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The Innovative 3G Technology in the Variable Message Signs

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ABSTRACT

This article presents the innovative 3G technology used in the VMS (variable message signs). The 3G optics is an advanced lenticular solution that allows an effective mixing of three colours (RBG) without the effect of the colour change depending on the viewing angle. This technology is in opposition to the previously used systems with the separated light beam distribution for the red, green and blue colour. The work describes in detail the functional and technical performance of the new VMS technology and summarizes the characteristics of the parameters obtained from the previously used light beam distribution technology. An important element of the study is to present a measures of performance and efficiency associated with the power consumption, light output, light distribution, visibility, legibility, reliability and durability. Particular attention was paid to the evaluation of the VMS optical performance efficiency. In addition, in the presented work were shown examples of the installed 3G VMS, as well as examples of graphic and text messages displayed on 3G signs.

KEYWORDS: variable message signs, LED optics, 3G signs

1. Introduction

1.1 The Use of the RGB Model in Road Variable Message Signs

The RGB LED technology allows to display any colour from a palette of 256 colours, however, the basic range of colours used in road signs are: red, yellow, green, blue and white. In case of using the LED technology, the colour of the emitted light depends on the width of the energy barrier of used semiconductor material and in practice, at the present moment, does not cause any major problems to obtain the desired light colour. Only white colour is achieved by additive colour mixing or using a special phosphor changing blue (or UV) LED light on a white light radiation. The method of mixing colours (additive mixing) is carried out by placing in a housing 2, 3 or 4 LED of different colours. It is worth noting that in the road application colour rendering index is not applicable.

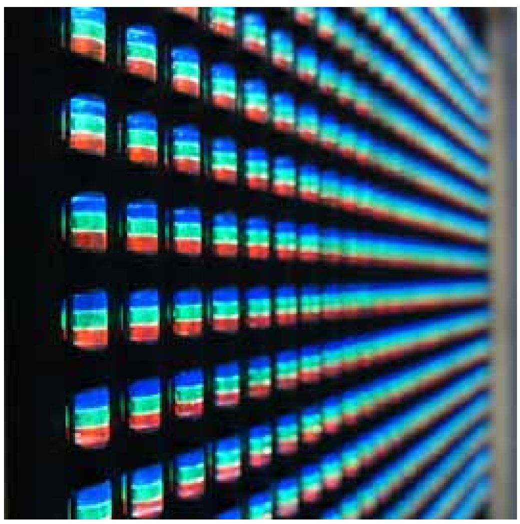

Fig.1. Example of the RBG matrix

1.2 Formal Requirements for Variable Message Signs

The basic formal requirements for the VMS signs are specified in [8]. The basic parameter of the RBG VMS is the colour space, which is described with the chromaticity coordinates. The chromaticity chart for the class C2, is shown in the fig. 2.

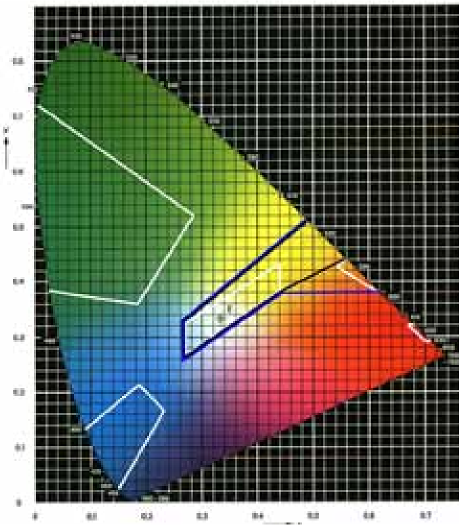

Fig.2. Colour space

Taking into consideration the limitations of the RGB LED technology, it is very important how the VMS manufacturer can deal with ensuring uniformity of the colour, in relation to those required by the standard 10 years of operation time. The classic RGB LED technology and LED aging effect leaves existing applications in Poland much to be desired in this respect.

Another important technical parameter, from the point of view of the 3G technology, is the angle of the light beam distribution.

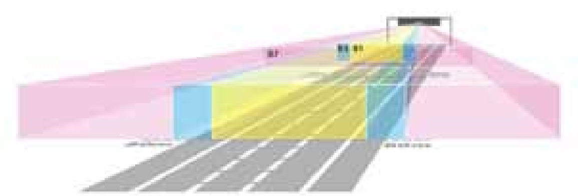

Fig.3. Light beam distribution

The choice of the light beam class distribution depends on factors such as class and width of the road, speed and capacity of human perception, especially in terms of readability of the graphic contents. The importance of the directional intensity of the radiation source and the light intensity at the point at which the recipient is able to read, for example a text message, cannot also be ignored. The larger the angle of the distribution, the greater the current must be used to power the LED in order to provide a fully readable information. This is strongly associated with the phenomenon of faster degradation of LED. An effective solution is to use optoelectronic systems which allows to focus the light beam emitted by the diodes.

2. LED Current as a Factor Determining the Efficiency and Reliability of the VMS

Light-emitting diodes produce monochromatic light, which follows directly from the principles of their operation. The intensity of the light is not too great when the source is a single item. Hence, the useful efficiency in real environments requires a parallel structure, in a functional sense, taking into account the use of many small parts to achieve proper illumination, effective in the realities of the road and its surroundings. In the physical sense (for interpretation in the form of a complex object) we are talking of course about the serial structure, because proper work requires the operation of all the constituent elements (LED). It can be considered in the form of the so-called mixed structure (serial-parallel), for which some elements function as a parallel object and redundancy allows the part of LED to be crashed, while maintaining a "full" functionality of a complex object. We can see how it can work in practice in reality of our roads when trying to determine, which has been encoded in a graphical puzzle, when only a part of the traffic sing is visible. If the objective function is to increase driver alertness, the effect can be achieved. However, in the meaning of the sign efficiency, it is not acceptable, and an attempt to define what percentage of defective parts can be tolerated may not necessarily be effective. The damaged LED distribution is important, and in this case it is quite difficult to define. Far better is to take efficiency of all the LED elements, treating the VMS sign as a serial object.

In this case, using the analysis presented in [1] may determine that the reliability of a complex object is expressed by the product of the probabilities of failure of individual elements, as it is legitimate to assume that the elements are independent.

The use of a lower reliability devices, for the reduction of purchase cost, is just as effective as throwing a rotten meat, fragrant otherwise, to the soup. It is worth to trace presented in the cited literature [1] examples to convince (mathematically) the reasonableness of such action. Assuming that the manufacturer of the equipment will also be the service provider, it can be assumed that the used components are of the appropriate quality.

Regarding the incandescent lighting elements, the failures are usually considered in a catastrophic way in the form of "turn on or not". For other types of items, it is assumed that the damage can be a parameterized, but the deterioration of the properties over a defined percentage is also regarded as catastrophic failure. The good example is buying "energy-saving" light bulbs with an average operation time labelled on the packaging. After a surprisingly short time bulbs begin to "fade", creating an intimate atmosphere in the room. The similar situation occurs with the LED. In contrast to the light bulbs at home, in the VMS signs the current supply of the LED elements can be changed. The result is, of course, the changes in the intensity of light, but by treating the problem in the right way, we can optimize the multidimensional problem.

The light output of the LED decreases gradually. In this case, a substitute for a parameter called the lifetime of the object, which is an approximate estimator of its properties [1], is used as the term of the operating time. This is a descriptor for a similar logical sense, except that the change in the intensity of emitted light to the 90% of the initial capacity is interpreted as a failure in order to eliminate the object of use.

Therefore, if (for example) a standard [8] requires that the device keeps its durability, when exposed to a corrosive environment, for a minimum 10 years, the selection of the components of a complex object is essential, because the use of the "n" elements (in simple terms) also "n-times" reduces the unit life related to a single element.

The lifetime of the object can be adjusted by the user, depending on the level of his technical culture. An example of this can be a daily use of a car. Indefensible is the thesis that one driver gets the same "successful" version of the engine and the engine of the second driver is frequently damaged. Experienced or trained user knows that a certain speed range allows an efficient and economical driving while other is just effective. Similar situation is with the light-emitting diodes. Selection of parameters for their actions can have a significant impact on the sustainability.

2.1 The Current Dependence

The basic parameter for the operation of the LED is the supply current. Voltage across the diode is a postponed value inherently related to its structure (known from basic electronics diode characteristics show quite small vertical or horizontal deviations, depending on the direction of polarization). Controlling the amount of the current directly affects the intensity of the light source (light). Just as higher engine speed in a combustion engine trigger the more power, the similar rotations reduce the trouble-free operation, so the higher LED current will give "more light", but at the expense of reducing the desired longevity. Figure 4 well illustrate this dependence.

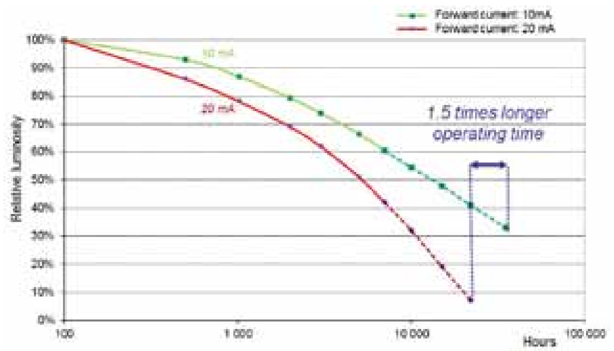

Fig.4. Forward current–relative luminosity characteristic

Although the ratio of 1.5 is spectacular, we should focus, in accordance with the ideas articulated above, at the 90% of the original optical quality. In this case, the different values (rather schematically indicated on the x-axis) for the lifetime of the object are still visible. If the reduction of the light intensity does not substantially affect the functionality of the sign (like taking "the foot slightly of the accelerator" does not affect the comfort and efficiency of the car), then for obvious reasons the supply current should be reduced.

2.2 The Temperature Dependence

It is well known that the current flow results in generating heat – the Joule-Lenz law. An increase in the current value, in accordance with the quadratic relationship, is reflected in the increase of the thermal energy.

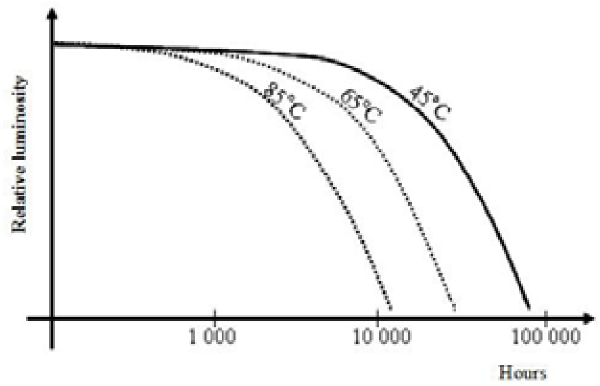

Fig.5. LED temperature dependence

The chart shown in figure 5 illustrates the dependence of the drastic decline in values of reliability as temperatures rise. Placing an object in a box over the road in our climate zone results in a high temperature of particular sign components. Providing a proper air conditioning is an absolutely essential quality mark of used variable message signs, and the fig. 5 should be one of the basic parts of the specification (in terms of temperature test operation in nominal conditions).

Possible operation, to be performed by the designer of the electronic control system, is the reduction of the supply current, of course without compromising the performance.

2.3 Verification of the Supply Current of the VMS RGB

The current supply of the so-called classical SWARCO FUTURIT RGB LED (Fig. 7a), with reference to the nominal current, oscillates at about 16-17% for the colours red and blue, and 7-8% for the green colour. Detailed values are shown in the Figure 6.

% of max allowed current		
red	green	blue
18.8%	21.0%	6.7%
18.8%	21.0%	6.7%
0.35%	0.40%	0.13%
18.8%	5.7%	
18.8%	5.7%	
0.40%	0.12%	
	7.7%	1.7%
	7.7%	1.7%
	0.16%	0.04%

% of max allowed current		
red	green	blue
16.0%		
16.0%		
0.3%		
	2.3%	17.0%
	2.3%	17.0%
	0.04%	0.29%

Fig.6. Supply current for white, yellow, green, red and blue colour.

3. Innovative 3G Technology

The 3G Optics Lens is an advanced solution that allows an efficient mixing of three colours (RBG) without the effect of changing colour depending on the angle of observation. This technology is the opposite of already used separated beam distribution systems for red, blue and green. The 3G technology allows to significantly reduce the power consumption of the VMS device, minimizing the "aging" effect in the life cycle of the object, increasing the MTBF (mean time between failures) and reducing costs of maintaining and servicing.

In the figure 7 are shown a classic RGB matrix and the 3G optics. In the classic system, each of the three LED (red, green, blue) has its own lens system (in the illustrated example lens have rectangular shape), whereas the 3G optics has been implemented with a lenticular system in the form of single circular lens.

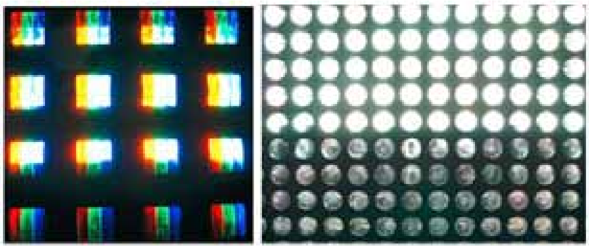

Fig.7. RGB matrix: left – classic matrix, right – 3G matrix

Application of a common optical system for the three colours has been possible with the use of LED SMD (surface mount device). Full colour in the LED SMD (Fig. 8) was created by placing 3 LED in a single housing. LED SMD is characterized by a small size (in this case 3.2 mm x 3.2 mm), high optical efficiency, low power consumption and long operation time.

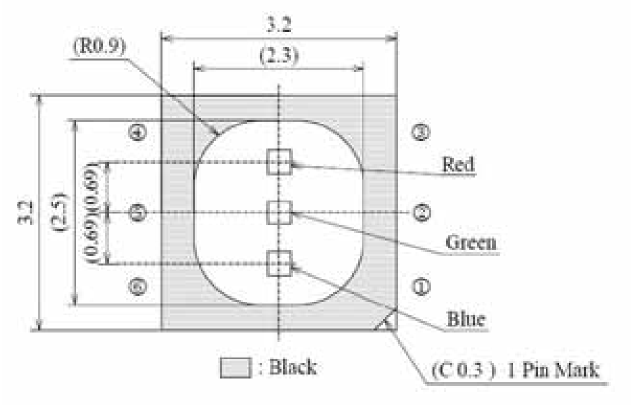

Fig.8. Led SMD RGB diode

Table 1. SMD RGB (Nichia STS-DA1-0125)

Colour	Forward current (nominal value)
Blue	35 mA
Green	35 mA
Red	50 mA

Table 1 presents the values of the forward (nominal) current for each colour. The highest value (50mA) has a red diode, while for the green and blue colours current is 35 mA.

Fig.9. The patented optical system

The 3G optical system (Fig. 9) consists of a focusing lens, front lens and LED housing. The optical system focuses the emitted light beam, providing the optimum use of light and preventing from the phantom effect, which is created as a result of sunlight illumination. With the 3G technology one achieves following technical functionality:

- Luminance: meet the requirements of the class L3 (*) EN 12966-1:2005 + A1: 2009 for all colours - a value is at least 25% higher than the required minimum values. The derived class of luminance for the 3G allows an excellent content readability even for long distances, regardless of the position of the sun.

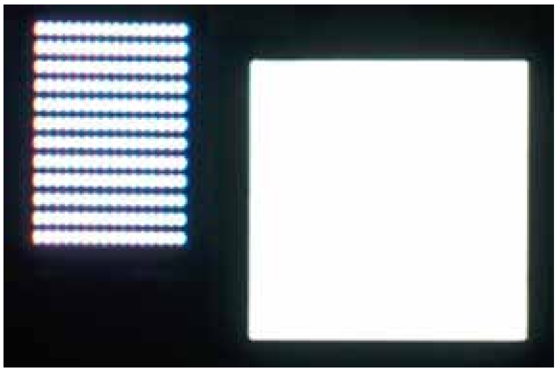

Fig.10. Comparison of the optical matrix performance – left is classic RGB, right the 3G optics

- The ratio of luminance: far exceeds the requirements of the R3 class of the standard [8] for all colours - providing high content readability even in the most adverse environmental conditions, in particular when the sign is exposed to a direct, blinding sunlight (high resistant to the phantom effect).
- The angle of light distribution: B6 meets the requirements of the standard [8] for all colours - a value is at least higher by 25% than the required minimum values. The 3G minimizes the effect of changing colour depending on the angle of observation
- Uniformity: meeting the requirements of the standard [8] for all colours – in order to achieve the standard, in average, the values are at least lower by 80% than the required maximum values was used.
- Lifetime: high quality optical performance has been achieved through the use of only 15% (supply current in relation to

the nominal current) of the LED light brightness. This clearly extended the durability of the LED components and other sign components to about 20 years of operation. During the whole period there is no sign of the optical performance degradation or the phenomenon of non-uniformity of colour. The use of low power consumption strongly affects the economics of operating and maintaining.

Fig.11. The effects of changes in the colour, depending on the angle of observation – on the left is the classic RGB, on the right the 3G optics.

% of max. allowed current			% of max. allowed current		
red	green	blue	red	green	blue
7.84%	7.37%	3.66%	7.30%		
7.84%	7.37%	3.66%	7.30%		
0.66%	0.62%	0.31%	0.61%		
0.09%	0.08%	0.04%	0.08%		
7.84%	2.94%			0.35%	3.67%
7.84%	2.94%			0.35%	3.67%
0.65%	0.25%			0.04%	0.31%
0.09%	0.03%			0.01%	0.04%
	3.94%	0.74%			
	3.94%	0.74%			
	0.33%	0.06%			
	0.04%	0.01%			

Fig.12. Supply current for white, yellow, green, red and blue colour – 3G technology.

- Performance: RGB systems use the maximum power at 160W/m2 - white light emission luminance of 15,710 cd/m2. Reduced power consumption, in addition to the obvious economic aspects, also results in savings in the selection of the diameter power cables and voltage-current protection.

It is worth noting that to achieve the white colour the supply current, with respect to the nominal value, of each component is: 7.84% for red LED; 7.37% for green LED and 3.66% for blue LED. These values are presented in detail in figure 12.

4. Measures of the Optical Performance

All of the features above are integrated and taken into account in the formula for the OPE (Optical Performance Efficiency):

$$OPE= (L_R \times I_N \times BW \times pp^2) / (a \times I^2 \times Lx) \quad (1)$$

where:

L_R – achieved luminance factor - see the test report of the Notified Body.

I_N[mA] – the maximum forward current - see the technical datasheet of user LED.

BW – beam width in accordance with standard [8] - see the research report and table 2 (BW).

pp [mm] – spacing between elements (pixel pitch) as defined in the standard [8].

a – number of light element, the LED of the same colour per pixel.

I[mA] – the supply current to ensure compliance with the requirements for the luminance and luminance factor – see the CE-certificate research report.

Lx – factor depending on the class of luminance obtained in accordance with standard [8] - see research report CE-certificate and table 3 (LX).

Table 2. Table conversion of the beam width (BX)

B1	B2	B3	B4	B5	B6	B7
0.005	0.007	0.010	0.020	0.015	0.030	0.120

Table 3. Table conversion of the LX factor

L1	L2	L3	L3*
4	2	1	0.5

An example of the calculation of the OPE for freely programmable RGB matrix, with pixel pitch 20mm, L3 *, R3, B6, C2 shown in table 4

Table 4. An example of the OPE calculation

Colour	W	Y	G	R	B
L_R	18.4	11.8	6.0	6,8	2.0
I_N	120	85	35	50	70
BW	0.03	0.03	0.03	0.03	0.03
pp	20	20	20	20	20
a	1	1	1	1	1
I	12.9	9.57	2.1	5.95	2.33
Lx	0.5	0.5	0.5	0.5	0.5
OPE	**318**	**263**	**1143**	**231**	**429**

Table 4 shows that the highest value of the OPE index was calculated for the green colour, and the lowest for the colour white.

5. Cost Comparison

An important aspect of these technologies is to compare the cost of purchase, operation and maintenance of signs. For comparison purposes signs with the matrix size of 1300x1300 mm were selected. The estimated cost of the sign are shown in figure 13. According to fig. 13 sign with the RBG 3G technology have the highest purchase price (over 20% higher in relation to the RGB technology with the front shield and 64% higher compared to the pre-defined characters).

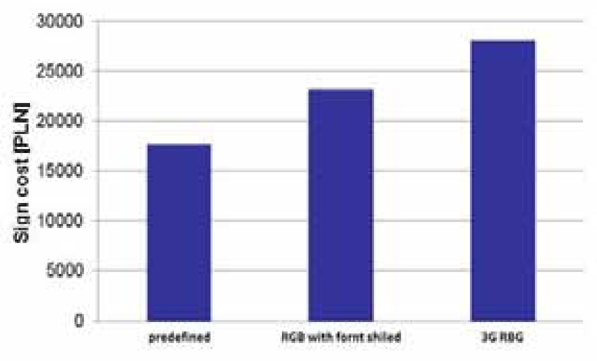

Fig.13. Summary of the sign cost

Next step is to compare the costs of operation, maintenance and repairs (table 4).

Table 4. Summary of other sign expenses

VMS technology	Maximum power consumption [W]	Typical power consumption [W]	Annual operating costs [PLN]	Operation time	Service costs [PLN]	Repairs after the warranty [PLN]
Predefined	40	17	74,46	at least 12 years	300	
RGB 3G	100	30	131,4	at least 12 years	400	1200
RGB with front shield	1250	375	1642,5	5 -7 years	400	1800

In regard to the annual operating costs, the use of the sign made in 3G technology is more than 12 times cheaper than the sign with the front shield. This is due to the power consumption of the sign with the front shield, which is over 12 times higher. Cost of operation is the lowest for the pre-defined sign, with the value of less than 100 PLN per year. Servicing costs are more or less at the same level for each technology. Worth noticing are repairs after the warranty, which for the 3G and sign with front shield cost respectively: 1200 and 1800 PLN. An important element is that the estimated life of the sign with front shield is almost two times lower than for the 3G and predefined technology.

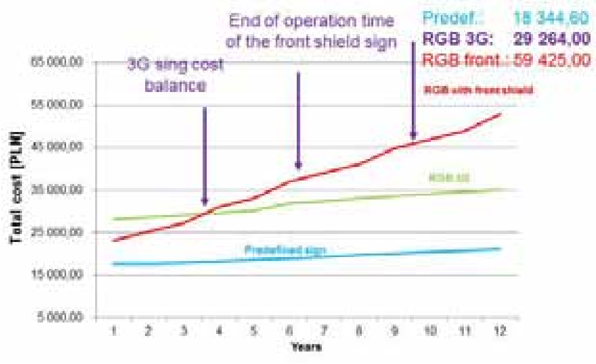

Fig.14. Summary of costs

To sum up the total cost (fig. 14), it can be seen that the cost of the 3G sign, in relation to the front shield technology, is at the same level after just 3.5 years. The total cost of use after 10 years will amount:

- pre-defined technology: 18 344,60 PLN,
- 3G RBG technology: 29 264,00 PLN,
- front shield technology: 59 425,00 PLN.

In relation to the total cost, it is worth paying attention to the necessity for a proper selection of the sign technology, depending on the desired functionality. For systems in which the predefined technology is sufficient, an predefined solution, from the point of economical view, is an optimal choice. However, if one is required to have a fully programmable matrix, the 3G technology is the best solution.

6. Contents Examples – the 3G Matrix

The basic range of colours (red, yellow, green, blue, white) which can be emitted in road signs are shown in figure 15.

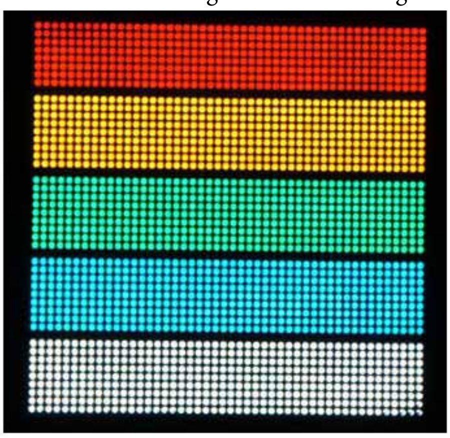

Fig.15. Content example 1

The 3G technology also allows to display the freely programmable, full-colour test messages and graphics. Examples of messages are illustrated in figure 16.

Fig.16. Content example 2

7. Example of 3G signs

An example installation of the 3G VMS is a sub-system of variable message signs implement in the project of protecting the roads technical conditions in Poland in city of Łódź. (fig. 17)

Fig.17. The variable message sign made with the 3G technology

Implemented sub-system of variable message signs informs the drivers about exceeding permissible weight of the vehicle, identifying the vehicle by the displaying licences number. Additionally, the system displays the signs and text messages, informing the driver about the need to stop the car at the Road Transport Inspection weighting station.

8. Conclusion

Choosing the technology of variable message sign can be reduced to four basic points:

- The choice of technologies depending on needs - the choice between cost attractive predefined signs, and fully programmable RBG technology.
- Consideration of the sign operation and maintenance cost - technology selection not only in terms of the initial purchase cost, but also taking into account the indirect costs arising from the exploitation process.
- Consideration of the sign durability and reliability - selection of technology for proper operation during the specified time period. The proper operation is understood as maintaining appropriate lighting parameters.
- Selection of certified signs with a complete report of the test – sign should fulfil the standard [8] and manufacturer should present the results of measurements required for the specific functional classes. Test should be made by a notified research body.

Notice: For colour version of the figures please contact the authors.

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