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VMS Parameters Impact on Safety and Reliability in Road Traffic Management

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Abstract

The topic of the variable message signs presented in this article was analysed in the aspect of proper choice of the light beam distribution angle. It was proven that the proper control of the beam is justified, depending on the road type and it's course, since the proper distribution angle lead to a compromise of effectiveness and reliability. The effectiveness is a result of the S-U-U criterion (see - understand - use), and the important for the object lifespan growth in the reliability is a result of lowering the power. The natural context of the discussion, especially in regard to the conscious moulding the traffic security level, are the main national and union standards.

1. Introduction

The devices that we use nowadays to transfer information from the road administrator to the driver - road user - constituted for the whole century. However, such devices require a permanent supervision by the human, since a sign is required to be:

a) adequate;
b) readable;
c) enduring.

Excessive snowing eliminates one of the attributes mentioned above. The possible, though not wanted, indolence of the technical personnel may have an effect in a form

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of obsolete warning, and many comments were written regarding the demoralizing effect of such situation. The best endurance is the best quality here; the stripes made of slippery rubber, affixed to the pavement or road, even after many years are very good substrate for a pedestrian to slip during the winter and get injured.

The readability of the sign is a derivative of many years of discussion regarding the signal, it should send to the driver. Therefore, in this case one can assume that concreteness, compactness and the further elements of an effective information are fulfilled.

The growing interest in the signs that differ in their idea from the existing ones, that is the variable message signs, can be justified with the electronic technology advancements. Thanks to the new technologies in the area of optoelectronics, it becomes possible to fulfil the task of dynamic sign update in order to improve the traffic management.

Public discussion regarding the growth of effectiveness of the information transfer thanks to the conceptual change of the message carrier is, however, less popular. In fact, the most modern signs (the VMS) do not have their formally established position; they usually owe it to the nonchalance of the owners and operators. A signs that is damaged, or wrongly programmed, reinforces the belief that it has a minimal effect on the traffic fluency.

The basic attribute of a modern equipment that determines it's usefulness at all is the quality that is directly and non-directly a result of the reliability of the used elements and of the knowledge about leading the light beam in the aspect of:

a) the optimization of the energy distribution angle in the information readability;
b) the optimization of the element that exposes the information as a function of minimizing the power supply.

The goal is to present multidimensional geometric relationship of the sign position regarding the road and the driver, the power supply effectiveness and reliability of the VMS device.

The thesis of the presented article saying that **controlling the light beam in** the VMS is profitable, is based on a logical assumption that the signs:

- are to be visible and understandable;
- as the fastest medium in sending the information, should work reliably;
- should be used selectively for the needs of the current lane.

2. Choosing the Correct Light Beam Distribution Class – the Basis of Theoretical Analysis

Contemporary traffic management systems (pol. SZR: systemy zarządzania ruchem) are up-to-date, comprehensive interdisciplinary solutions from the boarder of electronics, IT and telecommunications. In the most general view, it regards the topic of transportation –

[7], [8]. One does not to be convinced about the importance of this branch in science and practice of the Polish road engineering. The team of the authors represents both the science and the development unit. The activity profile is represented by the set of the object publications mentioned in the bibliography ([3], [4], [5]); it contains both the guidelines regarding specifically the topic - [3], and important, or even key issues of the qualities of the measuring techniques in the real life traffic situations, regarding the vehicle in motion weighting systems, or basic for the traffic safety, weather threads prediction. Variable Message Signs, according to the definition of the PN-EN 12966-*1 standard, is "a sign where the information shown can be changed or switched on or off as required. The information can be text and/or symbols."* - [10]. The standard mentioned above contains requirements and measuring methods regarding, among others, photometric parameters responsible for achieving the goal of the device. We also find there description of the goal: *"Because of the major demands on a sign for good legibility and visibility throughout the required viewing range..."* and the criteria of choosing a proper light beam class, as *"for visual performance there will be a difference between installation on highways - with good distance visibility and a narrow beam width - and installation in cities, where there is only short distance legibility and when a wide beam width may be required."* In the light of the quoted articles one can say that the VMS are basically designed to emit a signal, usually symbols of the traffic signs or text messages meant for the drivers. At the same time one must ensure proper readability and visibility of the signs by choosing properly photometric parameters – [1], [6], [7].

Tab. 1

A typical use of the VMS signs due to the beam width (BW) [3]

BW-class	Typical use of signs
B1	High speed road, two running plus one safety lanes, lane use sign mounted at gantry above traffic typically size ranges D and E
B2	High speed road, three running plus one safety lanes, lane use sign mounted at gantry above traffic typically size ranges D and E
B3	High speed road, four running plus one safety lanes, lane use sign or medium wide VMS mounted at gantry above traffic; VMS mounted at the side of the road and requiring a wider beam width to cover up to two lanes, typically size ranges D and E
B4	As B3 above, sign mounted at high level, typically size ranges D and E
B5	As B3, but extra wide sign covering more than two lanes, typically size ranges C, D, E
B6	As B5 above, sign mounted above and next to traffic
B7	For special applications, where very wide horizontal and vertical beam widths are required. In urban areas B7 could account for the interests of cyclists and pedestrians

The parameters responsible for the signs visibility and readability are, among others: luminance L, luminance ratio LR, the distance between the pixels, especially the illumination angle in the classes B1 to B7. Table 1, presented above, shows, on the basis of the standard PN-EN 12966-1:2005+A1, the recommended use of the signs for the specific classes from B1 to B7 in specific traffic organization project and local conditions.

An effective comparison of the beam width class requires an analytical approach to the problem. An example will be presented that will allow a comparison of particular classes in an quantitative sense. The B1 class is the narrowest one, whereas the B7 is the widest one. The B7 class is used very rarely, however it will serve as an example for the discussion regarding the B1 class. Table 2 presents the angles of the beam distribution for the classes in interest.

Tab. 2

The beam width of the B1 and B7 class

BW - class	horizontal (β)	Vertical (α)
B1	10 degree	5 degree
B7	60 degree	20 degree

The proper solid angle for the each of the classes can be calculated from the formula:

$$\Omega = \int_{90-\alpha}^{90} \sin\theta \, \mathrm{d}\theta \int_{0}^{\beta} \mathrm{d}\psi \tag{1}$$

The solid angle for the each class is presented at the Fig. 1:

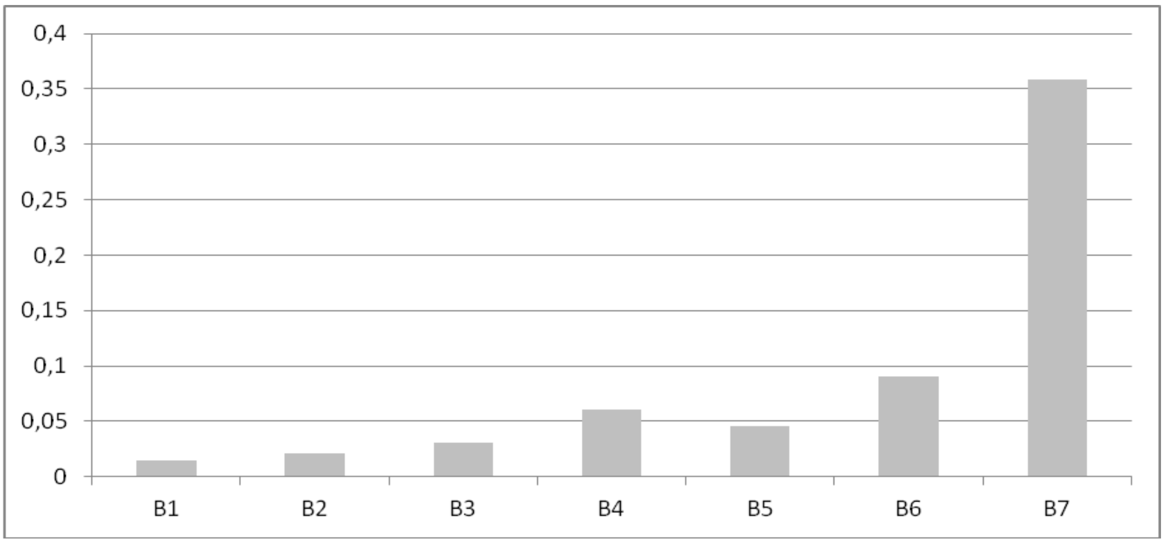

Fig. 1. Beam distribution classes in the solid angle function

For comparison (Fig. 1) the B7 class has 24 times bigger solid angle than the B1 class. Lowering the solid angle for the B5 class in comparison to the B4 is the effect of the used beam distribution angle.

The criterion of designing the VMS is the highest readability and reliability at road, therefore we assume that we want to have the same level of the ray intensity for both B1 and B7 class. It means that one need to increase the emitted power about 24 times, since the ray intensity is inversely proportional to the solid angle. For a sign with the nominal power of 1kW that would mean increasing the power to 24kW, making a use of such sign questionable! However, assuming one have a better visibility of the sign, an attempt to justify such choice can be done. Let us analyse the situation of a straight section of the road and the real visibility time for a sign with the vertical dimension of 2 meters.

Fig. 2 depicts a situation for the sign created in the B1 class and the text line height of 320mm. Only the main beam was specified in this figure. Each diode is visible with the same intensity.

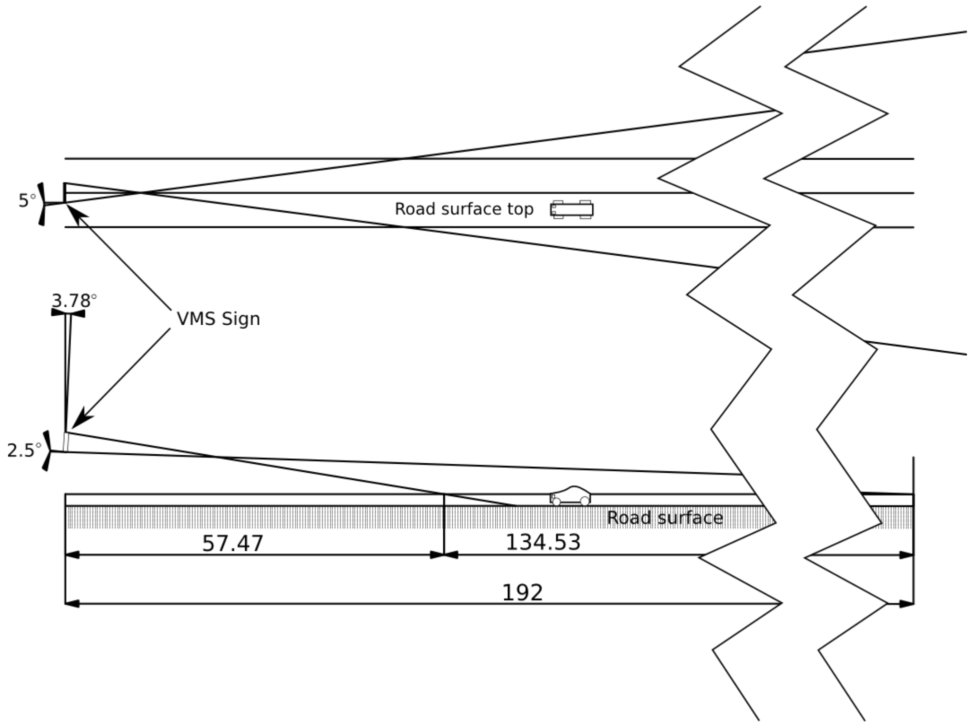

Fig. 2. Visibility of the B1 class sign

The maximum readability of a text line of 320mm height is about 192 meters. Sign setup as presented on the figure 2 makes it possible to read the whole content on a distance of 134,5 meter, starting at 192 meter and finishing at about 57 m.

It is expected that if the emitted power for the B7 class sign must be increased 24 times, in exchange we will receive a big improvement in the sign visibility time.

However, as it can be seen at Fig. 3, human perception limits the situation and in order to have full visibility, the sign, again, must be placed at 192 meters. For the B7 class sign with the same text line and power at the solid angle parameters , the sign visibility spreads to a distance of 175,5 meters, giving in comparison to the B1 class only 23 percent growth of the sign visibility. However, one need to take into account that the driver’s field of view is limited not only by the eye, but also by the windscreen (esp. in the cars), and as a result, the visibility may be bad in a distance of about 15 - 30 meters from the sign. This example shows, how important is a proper choice of the beam to the conditions, in which the sign will be set.

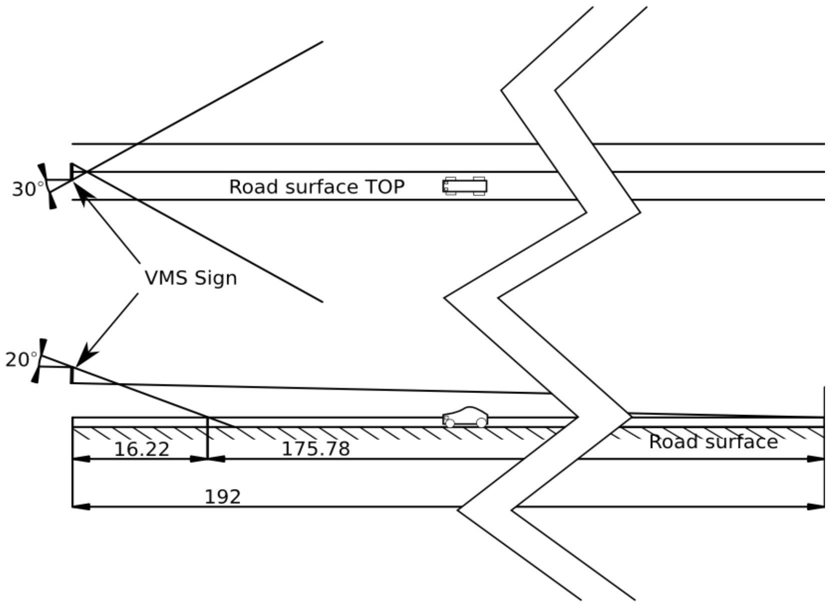

Fig. 3. The visibility of the B7 class sign

Of course an example given above is an abstract situation, due to the current LED technological abilities, and surely does not fulfil the reliability criterion set earlier. In the context of the work time and the element's reliability it is impossible to achieve growth of the diode emitted power by 24 times. It could be achieved by adding diodes, or by increasing the diode current. Assuming that the diode should be triggered to 30% of the rated current, making it technologically possible to keep the diode in a good condition during the exploitation of the VMS, as well as to save the proper level of the luminance, it is impossible to increase the diode current in the ration 1:24. Increasing the density of the diodes with no limitations is also impossible, due to the diode dimensions, or the dimensions of the optic unit, and, moreover, the difficulties in draining the large quantities of heat produced by the diodes.

Figure 4 depicts a course of the LED voltage function against the current. The two hatched areas present the diode power limitation at 40mW and 20mW; it corresponds to the work with the nominal flow respectively of about <20mA and <10mA.

In order to increase the diode lifetime, the current is set to the 30%-50% of the nominal flow (below the second grey area) depending on its characteristics: colour, nominal parameters, casing. The main boundary, behind which is the maximum nominal flow, is the dispersion of the heat (dissipation) created at the diode connector. Rising the temperature drastically degrades the semiconductor. Therefore, the maximum allowed constant operating current depends on the diode performance and the thermal resistance of the housing. None of these parameters can be drastically upgraded, mainly due to the used technology, and the environment of the LED matrix, where large number of them work on a small surface. It is the decisive factor in using low currents and the maximum light radiation by the advanced optic systems.

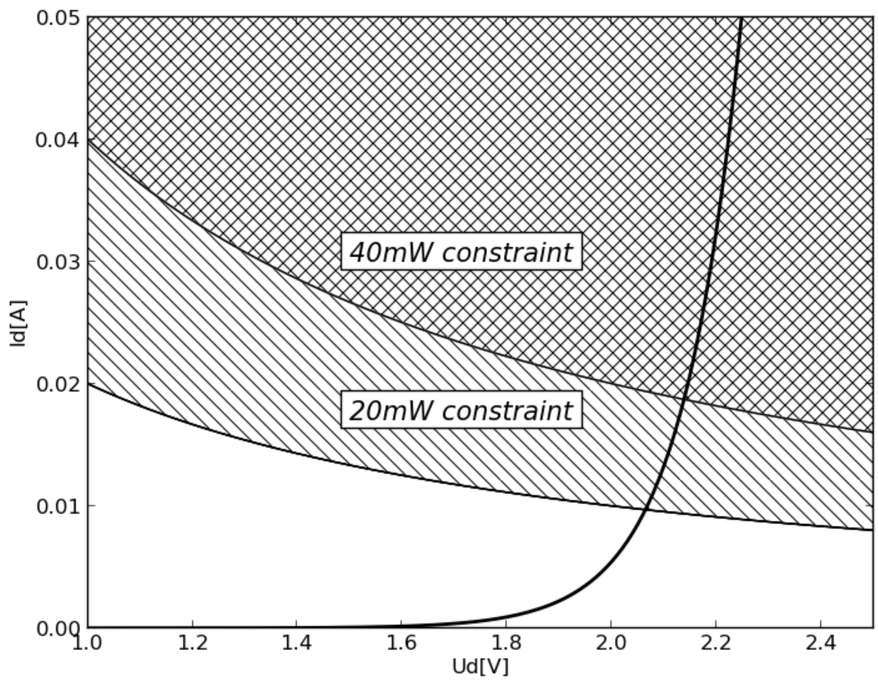

Fig. 4. Power limitations for the LED diode 40mW and 20mW

The technological boundaries presented above decide that the use of the optimal beam distribution angles become crucial when designing signs, as well as important technological issue.

3. Selecting the Light Beam Distribution Class in Terms of Local Conditions

As mentioned earlier, the selection of the light beam distribution class should be dictated by the traffic organization project and local conditions. The choice is made also due to the necessity of emitting the signal towards drivers, for whom the message is intended. One should have in mind important factors, such as the dimensions of the picture surface in the VMS. The figure 5 shows the signal range of the B6, B6 (+) and B7 beam on the straight section of dual carriageway with two lanes in every direction. One should notice that such location of the sign is not too advantageous (it is much better to put the sign above the road) and can be used only with relatively low speed limits, e.g. in cities.

Despite the certain inconvenience, it turns out that it is sufficient to use the beam in the B6 class assuring sign visibility for at least 6 s, and for the B6 (+) (distribution angle ± 19°) this time is more than 14 s[1]. In case where signs are mounted above the road surface, the B3 class can be sufficient enough to gain the far enough visibility from a long distance. Such class is usually used on motorways. When placing the signs along the road, an design engineer must analyse in details every location, and choose possibly straight sections. It is worth to get acquainted with the local conditions, especially in the urban terrain, in order to avoid covering the sing by the buildings or roadside flora. Designing the signs on an existing motorway usually is not very problematic. Of course projects must take into consideration the building code and obtain all the necessary arrangements and permissions.

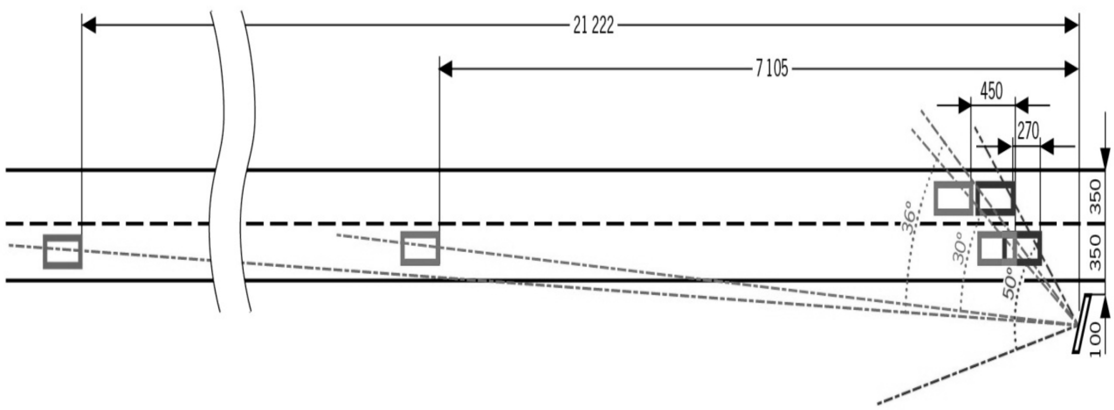

Fig. 5. Sign visibility simulation for different light beam distribution classes

The designer should carefully choose proper classes of parameters for the VMS, as some of their combinations are impossible or inefficient. For example, the use of the wide B7 beam is restricted to particular uses when we deal with very low speed and small distance observation. The mentioned standard [10] PN-EN 12966-1: 2005+A1 shows examples of the use of B7 class when signals send by the signs were meant for the pedestrians or cyclists, in some cases also for drivers at the parking lots.

In practice B7 class is used very rarely. Class B6 is sufficient, even in the city conditions. The choice of B7 will cause the necessity of reducing the distance between pixels and increasing the amperage of the current that powers diodes, as a consequence it will be disadvantageous for the sign durability with no essential visibility and readability improvement. One can notice in the second illustration that the distance from which the B6

[1] The VMS equipped in the optics usually fulfill the standards in excess. In this example the author used the catalogue card of specific producer, where for the beam with the horizontal width if B6 (±18°) and pp *(pixel distance)* = 20 mm diodes are powered with the maximum current of 7.3% of the rated current.

class can be used is sufficient from the target point of view. Using wider beam is going to be ineffective, due to the limited maximum distance, from which the message is readable. For this example, let us assume that the VMS displays a text message 160mm high. It is assumed that it is readable for most of the drivers at the distance of 96m, which is ensured by the B6 class. The message is not readable from further distance therefore the use of wider beam is unjustified. If we also take into consideration that some optical systems in VMS allow a wider beam distribution than the B6 class [7] (the area marked with green stripes at figure 5) one can see that further spreading the beam is not justifiable, since it already covers the area far beyond the distance from which the driver is able to recognize the signal or the message. The situation is similar for observing the signs from short distance. The use of B7 class increases the possibility to observe only by 2,7m. In a real-life situation on road it does not matter. Time in which the signs remains in the drivers field of vision for the B6(+) class while driving at 50km/h is at least 14s.

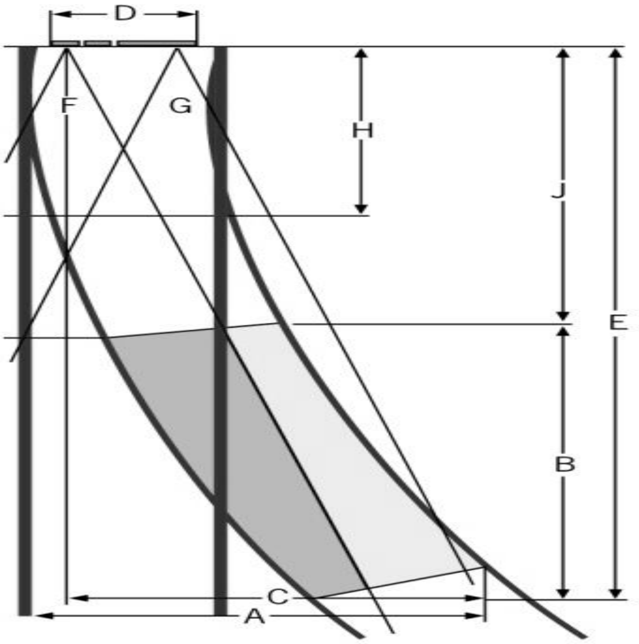

Fig. 6. This picture presents the selection of beam distribution class at the road sections near arcs

It is sufficient time for the driver to easily see, understand and comply the message emitted by the sign. In comparison, on a motorway this time is 4-6 s at minimum. An example scheme of selecting the light beam distribution class for the road sections near the arcs is illustrated above, by figure 6.

4.The Assessment of Sign Usefulness in Regard to the Beam Distribution Class and the LED Current

Some states introduce certain models describing usefulness of the signs in regard to their characteristics, including the light beam distribution class and the amperage of the LED supply current. Usually it is a combination of photometric and electric parameters. A good, but not well known at all, example of such model that quite well shows the idea, is the factor describing the Optical Performance Efficient which is defined by the following formula[2]:

$$\mathrm{OPE} = \frac{\mathrm{LR} \times \mathrm{IN} \times \mathrm{BW} \times \mathrm{pp}^2}{\mathrm{a} \times \mathrm{I}^2 \times \mathrm{Lx}} \tag{2}$$

where:

Tab. 3

Detailed description of the variables in the 2nd formula

LR	the luminance ratio (see the report from the notified body research)
IN [mA]	maximum, allowed rated current (see LED data chart)
BW	beam width in accordance to the EN 12966-1
pp [mm]	the distance between the elements (pixel gauge) in accordance to the EN 12966-1
a	the amount of light sources per element, the amount of LED of the same colour per pixel
I [mA]	power consumption by which the luminance and the luminance ratio (see the report from the notified body research) are fulfilled
Lx	luminance class in accordance to the EN 12966-1

The luminance ratio is calculated by equation:

$$\mathrm{LR} = \frac{\mathrm{L}_a - \mathrm{L}_b}{\mathrm{L}_b} \tag{3}$$

Values L_a and L_b are measured under solar simulator with illumination set to 40 000 lx where:

– L_a - sign is in “ON” state,
– L_b - sign is in “OFF” state.

Value of LR depends on other values like pixel pitch, LED current and VMS front surface.

BW value is calculated by following equation:

[2] The formula is typically used by well-known Austrian Company SWARCO-FUTURIT for the technical description of VMS features. The APM Ltd. cooperates with SWARCO in the area of VMS successfully

$$\mathrm{BW} = \frac{\alpha \times \beta}{10000} \tag{4}$$

Tab. 4
Beam class coefficient

BW	
B1	0,005
B2	0,007
B3	0,010
B4	0,020
B5	0,015
B6	0,030
B7	0,120

Table 4 shows values of BW for each beam classes. Presented formula (Eq. 2) lets us compare the parameters of the VMS with close coefficients. Also the OPE range of value cannot be clearly defined, it depends on the build and the purpose of the VMS board.

The formula (Eq. 2) contains seven variables, which are connected with the technology of producing the sign and the sign classification according to the standard [10]. Independent variables are: IN - the diode rated current, BW - beam width, and a - the amount of diodes per point. These parameters depend only on the technology, in which the VMS is made and its purpose. The variable potentially independent is the VMS board classification to a proper luminance group of the Lx mark, if we do not lower the LED diode current, or do not increase the distance value between the pixels, this class will not deteriorate (we will consider signs in the L3* class).

Tab. 5
Luminance coefficient

	Lx
L1	4
L2	2
L3	1
L3*	0.5

Table 5 present coefficient values, which are adopted for each of the luminance classes. The rest of the variables depend from one another and the technological parameters, they are: LR - luminance ratio / con-trast, pp - pixel pitch, and I - the diode current, by which the measurement was taken. The mutual dependence of those variables can be expressed by binding one value with others by the formula. In this case, the luminance ratio LR depends on the rest of the variables, as well as on the technological variables.

It was assumed that the contrast is a function LR(Ef(I, Qd, Qopt, IN, pp), B(pp, Al, Ab, La, IN)) where I, pp, IN are the parameters mentioned earlier, B is the function describing the amount of light reflected by the VMS matrix, Ab (albedo back plate) and Al (albedo lens) is the ability to reflect the light by respectively the surface between the lenses and the lens, and La (lens area) is the lens area. The value of the B function immanently depends on pp, because when changing the distance between pixels, the lens takes the most of the matrix space, decreasing the distance between the lenses.

The coefficient Ef (I, Qd, Qopt, IN, pp) - is the function returning the luminance value, which effectively contributed in achieving the contrast. Besides the current I, distance between the pixels pp and the amount of diodes per pixel IN, it adopts the Qd parameter, which reflects the loss connected to the diode thermal losses and the Qopt connected to the losses in the optic system.

The pixel pitch can be regulated in order to achieve the proper contrast values, as well as to lower the diode current. However, it is often technologically limited. The first factor is the size of the optic system, or the diode itself. The second important physical factor is the ability to drain the heat from the densely placed diodes, too high temperature leads to shortening the average lifetime of the LED diodes (as well as the lifetime of any semiconductor). The space between the pixels is conditioned mainly by thy economical and purpose factors.

The current I is the key parameter in the VMS board. Eventually the diode current is the main factor that determines the variable message sign lifespan. The level of the current I for which the specific VMS board fulfil the given requirements in regard to the rated diode current, cannot exceed 30%, and should be as low as possible. Exceeding this value causes a rapid drop in the diode brightness during the exploitation. Preserving the low current is connected mainly with the improvement of the Qopt parameter, the effectiveness of the optic system in focus the light of the LED diode in the given beam width.

An accurate analysis of the pattern without taking into account the relationship between the variables may be not effective. However, let us assume that by adjusting the diode current, we will try to worsen other parameters in order to keep the contrast (LR) at the same level. We assume then that first of all the Qopt parameter will be worse, or, to a lesser extent, the whole B function.

Let us consider freele programmable white graphical display VMS. It should comply with following specification: 16mm pixel pitch, L3* luminance class, R3 (luminance ratio over 16,7) and B6 beam width. White display with these parameters from Swarco Futurit have current I at 3.81mA which results in OPE = 1354:

$$\mathrm{OPE}' = \frac{25.6 \times 50 \times 0.03 \times 16^2}{1 \times \mathrm{I}^2 \times 0.5} \tag{5}$$

Sample values were put in the table 6.

Tab. 6

Juxtaposition of the influence of the LED diode current on the OPE factor value

I[mA]	3.81	6	12	18
OPE	1354	546	136	61

Graph 7 depicts the relation between the OPE value and the LED diode current, assuming that other parameters remain constant. A big drop of the OPE values can be noticed even when small changes in the current are done.

A comparison of the variable message signs on the basis of the OPE factor allows a relative quality sign evaluation. One should remember that comparing the OPE factor is useful, if it concerns signs with similar parameters and purpose.

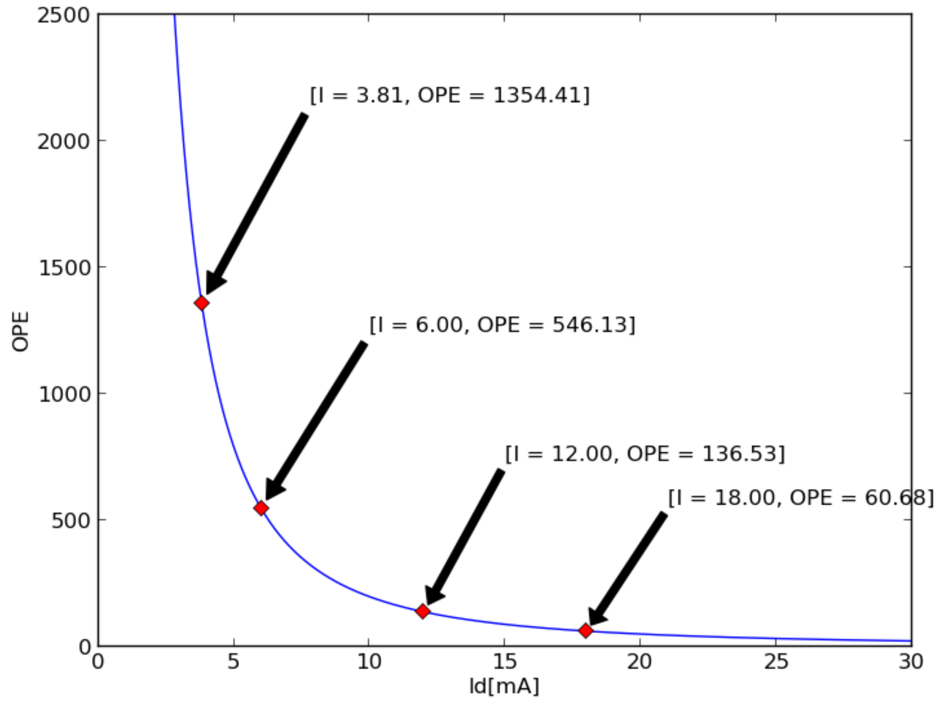

Fig. 7. The OPE dependence on the diode current value, with remaining variables staying constant.

Without going into details, it is worth to notice that the OPE value is calculated separately for each colour. It depends on how many diodes are in one element (pixel). Which means that in a case when the sign can emit white or red colour, the OPE factor is calculated separately for each one of them. It is similar for the RGB signs. The OPE factor is calculated for each colour.

Increasing the light beam distribution angle that is in the direct correlation with the amperage of the supply current significantly affects lowering of the OPE. As it can be seen, OPE factor is inversely proportional to the square of the amperage of the supply current which powers diodes. Therefore it diminishes rapidly with the growth of this factor.

5. Summary

The modernity of the contemporary (2013) road infrastructure still too often measures itself with the technical complexity, less frequently with the usability for the driver. Many solutions are commented in public in the context of introducing order from the dominant position (monitoring, effective violations detection), however, the efficiency of such actions will be seen a posteriori.

The clearness of the necessity of having information about the meteorological conditions, detours, road blocks, and other reasons of disturbances in the traffic flow, increases along with the dynamic popularization of mobile telecommunication devices. According to the authors, practitioners and theorists from the electronic, IT, and traffic engineering frontier, the effectiveness of an information transfer has nowadays a fundamental meaning for the traffic safety. In a specific local conditions, moving into improperly marked “milled” rectangular hole in the road can lead to (and very often does) damaging a vehicle. The effects depend on the speed. One of the used solutions is an additional punishment for the driver for not taking the necessary precautions. However, from the ITS systems development point of view, one can imagine a solution that includes a fluent transfer of information to the road manager, possible to realization, as the CB-radio users show constantly. It would be good to transfer this element of the community self-organization to the ground of a formal system.

An attribute of the present is the acceleration of the speed of information exchange, resulting in much shorter time of self-organization of a community. In case of such information exchange in a public form, the VMS signs start to fulfil a role of a monitor. However, they need to fulfil special requirements, such as: maximum entropy of information; durability; good visibility in various conditions; the smallest ration of the power supply to the visibility with the best visibility, etc.

The lack of knowledge may result in such laying of the sign that in order to work properly it will need a high amount of power (close to maximum) for the electroluminescent diodes, and even then the criterion may be not reached. One must effectively take care of the reliable basis of such designing that guarantees longer lifespan without deteriorating the parameters. However, one first need to clearly define the chosen, key parameters, for which, among other things, this article is devoted.

In the most general view, the leading role must be taken by the optics, which determine effectiveness of the used elements in the sign and it’s usability. Guidelines for the VMS usability can also be found in the publication given in the References as [3] - *Warunki techniczne - znaki o zmiennej treści. Zeszyt 83.* They were prepared for Polish conditions with taking into consideration the articles.

The effect of the argument presented in this material is the observation that one should avoid situations extorting the use of class with too wide beam. This comes from the fact that it has disadvantageous influence on the signs life span, durability and reliability. An additional side effect is the potential, adverse influence on the traffic safety level. The most important conclusion coming up from the analysis is the absolute necessity of taking into consideration objective factors regarding the intended investment. This conclusion can be summarized in a following sentence: selection of the proper parameter classes, especially the beam width, must be preceded by the thorough analysis of the road geometry and is closely related with the realization of traffic organization.

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