GUIDELINES TO ENSURE GOOD RETROREFLECTIVITY OF TRAFFIC SIGNS AT NIGHT

by

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ABSTRACT

Vehicle drivers use many "cues" to guide them on roadways. During the day, the driving task is relatively easy due to the number and visibility of cues available. Daytime cues may include traffic signs, vegetation, guardrail, ditches, pavement markings and shoulder treatments. However, at night almost all those cues disappear unless they are retroreflective. Retroreflective signs provide valuable information to drivers but the retroreflectivity gradually degrades over time. Unless signs are replaced at an appropriate time, they no longer meet the visibility needs of the driver.

The Federal Highway Administration in the United States of America is developing minimum maintained retroreflectivity guidelines. These guidelines will be available to all public agencies to make better decisions on proper timing of sign replacement.

This paper presents the concepts of retroreflectivity and how it affects nighttime visibility of signs. It also presents the proposed guidelines and some of the research that led to the development of those guidelines. These guidelines should lead to better visibility of traffic signs at night, which in turn should lead to fewer driver errors and fewer crashes. Ideas for training local road agency personnel in retroreflectivity concepts and sign management techniques are presented.

1. INTRODUCTION

The traffic accident situation in the United States of America is a major health and economic problem. Recent statistics show that approximately 41,000 people are killed and 3,250,000 injured every year. The estimated societal cost of these crashes is more than US$150 billion annually.

In the year 1999, 41,611 people were killed and 3,236,000 were injured in traffic accidents. This is not acceptable and we believe there is much room for improvement. Of those 41,000 annual fatalities, almost 50% of them occur at night yet only 25% of the travel occur at night. These statistics are shown in figure 1

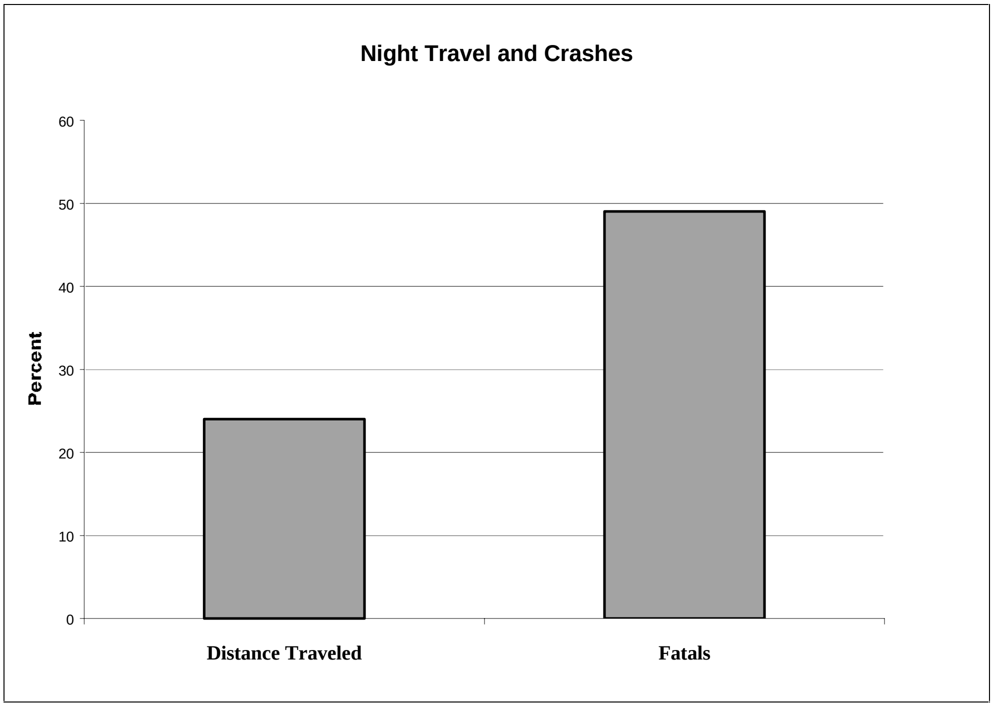


Figure 1: Percentage of Annual Night Travel and Facilities in USA

This is a large disparity that deserves attention. It is well known that fatigue, driving under the influence of alcohol, and our winter weather contributes to increased nighttime accidents. We also believe that visibility plays a major role. At night, the visibility of the roadway and surrounding elements is greatly reduced.

In the United States of America, federal, state and local government agencies, working together with academia and the traffic safety services industry, are dedicated to developing and maintaining a safe and efficient transportation system day and night. However, because of reduced visibility at night, this goal becomes more challenging.

2. RETROREFLECTIVITY OF SIGNS AT NIGHT

Drivers receive guidance information on roads from many sources, both natural and man-made. This guidance is sometimes referred to as driver cues. During the day, numerous driver cues are visible. These may include vegetation on the side of the road, guardrails, differences in side slopes, pavement markings, delineators, and signs. The cues are so numerous, the driving task is relatively easy. However, at night, most of those cues disappear. An example of roadway visibility at day and night is depicted in figure 2. The few remaining cues become critical to the performance of the driver.

(a) Daytime - many available, driver task relatively easy

(b) Nighttime - few remain, task more difficult

Figure 2: Driver Cues

The only way an object cue is visible at night is if it is artificially illuminated and some of the light falling on the object is reflected into the driver's eyes. The amount of light entering a driver's eyes from a certain object will have a great impact on how bright that object appears to the driver. If the light falling on an object can be directed and focused towards the driver's eyes, those objects would be more visible to the driver.

The light at night usually comes from sources such as streetlights or vehicle headlights. In areas without streetlights, the vehicle is the only possible source of light. Because the light from a vehicle is generally aimed in a downward direction, little light is directed upward towards traffic signs. With so little light directed at the signs, they must be very efficient at returning light back to the vehicle, and driver, so they are visible. This property of returning light back to the source is called retroreflectivity.

There are three basic types of reflection. The first is mirror reflection. If a light shines on a mirror, it is reflected in an equal and opposite angle from the direction it came from. The second type of reflection is diffused. This is the type of reflection that allows us to see most objects outside during the day, or in a building. The light from the sun or overhead room lights falls on different objects and the light is scattered, or diffused, in all directions. Some of the scattered light goes into our eyes, which allows us to see the objects.

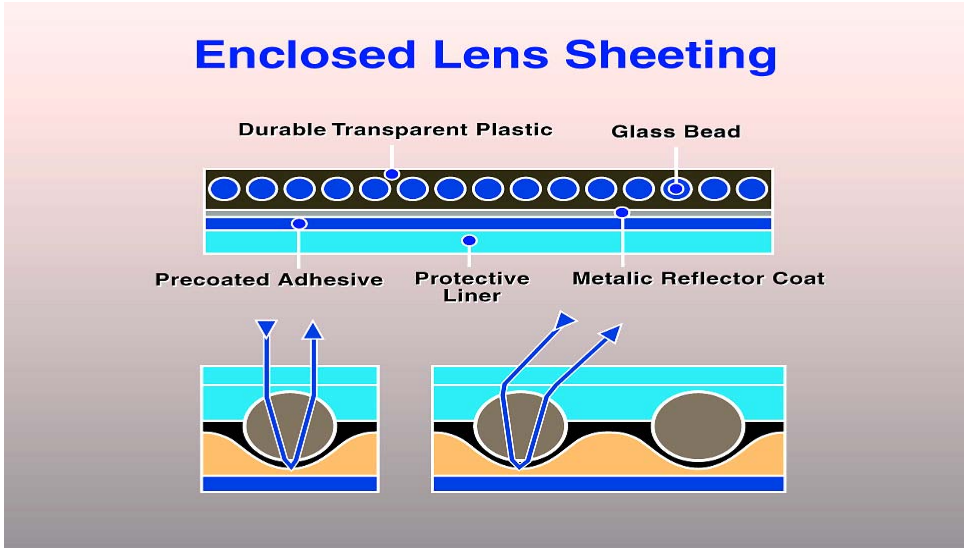
The third type of reflection is retroreflection. Retroreflection returns light to the source. In the case of roadways at night, the retroreflective materials may be traffic signs and pavement markings and the source is usually the headlights of a vehicle. Because a driver's eyes are close to a vehicle's headlights, some of the light returned from retroreflective materials reaches the driver's eyes which makes traffic control devices visible. Retroreflective materials that are efficient in returning light to a driver's eyes would appear brighter to the driver than materials that are not as efficient.

Retroreflection is important because traffic engineers use signs and markings to communicate important information to drivers. At night, if the signs and markings are not illuminated by other sources than vehicle headlights, the retroreflective characteristics increase the chance that a driver receives more information from these traffic control devices.

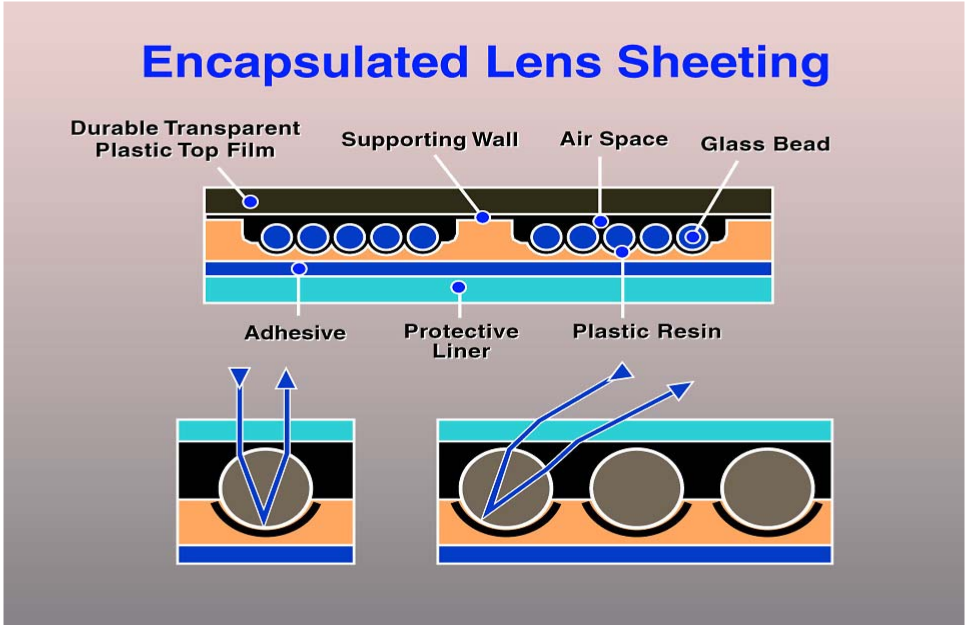
3. RETROREFLECTIVITY TECHNOLOGY

There are two basic technologies that make sign retroreflectivity possible. The first uses very small glass spheres (sometimes called beads). Small glass spheres are manufactured into plastic sheeting that is then applied to signs and other traffic control devices to make them retroreflective. The second basic technology uses micro-prismatic reflectors consisting of cube-corner elements manufactured into the sheeting material.

With the glass bead technology, there are two types; enclosed lens and encapsulated lens. The enclosed lens sheeting, commonly called engineering grade, has the glass beads embedded completely in a layer of clear plastic. The light from a vehicle goes through a layer of plastic, enters the glass bead, goes through some more plastic on the back side of the bead, and finally hits a metallic mirror layer on the back of the sheeting. The light is then reflected off this layer goes through the same medium of glass head and plastic layer back to the source. The encapsulated lens sheeting still uses beads as well, but in a more efficient manner. The light from the source goes through a thin cover layer of plastic then enters an air space before hitting the glass bead. The light passes through the bead and hits a metallic layer lying directly on the backside of the bead. The light is then reflected and returned in the direction it came from. The encapsulated lens sheeting is far more efficient because the light has to pass through much less plastic, losing less light in the process. Figure 3 shows the cross section of the glass head technology.



(a)



(b)

Figure 3: Glass Based Technology for Traffic Control Devices

With the micro-prismatic sheeting commonly known as diamond grade, the light goes through a thin plastic layer and enters an air pocket. It then hits a side of a plastic prism, which has been molded into plastic on the backside of the sheeting. The flat surface of the prism acts as a mirror and reflects the light to two more sides of the prism before being redirected back through the air and plastic layer in the direction it came from. Figure 4 shows the cross section of the microprismatic lens technology.

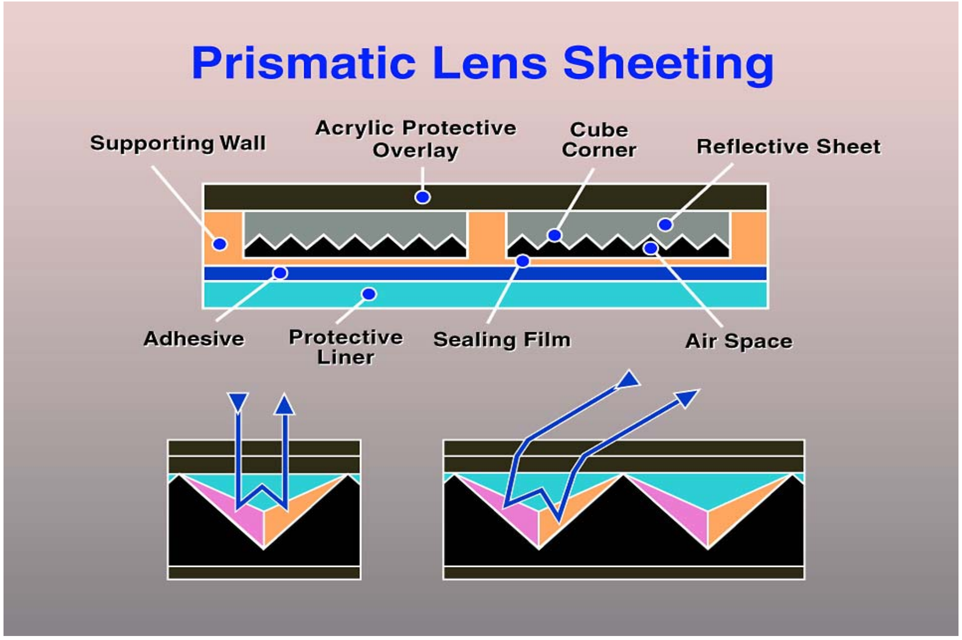


Figure 4: Microprismatic Lens Technology

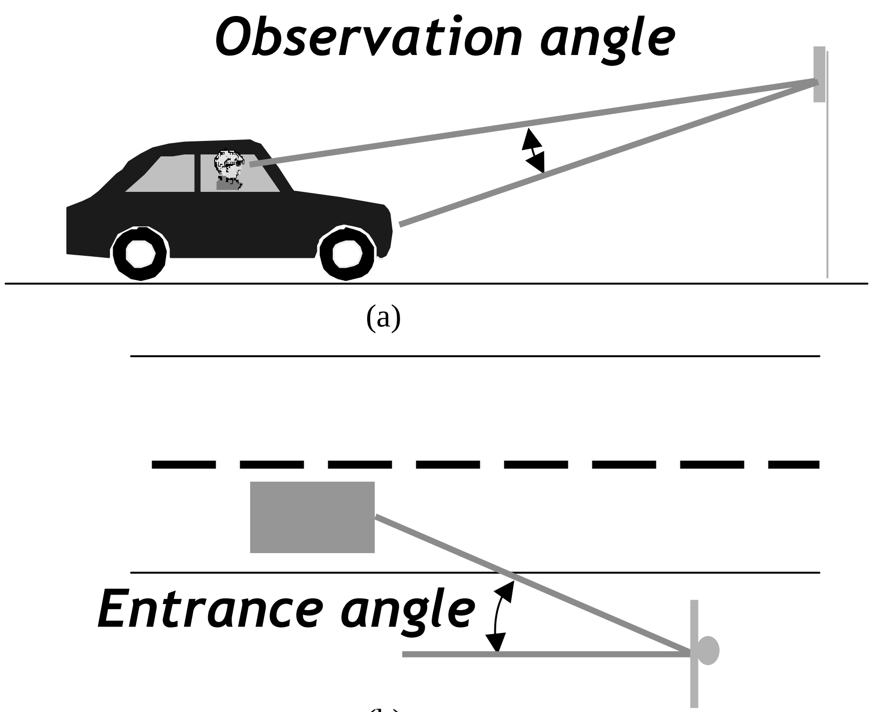
Both glass bead and micro-prismatic technologies take the given light from headlights that are falling on the sign and returns much of it back to the headlights in a cone pattern. If the driver's eyes are within the cone of returned light, the sign is visible to the driver. The cone pattern is such that the middle of the cone has more intense returned light. The returned light is less intense farther from the middle of the cone. Therefore, if the driver's eyes are closer to the center of the cone, which is at the headlight, more light will enter the eyes. This means that drivers in small cars, with their eyes closer to the same height as the headlights, will have signs appear brighter to them than drivers in a large vehicles. The opposite extreme is with a large truck where the driver's eyes are high above the level of the headlights. Because their eyes are at the outer limits of the cone, the signs will appear less bright to them. This concept is leading to decisions by many agencies to use sheeting that is more efficient, or brighter overall, to accommodate the needs of truck drivers.

The retroreflectivity of sheeting can be measured with instruments in the laboratory and in the field. Field measurements of retroreflectivity of sign uses handheld instruments that measures the coefficient of retroreflectivity (R_A). The handheld instruments measure the ratio of the light returned to a receptor to the light supplied from an internal source. R_A is basically the amount of light that comes out from the retroreflective material per amount of light coming in from the light source, at given geometries. The value is expressed as candelas per lux per square meter ($cd/lx/m^2$).

The magnitude of R_A values depend on two parameters namely, observation angle and entrance angle. Figure 5 shows schematically observation and entrance angle. These two angles are set at one geometry in most of the handheld instruments. The observation angle is the vertical angle at the sign between the incoming light beam and the reflected light beam going to the receptor. As this angle becomes larger, the

R_A value becomes smaller. The entrance angle is the horizontal angle at the sign formed between the incoming light beam striking the surface of a sign and a line coming out perpendicular from the surface. This angle increases when signs are placed further from the road or the sign is twisted away from the roadway. As the entrance angle becomes larger, the R_A value becomes smaller.

In the United States, the standard geometry for field measurement of sign retroreflectivity is 0.2° observation angle and - 4.0° entrance angle.



(a)

(b)

Figure 5: Parameters that Affect R_A Values

The retroreflective characteristics of traffic control devices gradually deteriorate over time due to the sun's ultraviolet rays, as well as heat, moisture, and chemical pollutants. This means the retroreflective properties of the sign become less efficient at returning light to the source. Because of this, it is important to replace traffic control devices that no longer meet the needs of the nighttime driver.

4. RECOMMENDED MINIMUM R_A VALUES

A major question is not whether the devices should be replaced, but when. How do we know when the device no longer meets the needs of the driver? The Federal Highway Administration (FHWA) is attempting to establish guidance for public agencies to determine the appropriate level of retroreflectivity needed by nighttime drivers.

The necessary R_A of a sign is dictated by the visibility requirements for a driver. Numerous factors come into play in determining this. These include driver's age, height and eyesight, type of vehicle, headlight type and alignment, road width and geometrics, sign location and orientation, traffic speed, weather conditions, and volume of oncoming vehicles (due to glare). All of these factors, plus many not listed, in different combinations, could in theory produce thousands of different R_A values necessary to meet the driver's needs at a specific point in time at a given location. A matrix with thousands of values for different conditions is not feasible to implement. Therefore, a sensitivity analysis was conducted to determine which factors had the greatest impact on the necessary R_A value. Those critical factors were determined to be sign type, size and color, legend type, sheeting material type, and traffic speeds. These critical factors were used by researchers to develop recommended minimum R_A values show on table 1 through 4. These values have been recommended by the researchers but have not been officially adopted by FHWA. However, they are the best values available and documented at this time and they are being considered for use nationally.

Table 1: Research Recommended Minimum R_A Values for Black Legend on Yellow or Orange Background (0.2º/-4.0º)

Legend	Sign Size (mm)	≥1200	900	≤750
	Material*	R_A (cd/lx/m^2)**		
Bold Symbol	All	15	20	25
Fine Symbol and Word	I	20	30	35
	II	25	35	45
	III	30	45	55
	IV & VII	40	60	70

* I = Engineering grade
II = Super engineering grade
III = High intensity grade
IV&VII = High-intensity prismatic grades (Diamond/VIP)

** Applicable for 0.2^0 observation angle and –4.0^0 entrance angle.

Table 2: Research Recommended Minimum R_A Values for Black/Red Legend on White background

Traffic Speed	> 70kph			# 70kph		
Sign Size(mm)	≥1200	750 - 900	≤600	≥1200	750 - 900	≤600
Sheeting*	R_A (cd/lx/m^2)**					
I	25	35	45	20	25	30
II	30	45	55	25	30	35
III	40	55	70	30	40	45
IV & VII	50	70	90	40	50	60

* I = Engineering grade
II = Super engineering grade
III = High intensity grade
IV&VII = High-intensity prismatic grades (Diamond/VIP)

** Applicable for 0.2^0 observation angle and -4.0^0 entrance angle.

Table 3: Research Recommended Minimum R_A (cd/lx/m^2) Values for White Legend on Red Background

Traffic Speed	≥ 72kph						≤ 64kph					
Sign Size(mm)	≥1200		900		≤750		≥1200		900		≤750	
Color*	W	R	W	R	W	R	W	R	W	R	W	R
All signs	30	8	45	8	50	8	25	5	30	5	35	5

* W = WHITE, R = RED
R_A values applicable for 0.2^0 observation angle and -4.0^0 entrance angle.

Table 4: Research Recommended Minimum R_A (cd/lx/m^2) Values White Legend on Green background

Traffic Speed	≥ 72kph		≤ 64kph	
Color	White	Green	White	Green
Ground Mounted	35	7	35	7

R_A values applicable for 0.2^0 observation angle and -4.0^0 entrance angle.

5. SIGN EVALUATION

Once the appropriate minimum R_A level is determined, we need to develop proposed methods to evaluate existing signs. Three methods seem to have some merit:

The first evaluation method would be to measure R_A values for every sign in the field on a regular basis. The field values can be compared to the tables above and signs can be scheduled for replacement when they approach the minimum R_A values. This might not be financially feasible for many agencies but it is not appropriate to preclude them from doing so. If the type of sign sheeting used is known to last over 10 years, perhaps an evaluation every other year would be adequate. If an agency replaces all the signs on a route at one time, perhaps sampling of signs for retroreflectivity measurements may be appropriate.

The second possible evaluation method is based on a service-life concept. An agency would need data on the expected life of the sheeting material in their geographical area. For example, if a sheeting is known to have a life of 10 years before it degrades to the minimum required values, an agency could set up a replacement program to replace their signs on a 10-year period cycle. Periodic sampling should probably be conducted to verify the expected service life.

A third possible evaluation method would be a subjective evaluation conducted at nighttime by a trained observer. This method would utilize the following steps:

1. Prepare calibration sign having minimum recommended R_A values.
2. Mount the calibration sign in a controlled area with no traffic.
3. Insure the inspection vehicle's headlights are reasonably aligned.
4. At night, the inspector sits in the inspection vehicle at a given distance from the calibration signs.
5. With the headlights on, the inspector looks at the calibration signs and tries to remember how bright it appear.
6. The inspector drives on the roads at a safe speed looking for signs. The inspector subjectively grades the signs as better or worse than the calibration sign. All signs judged to be in the worse category (or close to it) are recorded either by an assistant or on a tape recorder.
7. Poor signs are scheduled for replacement.

This trained visual evaluation method will not be as accurate in measuring retroreflectivity as measuring a sign with a retroreflectometer. However, instruments such as retroflectometer measure at one set of angles (observation and entrance). Actual roadway/sign geometrics may be different with every sign on the road. Therefore, signs with the same R_A may appear to be different brightness due to those geometries. In some cases, for a sign to appear as bright as the calibration signs, the sign may have to have sheeting with a higher R_A. This trained visual evaluation method may have the additional benefit of being able to identify signs in those special situations that require a higher $R_{A.}$

6. FUTURE PERSPECTIVE

The FHWA plans on continuing to evaluate these R_A values and different evaluation methods. FHWA intends to publish recommendations on retroreflection in the near future. In order to disseminate this information to all the cities and counties in the United States, FHWA plans on developing a training course that will be presented to the Local Technology Assistance Program (LTAP) centers. The training course will provide basic information on retroreflectivity. It will also provide hands-on training on the proper methods of sign evaluation. We hope that the LTAP centers will take the training course and present it to cities and counties within their respective states.

Because signs are the primary method we use to communicate information to drivers, agencies that implement a sign management program to evaluate their signs and replace them prior to the time they no longer meet the driver's needs may have a reduction in the number of nighttime crashes. Through surveys conducted in the United States, it was found that drivers want better signs. A good sign management program can go a long ways to provide them with those better signs.

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