IESNA Paper #57: WILL LEDS TRANSFORM TRAFFIC SIGNALS AS THEY DID EXIT SIGNS?

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ABSTRACT

Whenever a new light source enters the lighting market, luminaire manufacturers and potential purchasers of products that would use the light source need time to find the "best bets" in terms of application, design, efficiency and economy. We observe that the recent strong entry of light-emitting diodes (LEDs) into the traffic signal market in some ways repeats the same developmental pattern we witnessed for the emergence of LED exit signs. In this update we explore briefly several technical and economic questions: Will LED traffic signals be as successful in transforming the traffic signal market as they were in transforming the exit sign market? What barriers would delay progress? Will this pattern prove robust enough to be repeated for other lighting applications, such as outdoor or indoor illumination?

Since 1990 we have tracked the technical and market evolution of energy efficient exit signs. In 1996 we helped to accelerate this market transformation by conducting extensive in-depth interviews with manufacturers, code officials and specifiers. We also contributed a performance specification that was incorporated into the United States Environmental Protection Agency (U.S. EPA)/United States Department of Energy (U.S. DOE) ENERGY STAR Exit Sign program (Boyce, 1994; Bierman, 1995; Bierman and O'Rourke, 1998; Conway and Boyce, 1997; Conway *et al.*, 1997).

In 1998 we surveyed the manufacturers of exit signs and found that the four manufacturers that control 80% of the market in the U.S. are ENERGY STAR Partners. They offer a wide array of ENERGY STAR exit signs; three report that all their 1998 sales were ENERGY STAR labeled products.

In early 1998 we began to examine the standards used by traffic engineers for traffic signals, and designed an experiment to test the human visual response to the LEDs versus the incandescent lamps used in traffic signals (Bullough *et al.*, 1998; Bierman, 1999; Bullough, 1999). In late 1998 we surveyed news reports worldwide, and then conducted a market survey by telephone of more than 30 potential users of LED traffic signals in the state of California. From these studies and from our testing and observation of the design of products that incorporate LEDs, we can identify and describe a pattern of barriers, opportunities, and solutions.

LED TECHNOLOGY

Solid state LEDs are semiconductor devices. Depending upon the materials used in the semiconductor chip, LEDs emit energy in a narrow wavelength band of the electromagnetic spectrum. Prior to the mid-1980s LEDs were used primarily as indicator light sources because of their low light output. The first widely used signal application for LEDs in the lighting industry was exit signs. A promising material used in many red, orange and yellow LEDs is aluminum gallium indium phosphate or AlGaInP (Maranowski *et al.*, 1997); indium gallium nitride (InGaN) material is used in many green, blue and white LEDs (Nakamura, 1997). Unlike previous generations of LEDs, AlGaInP and InGaN LEDs have light outputs and luminous efficacies sufficient for a wide variety of lighting and signaling applications, including exit signs, automotive lighting and signaling, and more recently for traffic signals (Hodapp, 1997).

TECHNOLOGICAL OPPORTUNITIES

The technological characteristics of LEDs provide many important opportunities for their use in visually critical applications such as exit signs and traffic signals.

Luminous efficacy and energy use. Some LEDs available on the market have luminous efficacies exceeding those of incandescent lamps and approaching those of mercury and fluorescent lamps. LEDs emit light in a narrow wavelength band, so they are especially useful for sign and signal applications, which conventionally use incandescent lamps that are filtered to produce saturated colors (red, yellow, green or blue). LEDs, however,

require no filtering and thus signs and signals using LEDs require significantly less energy than their incandescent counterparts. For example, conventional exit signs used 24-40 W, while ENERGY STAR exit signs use less than 5 W per face. Similarly, red LED traffic signal modules require 85%-90% less electricity (Vargas, 1994; Delean, 1996; Snel, 1996; Haussler, 1997; Stahl, 1997).

Red LED signal modules are efficient and economic because the conventionally used incandescent sources require the greatest amount of filtering to create the red light required. The technical limits of filtering the light from an incandescent lamp to create red, yellow and green signal modules led to a technical standard for traffic signals in North America that has a different minimum luminous intensity requirement for each color (ITE, 1985). The luminous intensity standard for the red module is lowest, while yellow is highest and green is intermediate. With recently developed high efficacy red LEDs, the red signal module minimum intensity is easily achieved. Yellow modules are not as economical to replace with LEDs because the higher intensities required means more LEDs must be used in a module to meet the specifications. Green modules have been less successful because the InGaN technology used in green LEDs is less mature than AlGaInP technology and therefore more expensive. Green LED exit signs also are much more expensive than their red counterparts. Red LED exit signs have just recently become competitively priced with conventional incandescent exit signs, after many years in the market.

The low energy requirements of LEDs influence the decision-making process involved in specifying LED traffic signals. In our survey of California municipalities, 96% of the communities using LED signals reported the potential for saving energy as one of their primary purchase motivators. Lower energy demand and better reliability is strongly motivating the widespread installation of LED exit signs, too.

Product life for traffic signals. Incandescent lamps used in conventional traffic signals typically have a rated life of 8,000 hours. While this is significantly higher than the 750-to-1,000-hour life of other incandescent lamps, LEDs can have "useful" lives of 50,000-100,000 hours. Incandescent traffic signal lamps may need to be replaced on a biannual, annual or even shorter time frame. In comparison, most LED traffic signals have warranty periods of several years or more. In addition to the longer rated life, since LED signal modules often use dozens or even hundreds of individual LEDs, early failure of one or even several LEDs will result in a somewhat less effective, although still usable, signal.

Opportunities for economic savings owing to reduced maintenance costs are difficult to predict and to quantify. In our survey of California municipalities, only about 26% of the communities that used LED signals cited the potential for saving money due to decreased maintenance requirements as a primary reason for using them. This result generally agrees with results from another survey conducted by the California Energy Commission (CEC, 1999) which found that about 14% of the communities using LED traffic signals cited potential maintenance cost savings as important reasons for using LED signals.

TECHNOLOGICAL BARRIERS

Energy- and power-related factors. Under most circumstances, the reduced energy requirements of LED traffic signals is a significant advantage. Under certain circumstances, however, their low energy requirements have been a serious disadvantage. For example, in a recent installation of three-color LED traffic signals in Stockholm, Sweden, electrical "noise" in the power lines feeding the signals occasionally resulted in a signal being inadvertently switched on or off inappropriately (Lundberg, 1997a). The lower operating currents of LED units can also be incompatible with switching gear designed for incandescent signals in LED retrofit installations (Behura and Evans, 1998). Since 96% of the California jurisdictions we surveyed were retrofitting LED modules into existing signals, the possibility for load switching incompatibility must be carefully monitored. Control gear manufacturers are designing retrofit solutions on a case-by-case basis.

Because traffic signals are a 24-hour-per-day, year-round operation, and because there are so many of them in use throughout the U.S., power factor and total harmonic distortion are important concerns. Early LED traffic signal units had power factors less than 0.6 (Wyand, 1996). Through incentive programs mainly offered by utilities, for whom low power factors may increase their costs of delivering electricity, products with power factors over 0.9 are common (Lundberg, 1997a). Utilities usually encourage devices with low total harmonic distortion (THD), to minimize noise on system lines. Low THD can be difficult to achieve with low power devices, so tradeoffs between power and THD may be necessary for efficient operation of LED traffic signals (Behura and Evans, 1998).

Temperature-related factors. Like fluorescent lamps, the light output of LEDs is temperature dependent. Manufacturers' published ratings of LEDs are usually given for an operating temperature of 25°C. Products from

different manufacturers are difficult to compare directly; one manufacturer reports that the luminous output of AlGaInP (red, orange and yellow) LEDs at 55°C is 75% of that at 25°C, while at -40°C their luminous output is 192% of that at 25°C (Hodapp, 1997). Without a mechanism to compensate for this phenomenon, LED traffic signals in climates where solar radiation produces high temperatures inside the signal enclosure could result in unacceptably low signal intensities. Approximately 27% of the participants in our survey of California municipalities were aware of the temperature-related output of LEDs. Signal manufacturers are incorporating temperature-compensating circuits into their products.

Another temperature-related factor that might be of concern when using LED signal modules is the fact that compared to incandescent lamps, LEDs emit very little energy in the form of heat. Hypothetically, this could affect the visibility of LED traffic signal modules in winter climates if the heat from incandescent signals contributes to keeping the devices free from snow and ice buildup (Winer, 1997). Although some specifiers mention this concern, we have not found this problem documented for any field installations.

Narrow distribution. Most LEDs available on the market have luminous intensity distributions that are very narrow (only several degrees) compared to the much larger incandescent or fluorescent lamps used in signs and signals. Directionality is an advantage for certain kinds of optical arrays that are viewed from a fixed point or from great distances. It is an impediment to visibility, however, for signals viewed from steeper or oblique angles, if the signal's luminous intensity is not sufficient enough to be conspicuous. Most current specifications used by jurisdictions require that LED signals have the same intensity distribution as incandescent signals. Unlike most incandescent signals, the luminous intensity of an array of LEDs may drop off suddenly beyond the minimum angles specified. The city of Denver, CO experienced this phenomenon in early span wire installations that are susceptible to wind movement (Winer, 1997). In addition, early LED signal modules that were installed as part of experimental or evaluation programs did not conform to standard specifications, and they may have non-standard luminous intensity distributions.

The perception of LED signal modules as being unsuitable except for installation along very straight roadways may be a result of anecdotes and "folklore" about early prototypes and field installations. In May 1998, the town of Farmington, ME wrestled with this issue as it tried to decide whether traffic signals using LEDs could be suspended over intersections using a single tether cable (Jespersen, 1998a, 1998b). In addition, 23% of the participants in our survey of California municipalities reported that they believed LED signal modules to be less suited for suspended, span wire types of installations.

EVOLUTION OF OPTICAL DESIGN OF LED SIGNS AND SIGNALS

To maximize the performance of LED signs and signals, manufacturers have grappled with three factors: cost of materials including the light source, active power demand, and visual performance. These three factors must be balanced in the optical and physical design of a product. We observe that traffic signal design seems to be following an evolutionary pattern quite similar to that of LED exit signs. Figure 1 shows several generic optical design concepts found in exit signs that we have examined. Figure 2 shows generic optical design concepts for traffic signals. Each series of illustrations begins with the use of an incandescent lamp in a simple chamber, moves through several successively more efficient designs using LEDs, and ends with a design that uses very few, high light output LEDs in a specially shaped reflector. Figure 2e is a concept that incorporates three colors of LEDs in one module, which would eliminate the need for the physical redundancy of three signal modules (one for each color). This type of signal would not meet current traffic signal standards, but it might foreshadow future products and new performance standards. A single traffic signal module may be unsatisfactory because it does not display the dynamic "movement" associated with the sequence of green, yellow and red in conventional signals.

ECONOMIC OPPORTUNITIES

Energy and maintenance savings. LEDs provide significant technological opportunities which in turn lead directly to economic opportunities. To persuade specifiers, these factors must be quantified as savings in real dollars. Numerous studies document energy and operating cost savings for exit signs (see Figure 3). For traffic signals, the cost of electricity was a relevant factor for 65% of the participants in our survey of California municipalities. Fewer municipalities are able or willing to quantify the savings attributable to lower maintenance requirements (Lundberg, 1997b), with some exceptions (Anonymous, 1996a, 1996b; Snel, 1996; Winer and Baker, 1996; Anonymous, 1997a, 1997b; Jones, 1997; Winer, 1997; Anonymous, 1998a).

Financial assistance. Since the 1980s, electric utility companies and government organizations have offered their customers substantial first cost rebates for energy efficient exit signs. More recently, financial assistance for LED signal installations has been provided by similar entities (Anonymous, 1998b; Ng *et al.*, 1998; Suozzo, 1998). The amount of the financial incentive can vary greatly, but such assistance can play an important role in a jurisdiction's decision to implement LED technology in traffic signals. More than half--56%--of the California municipalities we surveyed who purchased LED signals reported that they received rebates, loans or other financial assistance. Nine percent of them cited such assistance as an important reason for moving ahead with their first installations. In addition to providing often much-needed funds, media coverage and community discussions of the financial incentive programs help spread awareness of this efficient technology. From the records of visits to our web site's (`http://www.lrc.rpi.edu/ltgtrans/LED/`) articles on LEDs, we note that LED technology and applications are of very high interest to the public.

The role of specifications. Widespread adoption of a single performance specification for a particular product type plays a pivotal role in successful market transformations. The launch of the U.S. EPA/U.S. DOE ENERGY STAR Exit Sign program in 1996 gave specifiers a simple way to identify highly effective exit signs (EPA web site: `http://www.epa.gov/exitsigns.html`). The program is based on a performance specification that satisfies or exceeds the requirements of all relevant codes and standards. The exit sign industry strongly supports this program and nearly all U.S. manufacturers participate in it. The specification gives all manufacturers a common target for efficiency, visibility and readability. In June 1998, the Institute of Transportation Engineers (ITE) published its interim purchase specification for traffic signal modules using LEDs (ITE, 1998). Prior to 1998 many jurisdictions, including the states of California and Oregon and the cities of Philadelphia, PA and Davis, CA had developed their own specifications. Whereas the lack of widely-agreed-upon specifications had been a barrier to widespread acceptance of LED traffic signals, the publication of the ITE specification, even on an interim basis, will spur adoption of LED signals.

ECONOMIC BARRIERS

As a relatively new technology, LED traffic signals face some significant economic barriers, but most similar barriers for LED exit signs have been overcome in the past few years.

High initial cost. Just as the first LED exit signs were expensive ($150-$200 U.S.), early LED traffic signal modules were very expensive, too (Suozzo, 1998). LED exit signs can now be purchased for less than $25 U.S. In 1998, we found that prices for red LED traffic signal modules averaged $132 U.S. for 300 mm diameter units and $101 U.S. for 200 mm diameter units. Green LED signal modules are more expensive than red modules (Bazzi, 1998; Warner, 1998). In comparison, the price of an incandescent traffic signal lamp reported in our survey averaged $2.34 U.S., with the reflector housing that supplies the optics in an incandescent signal costing about $15-$20 U.S. This first cost plays a pivotal role in purchase decisions. We anticipate that LED traffic signal costs will drop significantly as the volume of sales increases and as the volume of LEDs used in other lighting applications increases.

Electricity rates. Another barrier to LED traffic signal use is the availability in some regions of very low electricity rates. In Canada (Delean, 1996), acceptance of LED traffic signals is less than in the U.S., where electricity rates are usually higher. Higher electricity rates mean that energy savings will have a higher economic impact. If jurisdictions pay a relatively small amount per kilowatt-hour for the operation of their traffic signals (or a fixed amount per signal or intersection regardless of energy use), energy savings will be relatively unimportant. We found that 12% of the California communities that chose not to use LED signals did cite low electricity costs as a relevant factor in their decisions.

In some cases, the agency that purchases traffic signal equipment can be different from the agency that pays electricity or maintenance costs. In such an arrangement, LED signals might not be used because the agency purchasing them must absorb the higher initial costs but will not experience any energy or maintenance savings. Cost-sharing agreements between agencies in such circumstances could foster additional market penetration when feasible.

Delays in product delivery. When exit signs began to be in high demand in the mid 1990s, some manufacturers reported delays in delivery of high efficacy LEDs; however, this delay was likely due to the customer priority that the high volume automotive industry received over the "niche" demands of the exit sign industry. While increasingly uncommon, delays in delivery of ordered products have occurred during installations of traffic signals (Winer, 1997). Certainly, such delays cause problems especially when financial assistance such as

rebates or grants are dependent upon timely installation of LED products. This potential barrier can be a daunting one unless jurisdictions incorporate significant penalties to suppliers if delivery targets are not met promptly.

CONCLUSION

Clearly, the attractive attributes of LEDs as a light source are causing significant changes in sign and signal markets. This is an emerging technology that will continue to improve in efficacy, in product packaging and in versatility for the lighting industry. The introduction of the ITE purchase specification in North America will speed up the adoption of LED traffic signal modules, just as the introduction of the ENERGY STAR Exit Sign program sped the adoption of LED exit signs. The documented success of LEDs in these two applications, plus up-to-date technical information on issues such as temperature performance, visibility and economics of LEDs will help spread the use of LEDs to other lighting applications. Some barriers, such as high initial costs of LED signal modules coupled with low electricity costs, will continue in some regions. In certain cases, financial incentives such as rebates, grants or low-interest loans may effectively encourage additional agencies to convert to LED signals. Taking steps to provide objective information about LED traffic signals, and possibly developing financial incentive programs for agencies considering them, can help to overcome many of the barriers identified in this paper. We anticipate that manufacturers of outdoor luminaires will find LEDs of increasing interest, and that manufacturers of task lights and decorative luminaires may soon explore LEDs as a useful light source, provided that LED manufacturers can "package" individual LEDs into suitable optical arrays that are easy to incorporate in luminaires.

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Figure 1. Evolution of exit sign optical design. **a)** incandescent lamps behind colored diffuser and opaque stencil; **b)** LEDs arranged in a matrix to spell out EXIT; **c)** LEDs arranged to spell out EXIT, but located behind diffuser and stencil; **d)** LEDs arranged to illuminate housing interior; **e)** LEDs and reflector arranged to illuminate housing interior; **f)** high-output LEDs arranged to illuminate housing interior.

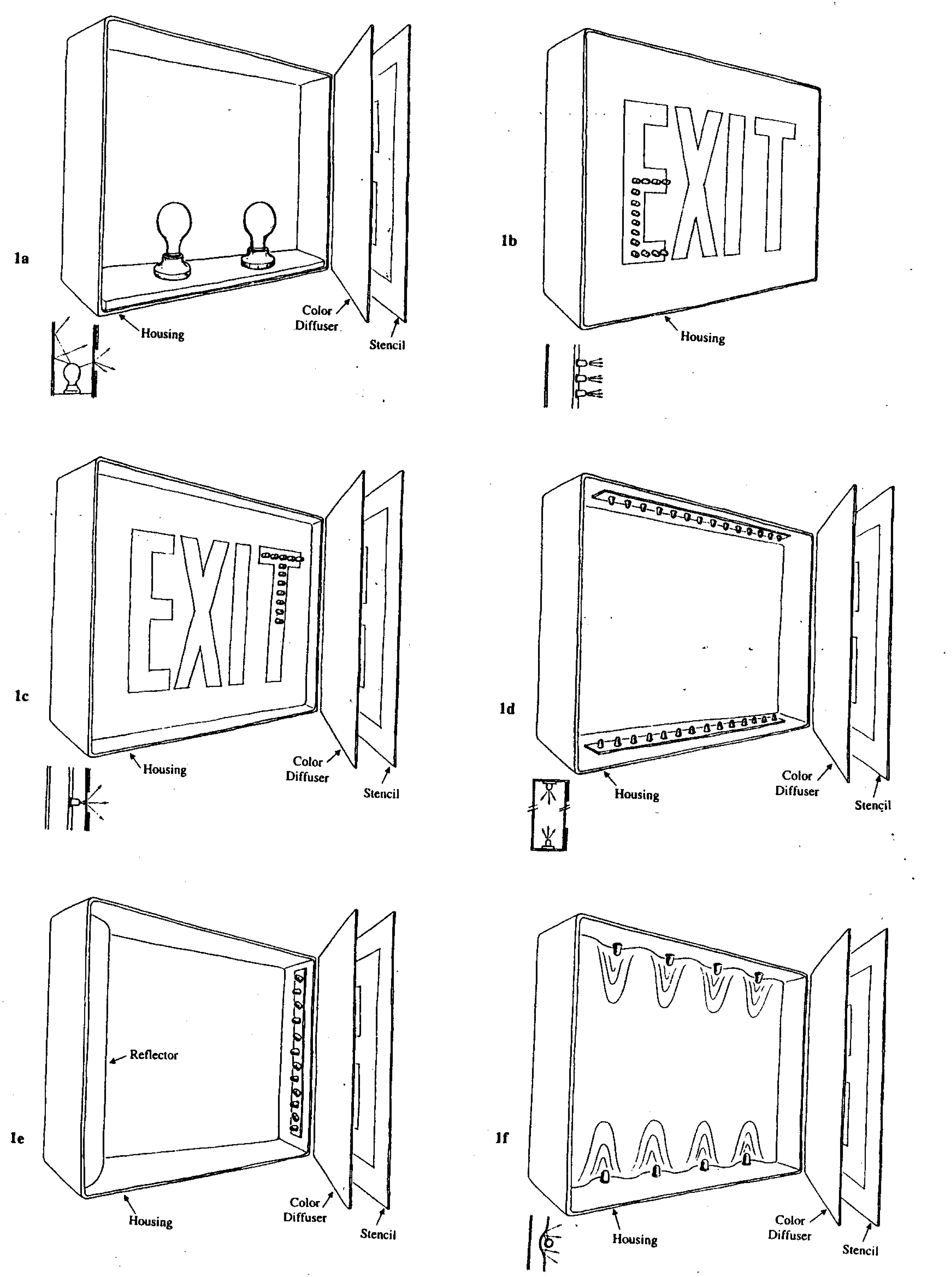

Figure 2. Evolution of traffic signal optical design. **a)** incandescent lamp and reflector; **b)** LEDs arranged directly to form signal face under a smooth lens; **c)** LEDs arranged behind an articulated lens array; **d)** high-output LEDs and reflector to create light distribution similar to (a); **e)** three-color signal module employing red, yellow and green LEDs in a single unit.

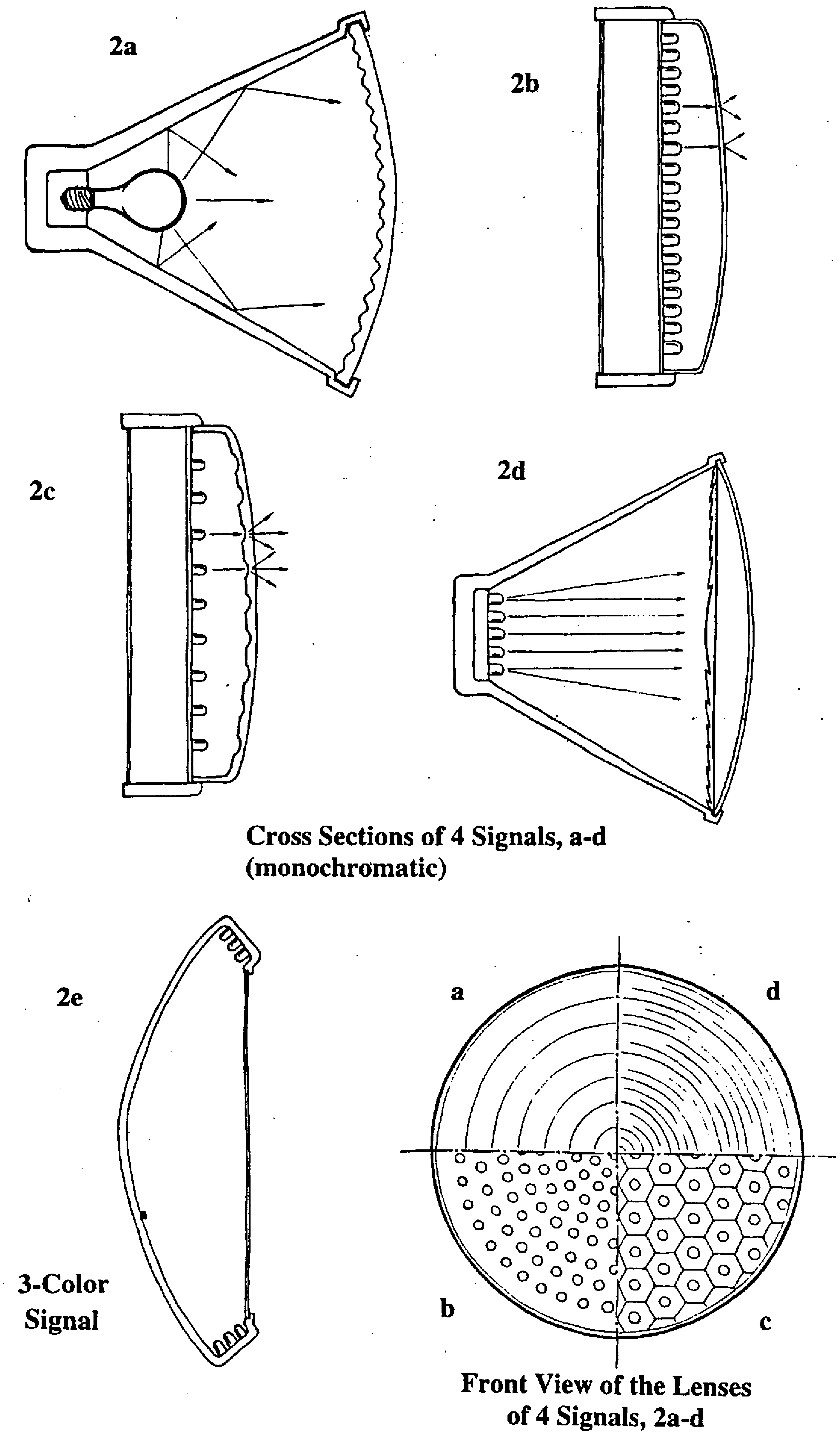

Figure 3. Life cycle costs of exit signs in two areas of the U.S. [from Conway and Boyce (1997)].