yellow Expose	Yellow Develop	Yellow Erase	Tellow Toner	Black Charge	Black Expose	Black Development	Black Erase	Black Toner	Photoconductor	Transfer	Fuse	Mechanical Module	Process Controls	Cleaning
Cyan Charge	X							X				X						X			X			X		
Cyan Expose		X																			X				X	
Cyan Development			X	X				X	X			X			X			X		X				X	X	
Cyan Erase			X	X	X															X				X	X	
Cyan Toner			X	X				X	X			X			X			X		X	X	X	X	X	X	X
Magenta Charge			X	X	X	X						X						X		X				X	X	
Magenta Expose			X	X		X														X				X	X	
Magenta Development			X	X		X	X	X				X			X			X		X				X	X	
Magenta Erase			X	X		X	X	X	X											X				X	X	
Magenta Toner			X	X		X	X	X		X		X			X			X		X	X	X	X	X	X	X
Yellow Charge			X	X	X	X	X	X	X	X	X							X		X				X	X	
Yellow Expose			X	X		X	X				X									X				X	X	
Yellow Develop			X	X		X	X				X	X			X			X		X				X	X	
Yellow Erase			X	X		X	X				X	X	X		X				X		X			X	X	
Tellow Toner			X	X		X	X				X	X	X		X			X		X	X	X	X	X	X	X
Black Charge			X	X	X	X	X	X	X	X	X	X	X		X	X			X		X			X	X	
Black Expose			X	X		X	X				X	X			X	X			X		X			X	X	
Black Development			X	X		X	X				X	X			X	X			X		X			X	X	
Black Erase			X	X		X	X				X	X	X		X	X			X	X	X	X	X	X	X	
Black Toner			X	X		X	X				X	X	X		X	X			X	X	X	X	X	X	X	X
Photoconductor	X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Transfer			X	X		X	X				X	X			X	X			X	X	X	X	X	X	X	
Fuse				X		X	X				X	X			X	X			X	X	X	X	X	X	X	
Mechanical Module	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Process Controls	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cleaning				X					X						X				X		X				X	

Figure 14 Design Structure Matrix for image on image color xerography

An ideal DSM is a *diagonal matrix* in which the development of each subsystem can proceed independently of the development of other subsystems. This does not mean that there is no interactivity between these subsystems, on the contrary the subsystems may be highly interactive. Rather, it means that interface specifications between subsystems are completely defined and stable. In this ideal case, each

subsystem can be developed independently and asynchronously of other subsystem development tasks. Metaphorically, each subsystem could be developed in a separate room with no communication between rooms. Upon completion, each subsystem is delivered to the system integration room and the system is put together, and if the interface specifications are right, the system functions according to its requirements.

Unfortunately, real systems are not like this and are not well represented by purely diagonal design structure matrices. Realistically, system architects can hope for systems that can be represented with design structure matrices that are in a *lower triangular form*. Lower triangular form matrices imply that the system can be developed without iterative feedback loops. Sub-system B may require task completion by sub-system A, but the sub-system B tasks are not depending on completion of the sub-system A task, i.e., there are no iterative feedback loops. In this case, planning can proceed sequentially and orderly and a given task can be completed when its predecessors have been completed.

In the case of image on image printing, however, there are several iterative feedback loops that prevent simple, sequential planning. As shown in Figure 14, the matrix has several components in the upper triangle, which imply that the development of certain subsystems must be iterative. For example, the optimal critical parameters for yellow development and toner will depend on the characteristics of cyan and magenta development and toner. Conversely, the characteristics of yellow development and toner may drive design changes in cyan and magenta development and toner.

The design structure matrix shown in Figure 14 for image on image printing shows iterative feedback loops, and though the severity of these loops varies, the development of the entire marking engine takes place within an iterative development cycle. Planning tends to overlook these iterative cycles by using sequential plans. The result is a project that may not meet schedule, but before turning to general conclusions, let us consider an alternative color printing architecture, namely, intermediate belt transfer.

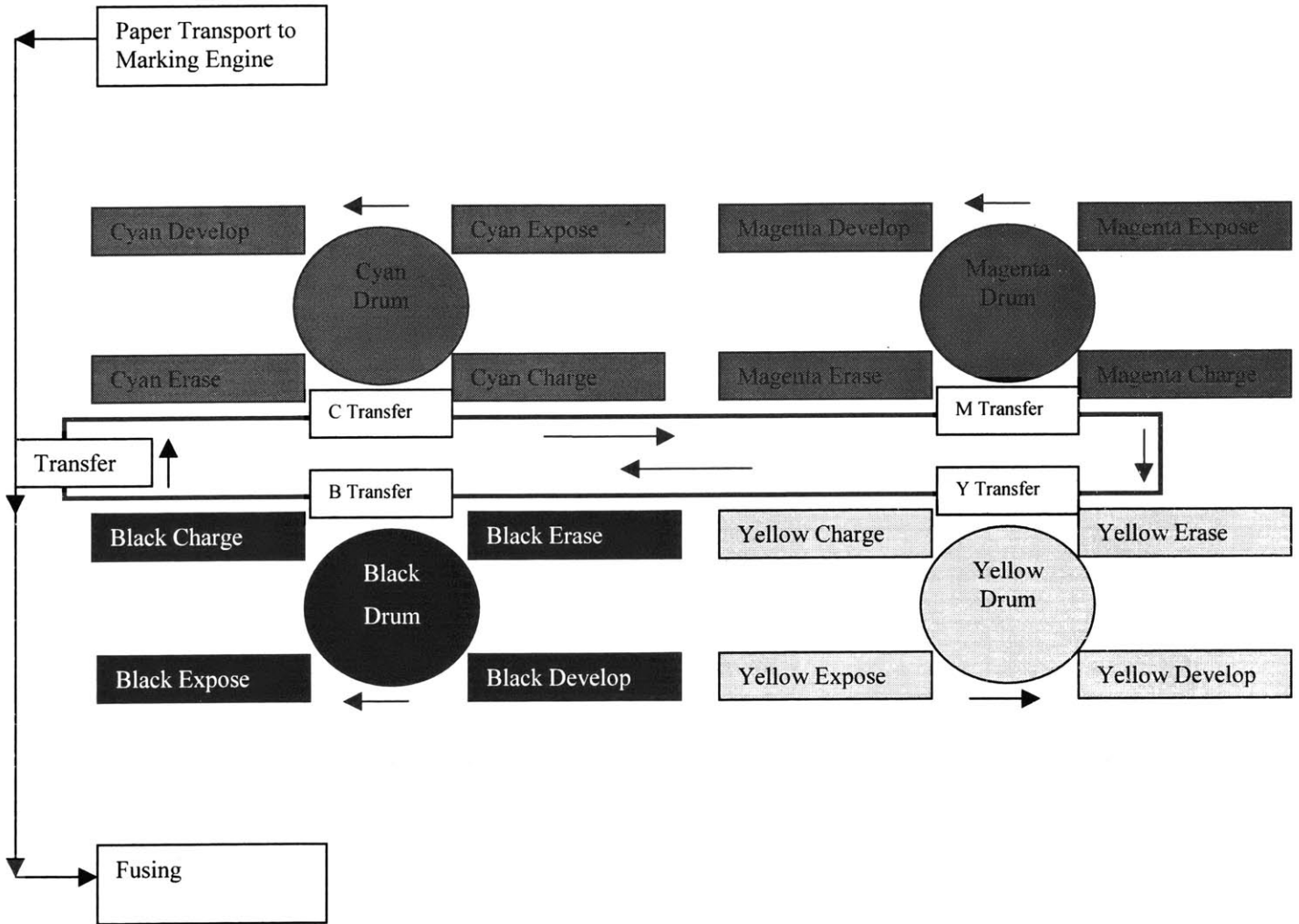


Figure 15 Color xerographic architecture based on intermediate belt transfer (IBT)

With an intermediate belt transfer (IBT) architecture, the cyan, magenta, yellow and black images are developed separately onto their unique photoconductive drums. Then the images are transferred onto an intermediate belt before they are finally transferred to paper. Although developed images are transferred on top of one another on the IBT, the images are not developed on top of one another and transferring existing images on top of one another is more robust process than developing images on top of one another. These facts can be seen in Figure 16, the design structure matrix for intermediate belt transfer technology:

	Cyan Charge	Cyan Expose	Cyan Development	Cyan Erase	Cyan Toner	Cyan Cleaning	Cyan Photoconductor	Cyan Transfer	Magenta Charge	Magenta Expose	Magenta Development	Magenta Erase	Magenta Toner	Magenta Cleaner	Magenta Photoconductor	Magenta Transfer	Yellow Charge	Yellow Expose	Yellow Develop	Yellow Erase	Yellow Toner	Yellow Cleaner	Yellow Photoconductor	Yellow Transfer	Black Charge	Black Expose	Black Development	Black Erase	Black Toner	Black Cleaner	Black Photoconductor	Black Transfer	I Belt Transfer	Fuse	Mechanical Module	Controls
Cyan Charge	X																																		X	
Cyan Expose	X	X																																		X
Cyan Development		X	X																																	X
Cyan Erase			X	X																																
Cyan Toner				X	X																												X	X		X
Cyan Cleaning				X	X	X																														
Cyan Photoconductor	X	X	X	X	X	X																														X
Cyan Transfer		X		X	X	X	X																									X				
Magenta Charge								X								X																			X	
Magenta Expose								X	X																											X
Magenta Development								X	X	X																										X
Magenta Erase								X	X	X																										
Magenta Toner								X	X	X																						X	X			X
Magenta Cleaner								X	X	X																										
Magenta Photoconductor							X	X	X	X																										X
Magenta Transfer								X	X	X	X	X	X																				X			
Yellow Charge															X																				X	
Yellow Expose															X																					X
Yellow Develop															X																					X
Yellow Erase															X																					
Yellow Toner															X																		X	X		X
Yellow Cleaner															X																					
Yellow Photoconductor															X	X																				X
Yellow Transfer															X	X	X	X	X	X	X													X		
Black Charge																																				X
Black Expose																																				X
Black Development																																				X
Black Erase																																				
Black Toner																																	X	X		X
Black Cleaner																																				
Black Photoconductor																																				X
Black Transfer																																				
I Belt Transfer				X	X																											X	X			
Fuse				X	X		X																										X	X	X	
Mechanical Module	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Controls	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 16 Design structure matrix for intermediate belt transfer (IBT) color architecture with highlighted marking modules

Modularity and its Advantages

Image on image and IBT printing architectures can be compared from various perspectives. We shall see that there are some considerations that argue for an IBT architecture, but before turning to these points, let us consider the basic argument for an image on image architecture. An image on image architecture requires fewer sub-systems. The illustrations of the IBT and image on image architectures, Figure 13 and Figure 15, show that image on image only requires a single photoreceptor belt, whereas, IBT requires four photoconductive drums as well as an intermediate transfer belt. In image on image, images are developed onto the photoreceptor and then transferred to paper, whereas, in IBT images are developed onto drums, transferred to an intermediate belt, and then transferred to paper. Hence, IBT adds an intermediate step to the process, and, in this respect, image on image might appear to be less complex than IBT.

But from the perspective of modularity and design structure matrices, it appears that IBT is advantaged over image on image. The design structure matrix for IBT (Figure 16) has fewer global feedback loops than the design structure matrix for image on image printing (Figure 14). With IBT there are still system wide feedback loops involving fusing, process controls and intermediate belt transfer. These tasks still need to be managed from a system integration perspective. Nonetheless, *the IBT architecture offers an important advantage* because the individual marking modules for cyan, magenta, yellow and black and white are relatively de-coupled from one another and can therefore be developed more independently. A given IBT marking module consists of a drum along with charging, exposing, development and erase sub-systems; hence, there is one marking module for each color. In Figure 16, the individual marking modules are identified as highlighted boxes. There are still iterative feedback loops for the tasks *within* a given marking module, as indicated by the circular feedback loops in Figure 16. But these loops are confined to the marking modules, thus enabling more independent development of the individual marking modules.

Finally, let us now turn to the question of why increased modularity and fewer and smaller iterative feedback loops are important. One advantage of the IBT

architecture is that the individual marking stations can be developed independently and asynchronously. Product development is advantaged when tasks can proceed independently. Iterative feedback loops make planning difficult and they typically add time to development cycles. Product development with iterative feedback loops requires more communication, more interfaces between groups and in general has the potential for more delays. *In fact, we might speculate that time to develop a given iteration of a product is proportional to the number of sub-systems in its largest feedback loops.* Within a given feedback loop, design changes to any one sub-system cause design changes to other sub-systems. Each of these changes requires communication, meetings, testing, analysis and so forth. The primary feedback loops in the IBT design involve five sub-systems. If for example, a design change is required in cyan development, then most of the ramifications are contained to the cyan marking module which consists of five sub-systems. On the other hand, with image on image, changes to cyan development will have ramifications that spread throughout a significant portion of the entire system, perhaps impacting as many as a dozen sub-systems. IOI, more so than IBT, is a system engineering and management challenge because the IOI architecture is less modular. The resulting product, however, is advantaged in terms of fewer photoconductors and the absence of an intermediate transfer belt.

But there is another important advantage to modular designs. Modules can be outsourced. True modularity means that a module can be developed and tested independently of the rest of the system. Furthermore, because of this independence, the development of the module can proceed asynchronously with the rest of the system. It can be developed at its own cadence and its development is no longer contingent on the completion of tasks related to other modules in the system. For these reasons, modularity is a key enabler to outsourcing and in terms of IBT architecture, the individual cyan, magenta, yellow and black and white marking modules are prime candidates for outsourcing. Looking back at the image on image architecture, however, an outsourcing strategy is more difficult because the system does not cleanly partition into modules. Let us now turn directly to the question of modularity and outsourcing.

Section 5: Outsourcing and Mistaken Modularity

From Vertical to Horizontal Integration

In the previous section I argued that architectural modularity is critical to rapid, independent and asynchronous development, whether done internally or through outsourcing. Because of increasing competition xerographic printers are looking more and more like commodities that are only distinguished by cost. In this climate, outsourcing strategies are seen as one increasing competitive advantage. Firms like Xerox can no longer afford to design all components of a printer, i.e., they can no longer afford to be vertically integrated. But just as blindly following the battle cry of *platform strategy* can backfire, so too, blindly following the charge towards *outsourcing* can have undesirable results. There are various reasons why outsourcing can fail, most of which are beyond the scope of this thesis. Outsourcing, for example, can fail because a firm selects incompetent partners. But, as foreshadowed in the previous section, outsourcing can fail because a firm fails to assess the modularity of its products—they outsource non-modular subsystems, or expressed differently, they outsource tasks that occur within iterative feedback loops without outsourcing the entire module that contains these loops.²⁵

Xerox is a prime example of a vertically integrated product development firm. Most of the development and manufacturing of the various components involved in making copiers and printers is done by Xerox. But due to increased competition from firms like Canon and Hewlett Packard, Xerox no longer believes it can afford to be vertically integrated. Instead, focus must be directed at what Xerox does best, its so-called “crown jewels”, thereby leaving the remainder to various partners.

Some recent Xerox products, the Xerox 212/214, were integrated by Xerox but many of the components within the system were developed and manufactured by partners throughout the world. When Xerox announced the Xerox 212/214 products it proclaimed to the press that these products were developed with “an entirely new

process for bringing products to market”, a process that is based on what Xerox calls extended enterprise, e.g., outsourcing with significant support of partners. In developing the 212/214 products, Xerox started with a “clean sheet” and then performed an exhaustive tear down of competitive copiers and printers. Xerox discovered that many of the modules in these devices were being made, and made well, by third-party suppliers. With this in mind, Xerox developed a product architecture, which consisted of a series of self-contained modules that could be individually specified and tested. The approach enabled Xerox to leverage the expertise of various partners and develop products quickly and cost effectively. The list of “best of breed” partners for the Xerox 212/214 include:

- ✓ Mack Molding of East Arlington, Vermont supplies plastic parts including the covers and paper-tray modules
- ✓ Ascent Power Technologies of Concord, Ontario, Canada, supplies the electronic sub-systems that control the copiers
- ✓ Fuji Photo Optical of Saitama, Japan supplies the scanner and laser imaging technology
- ✓ Shinano Kenshi of Japan that supplies the mechanical drive components and manufactures them in China
- ✓ Celestica /Ascent supplies the power supplies
- ✓ Xerox PCDU, in Webster, New York, supplies the xerographic print cartridge
- ✓ Xerox FBU, in Webster, New York, supplies the fuser
- ✓ Xerox Supplies, in Webster, New York, supplies the toner
- ✓ The Xerox 212/214 team supplies the process controls and xerographic expertise that integrates all of the xerographic modules into a marking engine

Potential Pitfall of an Outsourcing Strategy

Although the Xerox 212/214 products clearly takes advantage of outsourcing, most of the xerographic work is still done by Xerox. The only element in the xerographic system that is outsourced is the imaging system, which was developed by Fuji Photo Optical. More recently, however, Xerox has considered using extended enterprise more aggressively within the xerographic. In this section I will examine a potential pitfall of this strategy. Although the argument is based on the xerographic system, it applies equally well to any strategy in which non-modular subsystems are outsourced.

Problems can easily arise when (1) subsystems whose development is embedded within iterative feedback loops are outsourced to a partner, and (2) the complete module that contains these loops is not outsourced to that partner. In support of this conclusion, consider the black and white xerographic system shown in Figure 17:

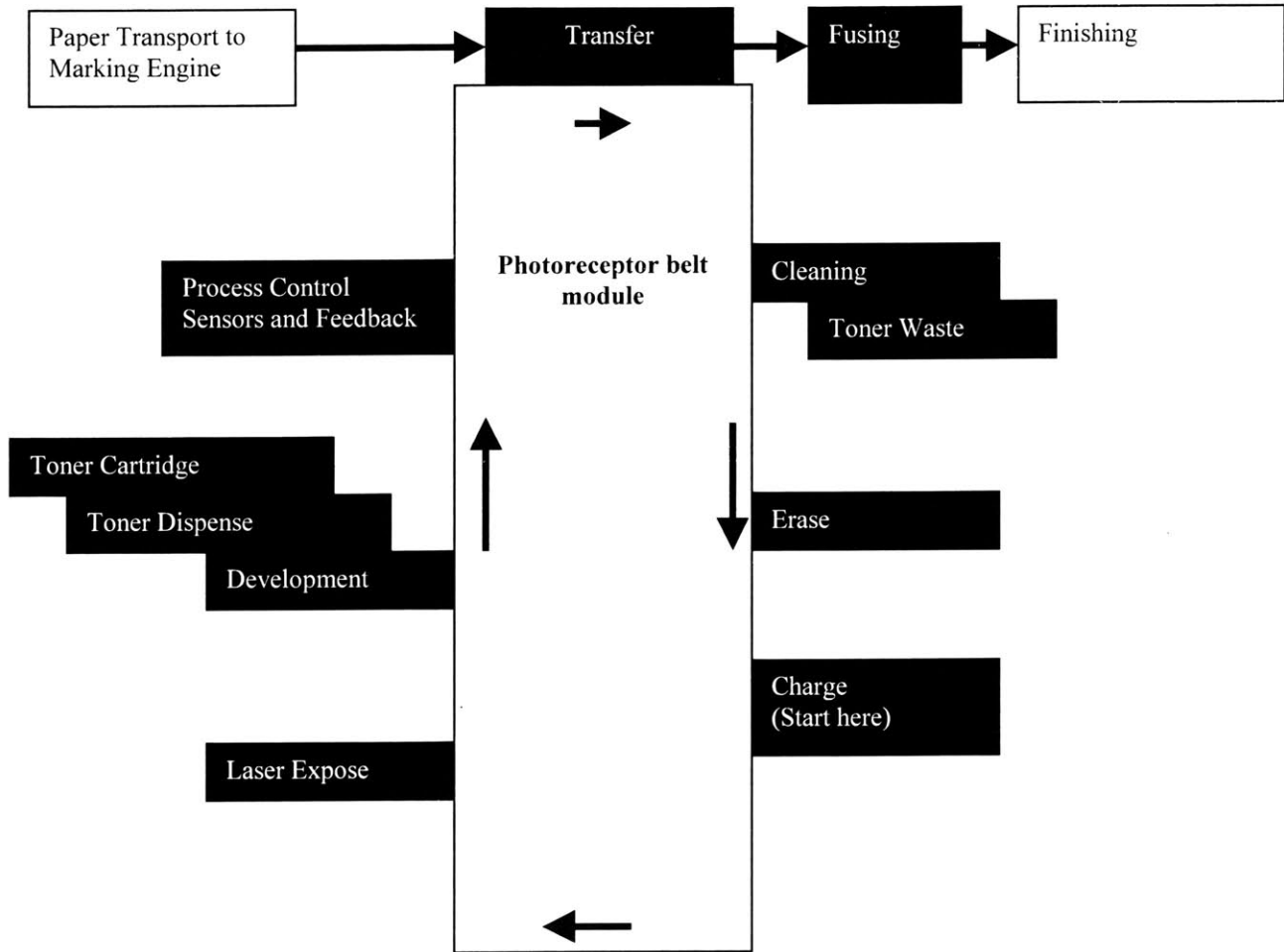


Figure 17 Architecture for black and white xerographic system

The design structure matrix for the black and white system shown in Figure 17 is shown in Figure 18:

	Charge	P/R Belt	Expose	Erase	Toner Dispense	Toner	Development	Transfer	Clean	Fuse	Process Controls	P/R Belt Module
Charge	X	X									X	X
P/R Belt	X	X	X	X							X	X
Expose		X	X								X	X
Erase		X		X								X
Toner Dispense					X	X	X				X	
Toner					X	X	X	X	X	X	X	
Development					X	X	X	X			X	X
Transfer						X		X	X	X		X
Clean		X				X		X	X			X
Fuse						X		X		X		
Process Controls	X	X	X		X	X	X				X	
P/R Belt Module	X	X	X	X			X	X	X			X

Figure 18 Design structure matrix for black and white xerographic marking engine

Figure 18 shows how the design structure matrix for black and white printing partitions into four main areas. One of these modules has been labeled the *electrostatic-centric module* because it contains the photoreceptor and subsystems that are designed to charge and discharge the electrostatic voltage on the photoreceptor. Another module has been labeled the *toner-centric module* because it contains toner supply and the subsystems that are designed to dispense, develop, transfer, fuse and clean toner. Process controls and the photoreceptor belt module involve integration

across the entire system, in fact, the former might be called process integration and the latter might be called mechanical integration. For this reason, it is natural for a firm to maintain control of these tasks and act as the overall integrator of the system.

However, the electrostatic-centric module and toner-centric module might be outsourced to partners. Although each of these modules has iterative feedback loops, these loops are contained within the modules. But if outsourced, there is strong motivation for outsourcing the entire module and not a single component of the module in order to avoid the risk associated with iterative design feedback loops that span across different firms. Of course, the risk associated with this type of outsourcing varies in accordance with the magnitude of the iterative feedback loops. For example, although tasks related to exposure occur within the iterative feedback loops of the electrostatic-centric module, it may be possible to “freeze” the exposure requirements and make them invariant with respect to design changes in the rest of the module. In the case of the exposure subsystem, to a large extent, the requirements associated with the laser, lenses, mirrors, polygon, and polygon motor can be specified *and fixed* early in the design process. For example, requirements for the wavelength and spot size of the laser diode and the rpm of the polygon motor can be fixed given the image quality and process speed requirements of the system. In this way, iterative feedback loops involving the exposure subsystem can be eliminated and the risk of outsourcing the exposure subsystem can be mitigated. But this is only the case if the requirements of *other subsystems within the electrostatic-centric module can be kept more fluid and amenable to changes driven by potential system level problems.*

The extent to which subsystem requirements can be specified and fixed early in the process is a matter of degree. Whereas the stability of the exposure subsystem requirements may exceed the threshold needed to justify outsourcing, the requirements of certain subsystems within the toner-centric module may fall below this threshold. In particular, outsourcing fusing, development and toner design to three different partners may cause real problems. Optimization of both development and fusing tends to make significant and often conflicting demands on toner design. Problems in fusing may force toner design changes. Problems in development may force toner design changes that in turn may generate problems for fusing. Because of these intrinsic design

challenges, *the iterative feedback loops are particularly strong in this area*; hence, unlike the case of the exposure subsystem, it may not be wise to simply freeze fusing requirements and place the burden of design problems on toner and development design. Typically, in order to meet system requirements, the requirements of all three subsystems may require change at various points in the design cycle.

In summary, outsourcing is more challenging when iterative feedback loops are strong. Design requirements tend to be more contractual when dealing with external versus internal suppliers. Changes in design may be seen as violations of contract or at a minimum may require re-negotiation. Lack of geographical proximity, as is more typical with outsourcing, makes these negotiations more difficult. These problems are only amplified when the *frequency* of design iteration loops increases. Therefore, it is critical for product development groups to comprehend iterative feedback loops and the modularity of its designs when deciding what is, and what is not, a good candidate for outsourcing. Design structure matrices are useful in this context because they reveal the modularity of a system and the right and wrong ways to “carve up” a system. After developing design structure matrices, subsystems should be ranked in terms of modularity and these ranks should be used as criteria, among others, for deciding whether a sub-system should be outsourced or not.

Conclusions

Various strategies in product development have been examined. In particular, we have examined product families and parts reuse, platform strategy and outsourcing. These three topics are interrelated. Platform strategies and outsourcing depend on modular design. The elements of a platform can be outsourced if the design is modular. Platform strategies typically result in product families whose members may have many parts in common, but high part commonality is neither a sufficient or necessary condition of a successful product family. In each case, the strategy was examined, potential pitfalls or misconceptions were identified, and a revised strategy was recommended. To a large extent, the theme has been, in strategically responding to competitive threat, be careful not to jump from the frying pan to the fire.

In concluding, I will end with some final cautions about platform strategies and then turn to some reflections on modular design at Xerox. Platforms are different from products and it is imperative that senior management evaluate platforms and products with different criteria. The objective of a platform is not to directly develop a new product, but to create the pieces or elements that enable the development of subsequent products. If genuine platform development is confused with development of the initial product then senior management will be disappointed when the first product is not financially justified (or late to market). Meyer and Lehnerd make this point as follows: “When senior management treats new platform development efforts as if they were derivative product developments, in terms of both time and resources, the tangible results of the new platform efforts will probably be disappointing.”²⁶

Finally, if there was a single theme that lay beneath the various discussions, it was architectural modularity. Modular designs enable asynchronous and independent product development, outsourcing, and plug and play platform strategies. For this reason, I will conclude with some reflection on Xerox as it relates to modular design. Ironically, what may have once been an asset for Xerox may, in the current climate, act as a subtle, unrecognized source of competitive disadvantage. With the success of the Model 914 in the 1960s, Xerox began to monopolize the rapidly growing copying and

²⁶ Meyer and Lehnerd (1997, p. 161)

printing industry. Monopolies tend to vertically integrate, and in this respect, Xerox was no different. Until recently, Xerox designed and manufactured almost all aspects of its copiers and printers. Most of the work is still co-located in Webster, a suburb of the Rochester, New York. Product development units, research and technology, toner, exposure, photoreceptor, and fusing design and manufacturing units, all reside within an enormous industrial complex in Webster.

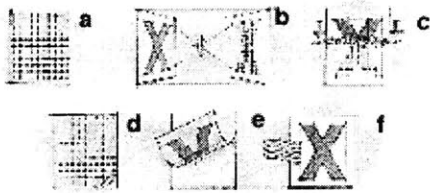
The early success of Xerox relied on the vertical product integration provided by these resources and facilities. In terms of end to end development, no firm could match Xerox's development and manufacturing assets. *But ironically, these assets and their history may in some respects be a source competitive disadvantage today.* The culture and behavior of a vertically integrated, co-located product development style does not demand module design and stable design interface specifications. Everyone knows everyone and we work together. The product development team integrates the overall design and their friends in fusing, toner design and photoreceptor are right next door. If toner design changes are needed, the product development team works with the toner supply group. Likewise, changes in photoreceptor design or the laser imaging system might be entertained right up until the launch of a product. We are all part of the same team, and if design specification changes are needed for the good of the team, then that has been the right thing to do.

But what this suggests is that *vertical integration and close proximity enable non-modular designs and iterative feedback loops in the design process.* Contrast this situation with that of a more horizontally integrated firm. These firms have become accustomed to developing relatively fixed design requirements for their partners since, in these cases, making changes in design requirements is more awkward and difficult to negotiate; hence, outsourcing and lack of co-location tends to breed more modular designs. In effect, our histories determine our design cultures, and the culture left by Xerox's history may find difficulty in transitioning to a more modular and horizontally integrated design approach.

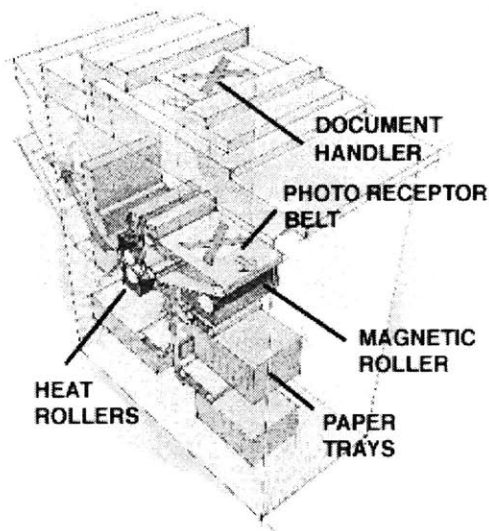
Appendix A: Xerographic Process Overview

A typical xerographic process begins with a corona charging device that charges a photoconductor surface (drum or belt) to some voltage, e.g., - 500 Volts. A laser beam is then moved across the photoreceptor by directing the beam onto a spinning polygon mirror. The laser beam is intensity modulated so as to reflect the printing information. A standard modulation resolution is 600 dots per inch. Pixel areas on the photoconductor (1/600 inch areas) that are exposed with light are discharged in voltage, from, for example the initial -500 Volts to -100 Volts. Areas that are not exposed are therefore left at -500 Volts. Development sub-systems typically have a voltage bias, for example, -350 Volts. Hence, when the photoreceptor passes underneath the development system the discharged areas (-100 Volts) see a development voltage of 250 Volts (350 – 150). The toner is negatively charged, therefore the development field causes the toner to move from the development sub-system to the photoreceptor until the field is neutralized. The toner is then transferred to paper with a corona device that negatively charges the back of the paper, causing the toner to move from the photoconductor to paper. Finally, the toner is fused in the fusing sub-system, typically, by moving the paper between a pressure roll and a fusing roll. The fusing roll is hot, on the order of 385 degrees Fahrenheit. A second explanation of the process is as follows.

PHOTOCOPIER moves a document from the handler to the glass platen (*not shown*), where the pattern of the image is projected by lamps, mirrors and lenses onto a photoreceptor belt (or drum). The electrostatic charge on the belt fades in areas receiving light from the projected image. Magnetic rollers brush the belt with dry ink (toner), which because of its static charge clings to the image area on the belt. A sheet of copy paper approaching the belt is also given a static charge sufficiently strong to draw the image pattern in the toner away from the belt. Rollers then apply heat and pressure to fuse the toner image into place. For color copying, a multi-step process is used, which scans the image through color filters and then applies separate toners for magenta, cyan, yellow and black.



DRY COPYING exploits the principles that materials with opposite electrical charges attract one another and that some materials conduct electricity better after exposure to light. In the basic xerography process, a photoconductive surface receives a positive electrical charge (*a*). An image is then exposed on the surface; because the illuminated sections (the non-image areas) become more conductive, their charge dissipates (*b*). Negatively charged powder spread over the surface adheres through electrostatic attraction to the positively charged image area (*c*). A piece of paper is then given a positive charge (*d*) and placed over the surface, where it attracts the negatively charged powder (*e*). Finally, heat fuses the image as etched in powder to the paper (*f*).



Appendix B: Competitive Landscape

There is no doubt that the printing industry has become fiercely competitive. Starting in the 1960s, the Xerox monopoly in xerographic copying began to decline. The effect of increased competition, however, was not fully appreciated until the 1970s. Between 1971 and 1978, 77 different plain paper copiers were introduced in the US. From 1978 to 1980, another 70 were introduced. From 1976 to 1982, Xerox's share of worldwide copier revenues dropped by half, from 82 to 41 percent. Many of these copiers were desktop, low-end, copiers that were introduced by Japanese firms, most notably, Canon, Ricoh, Toshiba, and Sharp. The days of 20 percent-plus profit margins were gone. Japanese profit margins were on the order of 5 to 6 percent.

Today, Canon is the biggest problem for Xerox. Canon, like other Japanese companies, started with low-volume, smaller desk-top copiers, then entered the mid-volume market and today is on the threshold of the high-volume, production market. In March of 1999, Canon introduced a new line of digital copiers, the ImageRunner series, which targets the mid-volume office market. Then, in January 2000 Canon introduced a challenge to Xerox's near-domination of the high volume digital copiers. Heidelberger Druckmaschinen AG, a German printing-press maker, which bought the technology from Eastman Kodak in 1999, makes Canon's new high-volume machine. The Heidelberg machine is a threat to Xerox's highly successful DocuTech series, but the machine is very costly. Last year, Xerox's high-end Docutech printer line had \$2.3 billion in revenue, more than 10% of Xerox's total revenue. Having started with low-end desk top copiers, Canon's attack plan now has them in the heartland of Xerox, namely, the high volume market segment.

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