IMPROVING VEHICLE REAR LIGHTING AND SIGNALLING

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Abstract

Measures that can be taken to improve vehicle rearlighting and signalling are described in broad outline. These measures relate to the visibility of a vehicle, determination of its position (and derivatives), the additional indication of specific vehicle-characteristics and preferable coding methods to be applied to the design of these indications. Each of the proposed measures is briefly discussed and/or documented. Some remarks relevant to the design of implementation programs, are made.

Introduction

In the evaluation of rearlighting systems criterion-measures will have to be selected. If the ultimate criterion is related to safety, or, more specifically, to a reduction in frequency and/or severity of rear-end accidents - as is the present point of view - then this constitutes a difficult task. Except when rather simple modifications are involved - such as the presence of running lights during daytime - accident data are not available. Moreover, it would seem to be impracticable to collect such data in the near future, that is, data which are sufficiently differentiated to have implications for the design of rearlighting systems.

An experimental evaluation method by way of substitution would be possible if some set of dependent variables could be accepted on the basis of an empirically verified relationship with accident-occurence. With the present state of the art in driver behaviour research however, no results can be regarded as sufficient for this purpose.

It should be recognized therefore, that at present countermeasures in this field cannot be determined by strictly empirical means but will inevitably be the result of some mixture of assumptions, analysis, experimental results and opinion. This is of course a situation which is not unique to the determination of countermeasures in the field of vehicle lighting and signalling.

The basic task in which vehicle lighting and signalling can be of assistance to a driver following or approaching a car may be taken to be the prediction of

future positions of that vehicle over a certain time interval. The positions as such as well as the time at which any specific position is taken have to be considered. To be able to accomplish this the vehicle will have to be detected and localised, its movement-characteristics will have to be determined and possible changes or constancy of the movement-characteristics during the time-interval for which positions are predicted will have to be anticipated. A further differentiation in sub-tasks is possible.
From this point of view improving rearlighting and signalling will mean designing the system in such a way that the general performance of these tasks is affected with respect to speed and/or error.
The hypothesized link with accident-occurence may be constructed along the following lines: Accidents are considered to coincide with the occurence of extreme values (or a combination of extreme values) on certain performance variables, such as those mentioned above. Influencing general performance, for instance by shifting mean performance, will also have implications for the frequency of these extreme values. In this sense an effect on accident-frequency may be hypothesized.

Vehicle and signal detectability

For the practical traffic situation a division in several sub-problems is possible. The first concerns those circumstances in which vehicles as such are sufficiently detectable and those in which additional lighting is necessary.
The answer here should be obvious for situations in which surrounding luminances are low (night) or light transmission is reduced (fog, etc.). The question is then reduced to whether or not daytime lighting of vehicles is necessary. Several studies are relevant to this question.
Vehicle luminances in general have been compared with surrounding luminances in general[1)] and visibility ratings of vehicles in diverse traffic situations have been obtained[2)].
Some accident data are also available:
An experiment has been performed in which some 300 non-lighted vehicles were compared with an equal number of lighted vehicles on their accident-history over a period of one year[3)]. Accident records from a number of American States in which daytime lighting has become obligatory for motorcycles have been analysed[4)].
All of these studies point towards a beneficial effect of daytime lighting of vehicles. The basic point seems to be that in at least some daylight situations

vehicle detectability may be insufficient while drivers either cannot asses this (their own vehicle's) detectability in an adequate manner or, if they can, do not act accordingly (by switching lights on)[2].

A second problem concerns the determination of light-intensities in such a way that with variable surrounding luminances and transmissiveness of the atmosphere vehicle detectability remains adequate while glare-effects are kept at an acceptabel level.

On prior grounds it would seem improbable that with the existing large variations in surrounding luminances and transmissiveness light sources of one single intensity could meet such a criterion. Some illustrative results are available, indicating for instance that for signalling lights maximum intensities acceptable at night are lower than minimum intensities acceptable in daytime or fog[5, 6].

The problem should in fact be stated somewhat differently. An optimum contrast (or range of contrasts) may be assumed. The problem is then reduced to that of keeping contrasts at the desired value, that is, adapting light-intensities to the surrounding luminance and transmissiveness of the atmosphere. Formulated in this manner the problem appears to be largely technical (or economical) in nature. Manual operation of such a multi-level system should of course be avoided. If automatic operation is not possible the number of levels to be used will be determined by the condition that at least additional complexity in the operation of the system should be avoided. This requirement can be taken into account in a four-level system in which the lights are switched on automatically after ignition and a driver has to operate two switches, one to select day or night-intensity and one to select the intensity for clear weather or fog etc. This would not be more complicated than many present lighting systems in which a light-switch (on/off) and a foglight-switch (on/off) have to be operated.

A multi-level system cannot avoid glare arising from a decrease in viewing distance. Especially with nighttime fog glare-effects may be considerable if high intensities are used and viewing distances are small. One way to reduce these effects would be by increasing the area of the lightsource (for "area" lightsources the increase in glare-effects with decreasing viewing distance will be substantially less than for "point" lightsources). Other, more technical solutions are also possible. For instance the light beam may be specified in such a way that emission in directions above the horizontal plane through the light is reduced.

If the position of the lightsource is lower than that of the observer's eye the emission in the direction of the observer's eye will then decrease with decreasing viewing distance.

It would seem that the specific intensities to be selected are very much dependent on the technical solutions with regard to "multiple levels", "cutting off" lightbeams etc. Another question that enters into this decision is the intensity ratio between brake en taillights. Presently, and in connection with the poor definition of brakelights, a ratio of at least 10 : 1 is frequently considered preferable. In this case intensity limits for brakelights immediately set limits to taillight intensities and vice versa. If the brakelights were better defined however, (not on the basis of an intensity-discrimination) this requirement could be eliminated and a lower ratio accepted.

Information about relative position and derivatives

In a reduced visual environment a vehicle's taillights will provide the information necessary to estimate its position, speed etc. The physical properties of the lightsources and their (changing) position relative to the observer will determine the properties of the retinal image. Given these interrelationships the position of the object may be derived from the properties of the retinal image, in this case its size or illuminance. As far as size is concerned the projected lightsources as well as the projected distance(s) between two (or more) sources may be taken into consideration. Several studies have shown that the angular separation between taillights is by far the most powerful source of information [7, 8, 9].
The visual angle subtended by the taillights is not only determined by the distance relative to the observer, but also by the separation distance between the taillights and the orientation of the vehicle relative to the observer. More information will therefore be provided if the orientation and separation distance are known. At present the range of separation distances between taillights is such that maximum values may be about three times as large as minimum values (small cars with taillights not at the most sideward position versus trucks). This variation will be introduced as a source of error in the estimation of distances and even more so in the estimation of relative speeds since the speed of the lightsource projections on the retina - relative to each other - is (inversely) related to the square of the distance. Standardization of separation distances therefore seems desirable. This may be combined with extra sidemarking lights for vehicles exceeding a certain width. In this manner the separation distance between the two outer lights is also kept at the maximum value. This may be considered desirable since with larger separation distances the magnitudes of differences in visual angle with changing relative position will be larger [*].

[*] and more detectable if just noticeable differences are constituted by a constant fraction of the initial stimulus value plus a constant value, which seems to be a reasonable description for the case of successive judgements [10]

Furthermore, inner and outer lights may under certain circumstances serve as a kind of fusion-display. Information about a vehicles orientation toward the observer will be given if side-marking lights (front and rear) emit light in sideward directions as well as to the rear and front. A pattern of two or three lights will then emerge from which the orientation may be derived.

It has also been demonstrated [9] that for single lightsources the angle subtended by the light is a more powerful cue for relative movement than its corresponding illuminance at the observer's eye (provided the angle is large enough to be able to regard the light as an area-source). This suggests that for vehicles carrying only one taillight enlarging the area of the lightsource would be recommendable since the viewing distance over which it will function as an area source will then be increased. A similar effect could of course be obtained by adding a second light, even if the separation distance between the two resulting lights is relatively small.

The modifications mentioned above may be taken to improve the possibilities to sense a vehicle's position, speed etc. relative to the observer. This does not imply however that position, speed and higher order derivatives can then be estimated with sufficient precision. Speed estimates usually contain a considerable amount of error [11]. Generally the human capabilities to sense and utilize derivative information are considered limited [12]. For the traffic situation as well as simulated approach and recess-situations demonstrative results have been obtained [13, 14]. These indicate at least that speed judgements are not veridical over the range of speeds encountered in traffic. As far as tendencies are concerned there is some basis to conclude that slow speeds tend to be over-estimated while high speeds are slightly under-estimated, which does not seem to be a safe bias. Moreover, the ability to detect relative movement as such, without estimating the magnitude of relative speed appears rather limited. For instance: with moderate viewing distances (80-160 m) thresholds for speeds of approach - detected on the basis of angular separation of taillights - may take values of about 25-60 km/h (if viewing time is short) [15]. Additional information therefore remains necessary, particularly when complex operations such as estimating speeds or speed changes and predicting changes in movement-characteristics are required.

This need for additional information is recognized in the specification of present signalling systems which contain obligatory signals for braking and anticipated changes of direction. Aside from the fact that this is a rather limited choice other objections may be raised from a safety-oriented point of view.

The signalled characteristics are more or less semi-critical when relative speeds and available time for action are considered. In the majority of braking manoeuvers relative speeds between vehicles are moderate whereas in situations where much higher relative speeds are involved no explicit signalling is required (e.g. emergency stops, stopped vehicle on express way). A second objection can be raised in connection with the frequency of the signalled characteristics. Braking and changes of direction are typically frequent manoeuvres while other (and more critical) characteristics are typically infrequent. Relative frequency may be related to informational content and rate of processing, driver expectancies etc. Without entering into these conceptual problems however, it may be stated that with decreasing relative frequency of stimuli reactions are generally slowed and/or contain more error [16, 17]. The implication here is that additional signalling - simplifying the perceptual and processing requirements - would be particularly appropriate for infrequent characteristics.
A third objection relates to the design of signals, given a specified number of signals and specified meanings (that is: indicated characteristics).

Signal design

To be effective signalling systems should be designed in such a way that each signal is easily detected and discriminated from other signals or a combination of signals, given the operational situation in which the system has to function. Relevant design principles relate to the selection of visual coding dimensions and number of values or distance between values on one dimension, the number of attributes to be used in order to define any one signal, the attributes of a signal-lightsource which are not relevant to the definition of its signal and the experience of the driving population with signalling systems in general and vehicle signalling. With regard to the operational situation in which the system has to function there seem to be several restricting conditions. One is that the viewing distance at which signals have to be identified is variable. This implies that the visual angle subtended by a signal-lightsource and its illuminance at the observer's eye will be variable. This in turn implies that size and luminance-coding will not be very effective if absolute judgements have to be made since the viewing distance will have to be taken into account in decoding the signal, which obviously complicates this process.
Moreover, luminance/intensity is generally taken to be a poor coding dimension if absolute judgements have to be made [12, 18]. Applied to present vehicle-signalling this leads to the conclusion that the discrimination of brake- and taillights will be poor.

Improvements can be made in this respect (color-difference, separating brake- and taillights), as is also demonstrated by results of experiments in actual driving situations [5, 19].
A second restriction is that distances at which signals have to be identified may be quite large, in some critical situations up to 200-250 m. [20]. At viewing distances of this magnitude most lightsources or patterns of light-sources will be "point"sources (if the surrounding luminance is low). This means that any coding method based on some one or two-dimensional structuring (number, size, length, pattern, form etc.) will be effective only for moderate viewing distances. For large viewing distances only properties of the emitted light (color, intensity) and temporal variations of these properties (flashing lights) remain as coding possibilities (unless very large lightsources or patterns - about a 70 m or more - are taken into consideration). Of these possibilities intensity may be ruled out on the basis of former argumentation. Using flashing lights for large viewing distances will also be consistent with restricting the use of flashing lights to infrequent, critical situations for reasons of a distracting influence [12] or, more specifically, a detrimental effect on the identification of other signals [21, 22]. Such an effect increases of course with increasing frequency of flashing lights. From this point of view the choice of flashing lights as indicators of a change in direction may be considered doubtful.
From research specifically directed at improving rearlighting and signalling, and mainly performed in experimental driving situations, the conclusion can be drawn that color coding and functional separation of signals (introducing a separation distance between signallights having different meanings) will result in relatively fast and accurate identifications, especially when combinations of signals have to be identified [5, 19, 21, 22]. With regard to color coding however, measures will have to be taken in order to prevent the colorblind from missing signals. This may be done either by specifying the colors in such a way that these become discriminable for the (some) partially deficient or by using color only in combination with another coding dimension. With regard to functional separation it may be noted that this is a rather broad categorization which encompasses coding methods such as number, pattern or line-orientation. Accuracy and speed of identification may be further increased by redundant coding, that is, defining any one signal by more than one visual attribute [23, 24]. It would also seem recommendable to keep signal-lightsources more or less constant with respect to those visual attributes that do not define the signal in question. Two arguments may be given in favor. One is related to efficiency.

If different signal-lightsources transmitting the same signal display inconsistent differences with regard to their values on other visual dimensions, these dimensions cannot be used for coding purposes and the already limited range of possibilities will be even more restricted. Secondly, there will be less noise: irrelevant differences between "same" signals may be interpreted as noise, from which the relevant visual attributes have to be separated in order to identify the signal.

Modification of the signalling system.

On the basis of the argumentations presented several changes with regard to the information provided as well as the design of signals seem to be in order. Additional information should be provided concerning low frequency, critical movement characteristics. Emergency stops, stopped vehicles and "low" speeds may be taken into consideration. Several problems emerge with regard to the specification and realization of such signals. Firstly, the activation of the signals: in order to get a reliable system manual operation should be avoided.
For emergency stops this should not be too difficult. Stopped vehicles and certain speeds however can only be regarded as infrequent or critical for specified situations. Automatic activation would therefore include not only sensing the vehicle's speed and subsequently activating a signal, but also sensing the situation with respect to the relevance of activating a signal since signalling in situations in which little information is thereby provided can only be detrimental. A compromise solution might be constructed as follows: automatically activated "stopped"-signal (semi-critical, always activated) and manually operated critical "stopped"-signal (automatic activation may be possible for some conditions, for instance having stopped after emergency braking). At present direct signalling of low speeds does not seem to be feasible. Indirectly, some form of signalling may be accomplished by indicating categories of vehicles which are generally characterized by relatively low speeds.
A second problem is that in change-over periods slowly growing numbers of vehicles will be able to display such newly introduced signals. This implies a decreasing frequency of the unindicated characteristics, a diminishing expectancy of these characteristics if these are not signalled, possibly resulting in an increased accident-probability for that condition. This means that during a change-over period an improvement in safety as a result of newly introduced signals may be (partly) at the expense of those not yet equipped with such a signalling system (a comparable objection may be raised with regard to signals provided on a "voluntary" basis, such as now used for "alarm" or backing up).

A third problem relates to the increasing number of signals. It may be stated that any increase in number will have some negative influence on the identification of other signals [25]. No explicit criteria can be adopted however which enable the specification of an exact upper limit. Some justification for an increase in number may be derived however, from the fact that mainly infrequent characteristics have been selected for additional signalling. Consequently, the probability of signals already incorporated will not change very much. Since signal probability appears to be a more important determinant of signal-identification than number of alternatives, negative side-effects may be assumed to be small. Furthermore, increasing the perceptual load here with regard to coded signals is coupled to a decrease in the load with regard to more "basic" perceptual processes.

Problems also emerge concerning the modification of signals incorporated in the present system. Present signals may be considered as "overlearned". Drastic changes in defining properties may therefore result in a temporary decrease in performance, even if these changes as such are improvements (this may be derived from a simple stimulus similarity-transfer model [26]. Moreover, during a change-over period there will be two signals defining one characteristic, which may also contribute to a temporary decrease in performance. These problems can be avoided if present defining properties are maintained and additional defining properties are introduced in order to improve the identification of signals. In this manner the "old" signals will be incorporated in the "new" ones.

Given the requirements discussed here and previously, signals may still be specified in different ways. Practical considerations also have to be taken into account. Some examples may be given, however.
Improving the discrimination of brake from taillights has already been discussed (separation). Intensity may be used here as a secundary coding dimension if relative judgements are possible (which means separation distances sufficiently large for the viewing distances involved). Flashing lights for the indication of changes in direction have been considered of doubtful value. A change in this respect, however, will be in conflict with the requirements formulated above. Definition of this signal on the basis of flashing characteristic, color (in the European situation) and number (if separated from other signals) will be sufficient. Limits may be set to the "irrelevant" properties of the signal-lightsources (fixing position, size etc.).

Emergency stops might be signalled by flashing brakelights and the semi-critical "stopped"-condition by steady brakelights (which is a compromise taking practical problems into account, but is also compatible with the present situation in which brakes may be - and frequently are - applied in the stopped condition). For the critical "stopped"-condition present "alarm"-signalling (simultaneously flashing direction-indicators) can be taken as a starting point. This signal as such however will not be sufficiently discriminable. Simultaneously flashing brakelights may be added (which may be done in such a way that brakelights and direction-indicators alternate).

Concluding remarks

The proposed changes in vehicle rearlighting and signalling have been devided into four categories, related to: vehicle perceptibility, position-information, the definition of present signals and the introduction and definition of additional signals. Since there seems to be no way to quantify the expected effects of any specific alteration it will be difficult to state preferences for countermeasures belonging to one or the other category or for specific countermeasures within any one category.

Different selections can be made.

Accepting this, it will be evident that any number of proposals for improvement may be constructed on the basis of this set of measures. This is even more so, since specific recommendations can be followed to varying degrees. For instance, if the idea of standardizing separation distances between taillights is accepted, it is still possible to consider different margins. To reach a final decision in such matters technical, economical and legal considerations also have to be taken into account. For these reasons no specific proposal has been included here, although some suggestions have been made for illustrative purposes. More or less specific proposals for improvement have been given by several other authors[5, 6, 27]. After superficial examination these proposals seem to differ widely. From the point of view taken here it appears, however, that there are very few fundamental differences of opinion. Rather different selections are made out of the set of possible countermeasures, or stress is laid on different considerations, for instance: compatibility with the present situation and providing for position-information ([27], in this case compatibility with the present American situation), the discriminability of presently incorporated signals[5], or the additional indication of critical movement-characteristics[6]. The main point here is, however, that it may be more conducive to the implementation of countermeasures in this field to indicate directions in which improvements can be undertaken than to present specified proposals in which differences - even those based on more or less arbitrary decisions - tend to be stressed more than similarities.

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