

Self-explaining roads

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Abstract

This paper discusses the concept of a structurally safe traffic system. The crucial question is how potential errors occurring in traffic can be reduced by revising the layout of the road environment. Two considerations play an important role: inherent safety and self-explaining properties. Inherent safety refers to the reduction of potentially dangerous encounters. Traffic systems having self-explaining properties are designed in such a way that they are in line with the expectations of the road users. The in this paper discussed “Self-Explaining Road” (SER) is a traffic environment which elicits safe behavior simply by its design.

1. Introduction

One of the major problems of road traffic is its level of unsafety. It is commonly estimated that over 90% of the traffic accidents are related to human error. Because better education, information and enforcement only have a marginal effect on accident reduction, it is crucial that the road and vehicle environment is adjusted to the human capacity limitation. Safety should be considered as a system property to be built into the road and vehicle environment (see e.g., Godthelp, 1990; Roszbach, 1990; Twisk, 1991). The crucial question is how design principles can reduce the probability of an error when executing the traffic task. Two aspects play an important role: inherent safety and self-explaining properties. Inherent safety refers to the reduction of potentially dangerous encounters. Traffic systems having self-explaining properties are designed in such a way that they are in line with the expectations of the road user. The so-called “Self-Explaining Road” (SER) is a traffic environment which elicits safe behavior simply by its design.

In recent years, the TNO Human Factors Research Institute has studied several aspects of Self-Explaining Roads. For example, Riemersma (1988) investigated how drivers internally represent different road categories. Theeuwes (1989, 1990, 1991a) investigated the role of drivers expectations on search strategies in traffic. Recently, Theeuwes and Godthelp (1992) applied the principles of enduring a safer road environment on rural 80 km/h roads, and inferred a list of design criteria for the development of SER.

2. Categorization of road environments

The idea that road users categorize the traffic environment is based on the general notion that people try to structure their world. It is not the individual objects, nor the individual environments that will be stored in memory, but an abstract representation of the world which contains a basic set of typical properties. These prototypical representations develop through experience. In order to ensure unity in the way people structure their world, it is required that there is a large consistency in the physical appearance of an object or environment and a large consistency with respect to the behavior displayed in relation to that object or environment. When these conditions are fulfilled, it can be expected that the prototypical representation of a certain object or environment will be more or less the same for everyone. For example, for people from the Western world there will be a large consistency with respect to the prototype of a chair: an object with four legs, a seat and a back; the typical behavior is that one can sit on the object. When confronted with another object (e.g. a stool a high seat without a back) which physically does not resemble a typical chair, categorization of that object as a ‘chair’ will be less easy. It should be noted that objects can also be solely classified according to the behavior in relation to an object. For example, a ‘bag’ on which one can sit comfortably but which does not at all resemble a typical chair, might still be classified as a chair.

It is reasonable to assume that through experience road users will develop a prototypical representation with respect to the different types of roads. When the physical appearance of a specific road environment is homogeneous and physically different from other types of road environment, it is expected that a prototypical representation will easily develop. For example, if one would ask road users to describe a freeway, then there will be consistency with respect to the type and the position of the road elements, road users and the relationship among them. If such a question would be asked with respect to the 80 km/h roads outside the built-up area, there will be not much consistency in the answers, because there is no coherence in the physical appearance of these types of roads, nor is there consistency in the behavior displayed on these type of roads. In addition, when there is not much consistency in the physical appearance of a specific type of road, road users might develop a biased prototype which reflects the type with which the road user happens to have a lot of experience: for example, the 80 km/h road which a road user takes to work every day. This biased prototype might be inadequate in other 80 km/h road situations.

Riemersma (1988) investigated subjective road categorization as represented in the ‘heads’ of the road users. For the built-up area, the results indicate that the official objective criteria of road categorization as used in the design of road environment are only marginally present in the subjective categorization. In addition, the study shows that the estimated safe speed depends only on the effort it would require to keep the car on the road. The probability of the occurrence of an encounter with another road user (e.g. a pedestrian) did not have an effect on the estimated safe speed. Outside the built-up area, Riemersma (1988) demonstrated that the hard shoulder which, in The Netherlands discriminates motorways from other types of fast roads, is not used in the subjective categorization. In addition, roads which were not motorways but which allowed a high speed were often erroneously classified as motorways (15–20%).

Mazet and Dubois (1988) claim that the categorization of road environments occurs only on the basis of the behavior displayed in these environments. This implies that different categories of roads that generally require the same type of behavior will subjectively be represented by the same prototype. A residential area where everybody drives 80 km/h (although the speed limit is 50 km/h) and a city highway where the same speed is utilized will be categorized in the same way, although they look quite different. Inadequate categorization is dangerous, because the inadequate categorization will induce inadequate expectations.

3. The effects on traffic behavior

The prototypical representation of traffic environments, which is the basis for the categorization process, contains “information” regarding the typical spatial relationships between the road elements and road users, so called *schemata* (Bartlett, 1932; McClelland and Rumelhart, 1981); and “information” regarding the typical sequences of events in time, so called *scripts* or *frames*. (Minsky, 1975). Classification of a road environment activates particular scripts and schemata which, in their turn, induce where – in place and in time – particular road users and elements can be expected. If the environment induces inappropriate expectations, errors in visual selection are likely to occur.

The nature of contextual effects on the processing of traffic scenes is thought to be the result of an interaction between incoming perceptual information and the higher level memory representations (i.e., schemata and scripts). For example, it has been demonstrated that objects that are obligatory in the schema are encoded more or less automatically (with a minimum use of the processing resources), whereas objects which do not fit in require more resource-expensive encoding processing, involving active hypothesis testing (Friedman, 1979). Loftus et al. (1983) argue that scenes are processed in two stages. Holistic information is extracted first, followed by search for specific features. The holistic information can be assessed within a single fixation of the scene (Potter, 1975). This information is thought to activate the scene schema which is held in a presumed pictorial memory system (Paivio, 1971). A search is then initiated for specific objects as held in temporal storage.

Recently, Theeuwes (1991a) demonstrated the effect of contextual information on visual search in everyday life traffic scenes. More specifically, the study explored the effect of the object-context relation “position” as defined by Biederman et al. (1982). This property refers to the fact that objects which are likely to appear in a given scene often occupy specific positions in that scene. This effect on “position” information is particularly important, because this relation might be violated in everyday life traffic situations. Theeuwes (1991a) showed that errors evolved when road users had wrong expectations regarding the location appearance of particular target objects. Fig. 1 gives an example of the stimulus material used in this study.

With respect to this example, subjects were instructed to search for a traffic sign and respond “yes” when they found it and “no” in case they thought that no traffic sign was present. In the upper picture, the traffic sign is positioned at an expected location which gave a search time of 1112 ms and 6% errors. In the lower picture, the traffic sign is positioned at the left side of the road which is an unexpected location given the overall



Fig. 1. Example of stimulus material. (In the upper picture the traffic sign is positioned at an expected location; in the lower picture at an unexpected location.)

layout of the scene. In this condition search time was 1745 ms and in 33% of the cases subjects thought that no traffic sign was present. Since both pictures are physically identical, that is, the conspicuity of the traffic signs is exactly the same for both pictures, the difference in performance can only be attributed to the top-down driven search strategy induced by the layout of the scene. Fig. 2 gives the mean reaction time and error percentage for 22 different traffic scenes in which different targets (e.g., traffic signs, bikes, cars) were present.

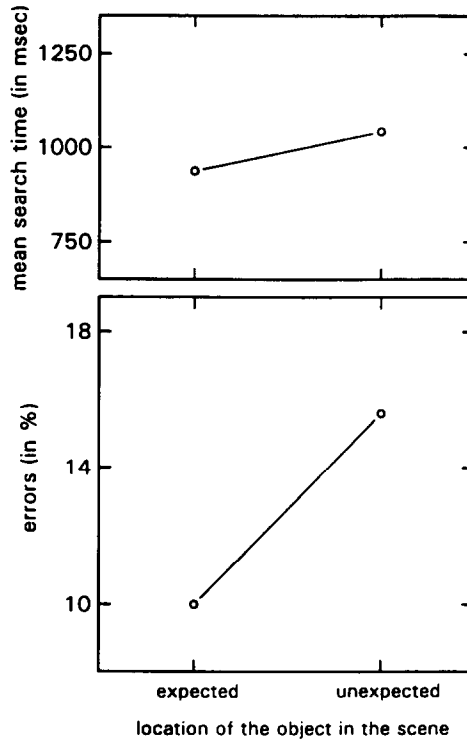


Fig. 2. Mean reaction time and error percentage for searching for a target object placed at an expected or unexpected location within a natural traffic scene.

As is evident in Fig. 2 visual search behavior is dependent on the expectations induced by the environment. The layout of the environment activates a particular schema which induces expectations where to expect the target object. As is clear from this study, search behavior is biased towards those portions of the visual field where the target is expected. It should be realized that the effects of contextual driven search might be much stronger in real driving, especially in conditions in which there is a relatively high visual load i.e., driving in busy traffic in urban environments or under reduced sight conditions, for instance when driving in the dark or in twilight. Especially in these situations, rapid resource-inexpensive and conceptually-driven feature detection is advantageous. As is evident in Fig. 2 objects at unexpected locations are not seen too late but, in most cases, not seen at all, i.e., when searching for objects at unexpected locations subjects tend to think that the target is not present. It is very likely that this type of errors also occurs when searching during actual driving. In fact, accident data seem to confirm this notion: a large portion of drivers (about 37% involved in automobile crashes do not act too late, but do not act at all to avoid the collision (Sussman, Bishop, Madnick and Walter, 1985). In addition, Malaterre (1986) claims that 59% of all accidents are the result of inappropriate expectations or interpretations of the environment. Note that accidents do not occur often which indicate that errors in visual sampling, i.e., detection misses, are not fed back to the driver. On the other hand,

correct expectancies, i.e., finding an object where you expected it, are consistently reinforced, because the traffic environment is reasonably predictable.

Given these considerations, it is clear that extremely dangerous situations may occur when the design of the traffic environment induces certain expectations, regarding the spatial arrangement of objects in that scene, which are not correct. The importance of inducing the correct expectations is supported by studies showing that visual selection does not so much depend upon the conspicuity of the target objects, but more on the demands of the search task (Theeuwes, 1990, 1991a, 1991b). Conspicuous objects are not perceived when they are irrelevant to the task at hand. This suggests that when a traffic environment induces incorrect expectations, conspicuous signs and/or other infrastructural measures can hardly correct these expectations, because they are simply not perceived.

Although there is no empirical evidence regarding the time frame of these expectations, it is likely that once expectations are set they cannot be changed easily. When initially the layout of a road indicates that it is a motorway the driver will continue interpreting the road as a motorway. Gradual changes to another type of road will lead to confusion and incorrect expectations. Consequently, the same type of road should connect a section which psychologically is interpreted as one: for example, a road connecting to cities, a road from a shopping to a residential area. Because people interpret a connecting road as a single psychological ‘unit’, it should be designed as such, that is, one type of road.

4. Self-explaining roads

Roads are self-explaining when they are in line with expectations of the road users. In The Netherlands, the design of motorways and woonerfs are to some extent self-explaining and inherently safe. On the other hand, a very large extent of the Dutch roads – for example



Fig. 3. The probability of the occurrence of slow traffic cannot be inferred from the road design: *Should you expect bicyclists on this road?*)The answer is ‘yes’.)



Fig. 4. The probability of the occurrence of oncoming traffic is often unclear: *Should you expect oncoming traffic?* (The answer is “yes”.)

the 80 km/h rural roads – are not designed according to the safety principles mentioned above. This type of roads is not easily classified, because it does not have any prototypical recognizable properties, nor does it compel the traffic behavior required on these roads. For example:

- The probability of the occurrence of slow traffic cannot be inferred from the road design.
- The probability of the occurrence of oncoming traffic is often unclear.
- The location and the presence of crossings and exits of driveways are not well marked.
- The estimation of the location and the required speed of curves are often difficult and inaccurate.

Figs. 3 and 4 give some examples of the issues raised above.

The use of consistent and easily understandable codes can to some extent reduce these problems. The design of roads should reflect the probability of encountering particular road users. Along the same line is the concept of “Positive-Guidance” as developed by Alexander and Lunefeld (1986). They also suggest that the traffic situation should be in line with the expectations of the road users.

An addition to the development of a road which is self-explaining, is the development of a modern traffic control system which can add some “intelligence” to the road environment. For example, navigation systems in the car with variable directional signs along the road can guide traffic, can reduce uncertainty in finding the optimal routes and can remove instabilities (e.g. traffic jams) in the traffic flow. Variable speed advice dependent on the local circumstances (intensity, rains, fog) can optimize the traffic flow.

Research on categorization of traffic environments is scarce and the way schemata and scripts affect traffic behavior is for a large extent unknown. Yet, purely on theoretical grounds, it is possible to identify some criteria which will increase the self-explaining character of roads. When developing the “road of the future” one should start with a few easy recognizable and distinguishable road categories. These types of roads should be designed in such a way that high speed differences and directional differences are not

possible (Koornstra, 1991). Four categories can be distinguished: motorways, highways connecting larger regions, rural roads connecting residential and shopping areas, and woonerfs, i.e., roads going from door to door.

For these four categories, self-explaining roads should fulfill the following tentative criteria:

- Unique road elements (homogeneous within one category and different from all other categories).
- Unique behavior for a specific category (homogeneous within one category and different from all other categories).
- Unique behavior should be linked to unique road elements (e.g., woonerfs: obstacles-slow driving; motorway; smooth concrete-fast driving).
- The layout of crossings, road sections and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviorally be completely different from crossing on a rural road).
- One should choose road categories which are behaviorally relevant.
- The same road category should connect a section which psychologically is interpreted as a single unit (e.g., a road connecting two cities).
- There should be no fast transitions going from one road category to the next.
- When there is a transition in road category, the change should be marked clearly (e.g. rumble strips).
- When teaching the different road categories, one should not only teach the name, but also the behavior required for that type of road.
- Category-defining properties should also be visible at night.
- The road design should expel speed differences and differences in direction of movement.
- Road elements, marking and signing should fulfill the standard visibility criteria.
- Traffic control systems should be uniquely linked to specific categories (e.g., on motorways, systems that regulate traffic flow and on rural roads, systems that restrict driving speed).

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