TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

IDEA ***Innovations Deserving Exploratory Analysis Project***

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report of Investigation

IDEA Project Final Report
Contract NCHRP-94-ID021

IDEA Program
Transportation Research Board
National Research Council
May 17, 1996

DEVELOPMENT OF LED LIGHT SOURCE FOR TRAFFIC CONTROL DEVICES

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

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IDEA PRODUCT

The product developed from this IDEA project consists of a multiuse light-emitting device with delineation and warning capabilities. The core of the innovation is a light-emitting diode (LED) light source. LEDs have a much longer life span than conventional lamps do and require less power to operate. The internal light source can be placed in different types of housings that would allow the device to be used as a delineator, raised pavement marker, or steady-burn/flashing warning light. The result is a device that requires less maintenance and is more flexible in its use.

LED technology offers several benefits when used in traffic control devices (TCD). Because of their size and low power consumption, LEDs can be used as a light source in devices that, until now, were considered too small to support light-emitting components. Their long life span and low power requirements also lead to products that require less maintenance and replacement of parts.

CONCEPT AND INNOVATION

The light source consists of a cluster of LEDs mounted on a modular support base. This type of design allows the same light source to be used by different housings and to act more like a traditional light source, such as an incandescent lamp. Currently, most LED TCDs mount the LEDs on a permanently fixed printed circuit board. Although this may be the most efficient method of producing the TCD, it can make replacing LEDs impossible. Of course, the LEDs may never need to be replaced, because LED lifetimes can exceed 5 years. However, LED lifetimes can be shortened by unnatural causes, which are often associated with the highway environment. A modular LED light source requires that only one type of replacement lamp would need to be stocked for any TCD design. The outward appearance of the prototype TCDs would be similar to their current conventional counterparts, making it easy for construction crews to begin using them. If successful, a method of retrofitting the LED light source into existing TCD housings would be investigated. The result is a device that requires less maintenance and less power and is more flexible in the way it can be used.

It should be noted that the prime innovation is the LED light source. However, because of the advantages of this light source, innovation can be brought to the TCDs that use it. One such example is point source reflectors. Until now, these delineators only reflected light from vehicle headlamps. The LED light source would allow them to emit light directly as well.

INVESTIGATION AND PROGRESS

The project was conducted in two stages. The first stage was the development of a prototype TCD system. This stage consisted of the design and construction of the internal hardware for the LED light source and the different types of housings required for the TCD system. In Stage 2, the prototype TCD system developed in Stage 1 was tested extensively. Laboratory testing was needed to collect data over a long period of time. The prototype was modified and improved based on performance.

STAGE 1: PROTOTYPE DEVELOPMENT

The design of the prototype TCD consisted of two subtasks: development of the internal light source components and construction of the external housing shells unique to each type of use. The internal hardware was completed first to determine how the outer housings would accept the common internal unit.

Light Source Development

A set of minimum design criteria was established to help focus the development of the light source. The criteria were grouped into three categories: intensity, beam width, and power consumption. The intensity criterion was further divided into high intensity flashing, low intensity flashing, and low intensity steady modes. Intensity and beam width criteria were based on the Institute of Transportation Engineers specification for flashing and steady-burn barricade warning light devices and are summarized as follows:

- The high intensity shall not drop below 35.0 candelas during the first 168 hours of continuous flashing (Type B flashing warning light).
- The low intensity shall not drop below 4.0 candelas during the first 336 hours of continuous flashing or shall not drop below 2.0 candelas during the first 168 hours of continuous burning (Type A and C warning lights).
- The effective beam width shall produce a lighted rectangle whose minimum horizontal dimension shall be 9 degrees each side of the vertical axis and whose minimum vertical dimension shall be 5 degrees each side of the horizontal axis.

It was decided that two types of LED light sources, low and high intensity, would be developed. The low intensity source would be designed with a minimum number of LEDs and would meet the intensity and beam width requirements of the low intensity flashing and steady burn warning lamps (Types A and C). The low intensity source is doublesided to allow the bidirectional light-emitting behavior of Type A and C warning lights. To meet the requirements of the high intensity flashing warning lamps (Type B), a source designed with more LED units was required. Figure 1 shows the two prototype LED light sources.

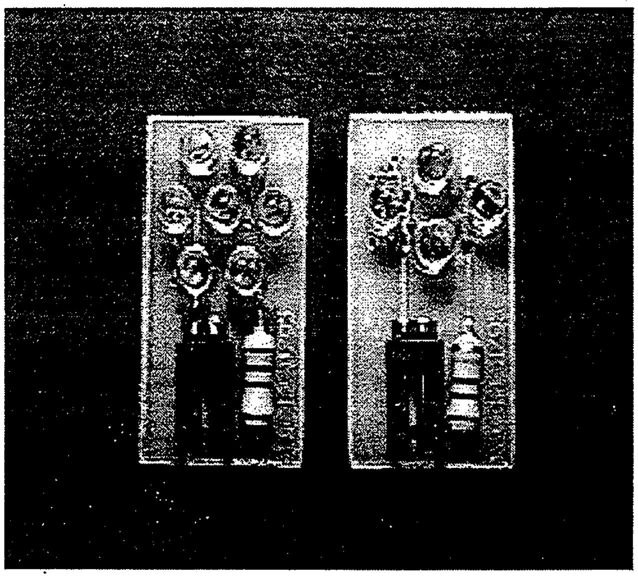

FIGURE 1 High and low intensity LED light sources.

The power consumption of the LED light source is controlled in two ways: (a) LEDs passively reduce the power consumption as a result of their electrical characteristics, and (b) an electronic power controller actively manages the power supply. The controller monitors the power supply level and feeds power to the LEDs accordingly. This results in a light source that stabilizes at a constant light output level that is a function of the power input. Actively controlled power management is most useful when used with finite power supplies such as a battery system. Figure 2 illustrates the difference between actively and passively controlled light sources. The figure shows that when the power supply is fresh (time = 0), the passively controlled light source produces as much light as possible, which might be wasteful or even detrimental. However, the actively controlled source tries to maintain a fixed light output level, which extends the life of the power supply.

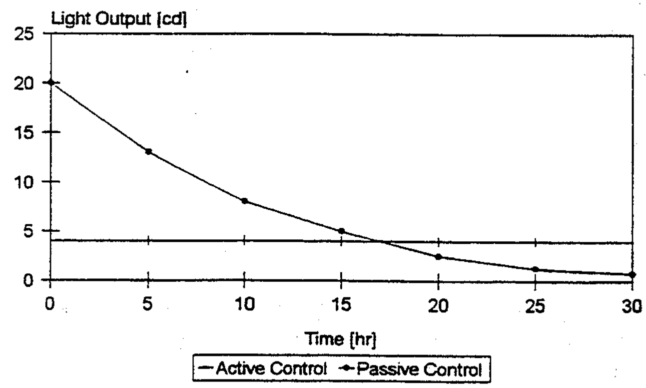

FIGURE 2 Expected results of power management schemes.

The power controller was developed as a separate module capable of driving several LED or incandescent light sources. The controller uses a special algorithm to feed power to the light source at a rate that yields a relatively constant light output. This process saves power when batteries are fresh by not overpowering the light source. Figure 3 shows the power controller. Because the controller is a separate module, it could be used to power traditional incandescent lamps as well as the prototype LED light sources.

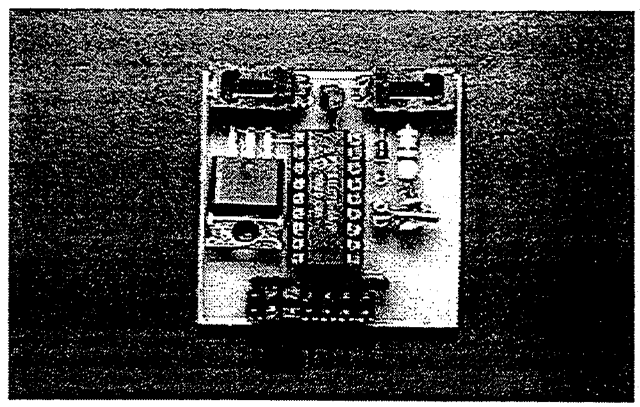

FIGURE 3 Power controller.

The electronic controller allows the user to set the intensity level and the flash mode. By using a photocell, the device is able to switch itself off and on depending on the level of ambient illumination. Using low cost controller also opens the possibility of using the TCD in a more intelligent manner. For example, a steady burn or flashing warning light device could be upgraded to include a basic workzone intrusion alarm with minimal cost and components by making further use of the existing controller.

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Prototype TCD Development

A dual use, flashing and steady-burn warning lamp device was chosen as the prototype TCD. Only minor modifications were necessary to convert the traditional device housing for use with the LED light source and electronic controller. Using off the shelf housings also made prototype development easier by allowing the researchers to focus more on the internal components.

Prototype Testing

To evaluate the performance of the LED light source, the steady-burn prototype TCD and a traditional equivalent were tested under similar conditions. The tests were conducted in a small laboratory and used the following equipment: Minolta illumination meter, data logging computer, battery power supply, and test bench. The illumination meter was used to measure continuously the light output of the TCD. The battery power supply consisted of four 1.5 v D-size carbon-zinc batteries. The batteries were connected in series to create a supply voltage of 6.38 v, but would exhaust sooner than an actual power supply. The computer sampled the measured illumination and supply voltage at regular time intervals and saved readings to a data file.

The testing procedure consisted of placing the TCD on the test bench and connecting it to a fresh battery power supply. The illumination meter was placed 1.5 m away from the test bench on axis with the TCD. The data computer was initialized to log data. Once the test was started, the experimenter needed only to check the equipment a few times a day. During these equipment checks, the illumination level was also noted and the test halted when the illumination fell below a minimum level.

The results of the tests were separated into several categories: duration, power use profile, and light output profile. The duration was simply the time period that the TCD output light remained above the minimum level of 2 cd. The profiles were used to describe the light-emitting and power requirement characteristics of the TCD.

TABLE 1 TEST RESULTS SUMMARY

	Duration [hr]	Average light output [cd]
Traditional light source	119	4.24
LED light source	190	7.5

Table 1 gives the duration and average light output of both TCDs. The table shows that the LED light source, with its active power management and higher efficiency, was able to produce a greater average intensity for a longer period of time than the incandescent light source. Figures 4 and 5 show the light output and power supply profiles of each device. As stated previously, the traditional incandescent TCD makes use of only passive power management and produced as much light as possible with the available power. As shown in Figure 1, the light output is greatest at time = 0 and slowly decreases as time increases.

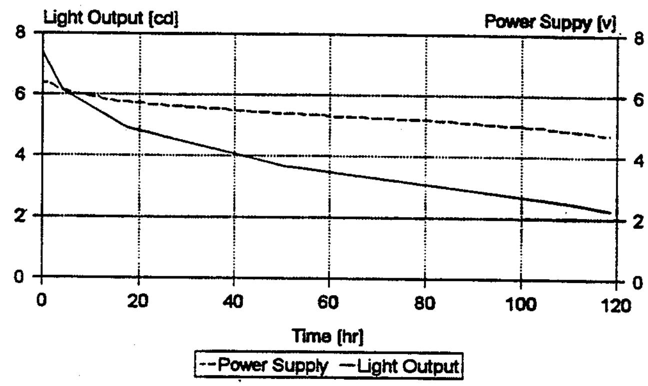

FIGURE 4. Traditional TCD light output and power supply profiles.

The LED light source power supply and light output profiles, shown in Figure 5, illustrate the effect of the active power controller. Without the active power management, the LED light source would have emitted a much higher intensity in the early hours of the test. However, it would not have been capable of maintaining such a high output for long. By conserving power, the LED light source was able to extend its useful duration. Comparing the power supply profiles shows that the LED light source was also able to use more of the batteries' energy before falling below the minimum intensity level. This is shown by the LED operating below 2 v and the incandescent at more than 4 v when the respective light output fell below 2 cd.

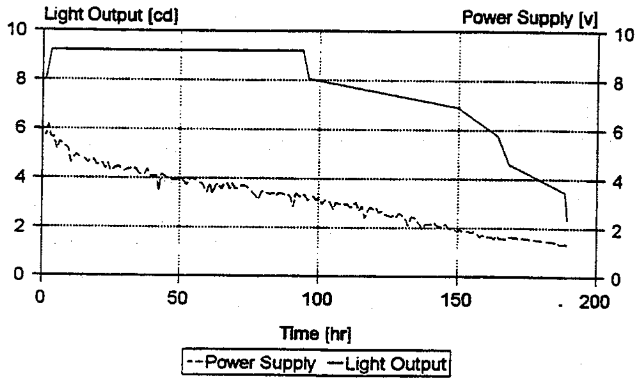

FIGURE 5 LED TCD light output and power supply profiles.

The figures also show that when the incandescent light output is at the cutoff (2 cd at time = 120 hr), the LED light output is still over 90 percent of its initial value. In fact, the LED light source remained over 75 percent of its initial value for nearly 170 hr.

STAGE 2: LONG-TERM PROTOTYPE TESTING

Long-term endurance tests of several prototypes and existing steady burn warning lights were conducted. These tests differed from those conducted in Stage 1. In Stage 1, the testing was accelerated by use of small versions of the actual battery power supplies. These batteries were exhausted sooner than actual sized batteries would have been.

In addition, various types of warning light units were tested, including a complete LED prototype, an incandescent unit, and an incandescent unit with a power controller. An LED prototype unit was also tested with a clear lens, instead of amber or yellow. Because LEDs already emit an amber color, it is unnecessary to use a colored lens. In fact, a large percentage of the light produced by the LED light source may be wasted when used with a colored lens because of transmittance effects. Therefore, when used with a colored lens, the LED light source might have to be driven at a higher intensity than if it was used with a clear lens.

Testing Procedure

All tests were conducted with the same laboratory setup. Photometric measurements of the prototype warning lights were made with the prototype located on a work bench 3 m from the measurement instrument.
Measurements were made using a Minolta T-1 illumination meter and were converted to luminous intensity by the inverse-square law. Multiple prototypes were tested concurrently. Any prototype not being measured was covered not to interfere with the measurement. Measurements were taken 3.5 degrees off axis to give a more conservative reading.

At the beginning of testing each prototype was equipped with the same brand of fresh batteries. Photometric measurements of each prototype were taken several times a day. Testing of a prototype was completed when the prototype light output dropped below a minimum level of 2 cd for a few hours.

Preliminary Results

Before testing began in earnest, a brief startup testing period was used to condition the test prototypes and establish a testing procedure. The preliminary tests revealed several points. The first of these was that the use of a clear lens did not affect the light output of the LED prototype. It was determined that the light emitted from the LEDs was so close to the color of the amber lens that there were no transmittance effects and therefore nothing to gain by using a clear lens.

Second, when the use of the electronic power controller with an incandescent warning light was tried, the prototype did indeed function, but because the controller was optimized for use with the LED light source the light emitted from this prototype stabilized too close to the minimum intensity level for practical use. The electronic controller could be reprogrammed to allow driving incandescent sources because this was not in the scope of the project it was not pursued.

The preliminary testing was also used to optimize the performance of the power controller. It was observed that the LED prototype emitted at a higher intensity than the incandescent unit during most of its lifetime, over 200. This level was 75 percent above the threshold intensity limit of 2 cd. Therefore, in an effort to reduce power usage, the initial intensity level was lowered to approximately 10 to 15 percent above threshold for the final long-term tests.

Final Results

In light of the preliminary results, two steady-burn warning lights were tested: the traditional incandescent type and the LED light source prototype with an amber lens. Figure 6 shows the results of the tests. The test data are actually a composite of several test runs. The average LED prototype remained above the minimum intensity level for 374 hours while the average incandescent lasted 270 hours. This represents a gain of nearly 40 percent. As expected, the LED prototype tried to maintain a constant light output for as long as possible.

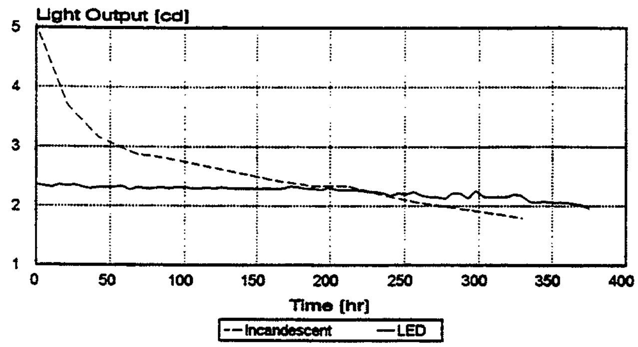

FIGURE 6 Results of endurance testing.

Once the controller could no longer supply a constant level of power to the LED light source (time = 335 hr), the output began gradually to drop just as the incandescent behaved from the start. The jumpiness of the LED light output can be attributed to the effects of the power controller's active management.

Conclusions

From the long-term tests, it was concluded that the LED light source and active power management extended the useful life of TCD prototype. Approximately 100 hours of continuous operation were gained. Assuming a daily operation period of 10, a real-world gain of approximately 10 days could be achieved.

The tests were conducted with the LED light source in steady-burn mode, but the flashing mode results can be roughly estimated as follows: the flashing mode operates at the same power level as the steady-burn mode but emits light only 10 percent of the time. Therefore, a useful lifetime of ten times the steady-burn lifetime should be expected. Unfortunately, a 3,700-hour test was beyond the scope of the project. The LED light source has another advantage over incandescent sources in flashing mode. Incandescent sources develop a high in-rush current when the source is flashed on that places more drain on the power supply than an LED source that does not create such in-rush currents.

The LED prototype may compare less than favorably with current commercial LED-equipped warning lights, which claim useful lifetimes of 400 hours and more. The largest contributor to this is that the LED light source was not designed to perform optimally in the prototype housing, which was designed for use with incandescent lamps. The LED light source was designed to be modular and be used in a variety of TCDs with little or no modification.

In addition to the low intensity flashing and steady-burn prototypes tested, a high intensity, flashing prototype unit was constructed. However, this unit does not meet the intensity requirements when used with an incandescent housing. It will therefore require an optimized lens for practical use, or await advancement in LED technology.

The power controller gives the prototype advantages over its commercial counterparts. The use of an intelligent power controller in the product design allows incorporation of future enhancements with minimal expense and effort. One such enhancement, in the case of warning lights, is adding workzone intrusion or hazard avoidance alarm capabilities.

Prototype Development Discussion

Because the goal of this project was to develop a system that could be used in many different types of TCDs, a discussion of problems encountered in the development of the prototype TCD is appropriate. A major factor in the design optimization was the physical size of the light source module and the power controller. The size of both modules was reduced as much as possible to fit in current warning light housings. An internal structure that supports the light source also required modification to position the LED light source at the optical center of the amber lens. Another shortcoming of using current warning light housing was the design of the amber lens. Current lenses are not optimized for use with an LED light source and may have diffused the light pattern more than necessary.

It should also be noted that the prototype double-sided LED light modules used in the tests exhibited a measurable variation in light output from one side to the other. Most of this effect was due to LED overheating during the soldering process of prototype construction.

Because the design has already been optimized for use with current warning light housings, retrofitting would be very simple. In fact, the prototype is really a retrofit itself. In addition, the amount of work necessary to create an optimized prototype has been minimized to the level of redesigning the amber lens.

PLANS FOR IMPLEMENTATION

The commercialization of the IDEA project is being explored. The product was designed to be an alternative light source for a variety of TCDs and not wed to a particular device. Therefore, various TCD type manufacturers will be contacted during this process.

Because the light source and power controller are separate modules, the application of the active power management may prove more attractive to manufacturers than the complete product.