Visual Perception of the Roadway and Roadside Elements by the Observer in Motion

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16. ABSTRACT
This study surveyed the fields of environmental design, highway research, and environmental psychology and found no body of research, much less any measurements, on the relationships between the driver and the landscape (natural and human-made) beyond the paved area of the road. The finding is remarkable, given the fact that landscapes are often in the focal vision and always in peripheral vision of drivers. The complete lack of information is also remarkable because of the growing national public support for scenic by-ways and the increasing community demands for landscape design along roadsides. Importantly, this study finding is disconcerting, given the possibility that the driver's perception of roadside landscapes likely relates to safety.

The study recommends a research strategy: 1) identify landscape variables, 2) determine the correlation between the landscape and safety, and 3) develop a knowledge base. Pilot studies should be conducted in areas (1) and (2), and the resulting knowledge base (3) should be tested in design applications. If the design applications merit continued study, then research should be conducted to produce a full knowledge base so that future landscape design can be better informed and therefore more cost effective.

17. KEY WORDS
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by a Moving Observer

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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STUDY SUMMARY

This study surveyed the fields of environmental design, highway research, and environmental psychology and found no body of research, much less any measurements, on the relationships between the driver and the landscape elements (land and water forms, vegetation and human made features) beyond the paved area of the road. The finding is remarkable, given the fact that landscapes (natural and human made elements) are often in the focal vision and always in peripheral vision of drivers. The complete lack of information is also remarkable because of the growing national public support for scenic by-ways and the increasing community demands for landscape preservation and design along roadsides. Importantly, this study finding is disconcerting, given the possibility that the driver's perception of roadside landscapes likely relates to safety.

We did find existing highway research methods (e.g., hazard surveys) that could be translated and existing computer graphic simulation technology that could be used directly to study the relationships between the driver's perception and the roadside landscape. We also found that existing visual data, collected and stored routinely by WSDOT and other state DOTs, provide excellent, handy resources for studies to begin immediately.

The study recommends a research strategy: a) identify landscape variables, b) determine correlation between the landscape and safety, and c) develop a knowledge base. Pilot studies should be conducted in areas (a) and (b), and the resulting knowledge base (c) should be tested in real highway applications. If the applications merit continued research, then it should be conducted to produce a full knowledge base so that future landscape design can be better informed and therefore more cost effective.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations emerged clearly from this study:

CONCLUSION #1

Almost no information exists concerning the sights a moving viewer or driver sees in the roadside landscape, nor does any knowledge of a driver's reaction to this visual information exist. This lack of knowledge is astounding, given two application needs: a) the likelihood that these landscape variables relate to safety, and b) the increasing amount of money being spent on landscape designs to satisfy public demands. Basic research on the driver's perceptual responses to landscape elements (vegetation and landform) is clearly needed. If we had basic knowledge about the driver's perception of the landscape, as we do about signs, then the design of these elements could be informed to enhance both safety and cost effectiveness.

RECOMMENDATION #1

Categorize landscape variables as they relate to the perception of a moving observer. These variables should relate to both landscape design and visual perception, but this categorization should not depend merely on current professional environmental design judgment because existing judgment is a product of our experience with stationary or slowly moving viewers. The development of these variables should involve studies of what a moving viewer sees.

RECOMMENDATION #2

Develop a knowledge base. Determine basic relationships between the landscape roadside and what a moving viewer perceives in this roadside landscape. Achieving any degree of success in this task would require many studies of varying roadside conditions and landscape elements. The results of these studies would help refine the initial categories (Recommendation #1). The research should begin with studies of the overall scene and continue with studies of details. For example, if moving viewers perceive shrubs and ground covers under a certain height no differently than a grass, then the design decision concerning plant material, and thus budget, will be better informed. In another example, does the spacing of trees paralleling a road affect the driver's perception of speed? One logical way to develop this basic knowledge is to obtain driver reactions in a controlled setting, a simulation of the real world. An effective way to simulate the driver's view of the roadside and to obtain a reaction might be to devise an interactive computer program that would be a substitute for the larger simulators used by the aircraft industry and Mercedes Benz.

CONCLUSION #2

Another conclusion is that the existing DOT video data, State Patrol Accident Records, and DOT incident data base provide ready means to categorize roadside landscape elements (Recommendation #1). Highway hazard survey techniques, along with the video records, provide an excellent basis for studying the correlation between accidents and roadside landscape. Further, existing video records can be manipulated graphically to simulate changing roadside views, and this simulation can be used in a controlled setting to study the driver's responses to landscape elements.

RECOMMENDATION #3

Determine any correlations between incidents and landscape categories. By examining highway and accident records that have been purged of factors known to contribute to accidents, such as traffic density, road conditions and driver impairment, and then comparing these data with the changing landscape variables (data taken from existing video records) seen along a road corridor, we could determine whether a correlation between accidents and roadside variables exists.

RECOMMENDED STRATEGY

1) Begin by combining Recommendations #1 and #3 into one pilot study to create an initial set of landscape variables and determine any correlation between landscape elements and safety.

2) Utilize the results of (1) to conduct a pilot study to test the feasibility and availability of computer graphic/simulation methods to study the basic relationships and driver responses (achieve Recommendation #2).

3) Utilize the results of (1) and (2) to determine the scope and direction of further study.

INTRODUCTION

RESEARCH OBJECTIVES

The objective of this project was to develop a research process for studying and clarifying the relationship between a motorist's perception and the visual character of landscape elements in the non-paved portion of the roadway. An improved understanding will inform both highway safety designs and more cost effective landscape designs. The tasks undertaken to achieve this objective were as follows:

1. a literature search of environmental psychology, landscape and urban design, highway research, and simulation/3D modeling techniques;
2. an identification of existing theories, concepts, and topologies to characterize the motorist's response and the roadside domain and an identification of appropriate technology, including computer simulation techniques;
3. an assessment of the relationship among the theories, concepts, and topologies identified in Task 2 and their usefulness in developing research strategy to achieve the overall objective; and
4. a recommendation for further research.

THE PROBLEM

Landscape elements in the roadside, such as vegetation, retaining walls, acoustical barriers, and earth forms are in the motorist's cone of vision. Human perception of these components and the character of this visual area affect drivers' responses. These responses relate directly to safety. While responses to the geometric characteristics of roads and related engineering components such as signing and striping have been studied, the relationship of motorists' responses to other non-pavement portions of the roadside, specifically vegetation, walls, and earth forms, has not been studied.

Further, design criteria for landscape elements in this roadside visual area are now the result of professional judgment and orthodox design concepts that are based on stationary observation data. In other words, landscape design that is appropriate for the stationary viewer, the viewer on foot or moving slowly through the landscape, is now used for roadside design in place of any specific knowledge about how viewers moving at highway speed actually see these landscape elements. Thus a better understanding of the moving viewers' perception of roadside elements will likely lead to more cost effective design criteria.

PREVIOUS WORK--LITERATURE CONCEPTS AND TECHNOLOGY

ENVIRONMENTAL DESIGN RESEARCH

The visual components and the visual character of non-roadway areas can be studied through the scholarship of landscape architecture and urban design. Additionally, computer technology in these disciplines is relevant. We reviewed only a small portion of the vast literature in 3D simulation and computer technology. However, we did review a video made for Mercedes Benz, which described a real-time/scale simulator similar to those used for flight training by Boeing. Also, we reviewed current imagining technology, GIS and relational database software, and the use of landscape simulation in the field of landscape architecture.

In the past 20 years, a great deal of scholarship in landscape architecture has focused on the visual characteristics of the landscape, as evidenced by three published bibliographies (1, 2, 3) and two national conferences (4 and 5). The preponderance of all of the studies has been on scenic quality, human preference for scenery, and differences in quality among landscape types. General conclusions from research on scenic quality are applicable to this study. Litton's work for the United States Forest Service (USFS) (6) showed that "expert" descriptions of the landscape are consistent and can be understood by lay persons not trained in environmental design. For example, his work over a 15-year period was commissioned and published by the USFS primarily for use by agency field staffs with no design training. A recent study by Higuchi (7) built on Litton's concepts, but provided a more complex analysis of the visual and spatial structure of the landscape. Another conclusion from scenic quality research is that highways can be analyzed by visual characteristics (8 and 9) and that expert scenic quality evaluations can be used to design highway routes (10), to train engineers (11), or to train lay persons (12).

Perhaps the most important and consistent findings of the past 20 years are that scenic preferences do exist and that likely this agreement is related to the information needs of humans as a species (13, 14, 15). In other words, we can begin to predict what visual information people will unconsciously search for and ultimately prefer in their visual environments. While this finding is relevant, so far the work has involved scenes as a whole rather than individual elements within the scene. It has also focused on humans' information needs to survive as a species, not on individuals in specific situations. No particular category of viewer, such as a bike rider or motorist, has been studied. Further, the scenic quality studies may convince us that a common language regarding the visual landscape can be agreed upon and used by people with varying backgrounds, but the specific studies are useless for our mission because all of them have focused on visual quality (what people like), not the perceptual character of the landscape (what people see).

Another important result of the research has been incorporation of the computer into study methodologies. Visibility mapping (the mapping and description of viewsheds in any terrain) is now a simple process with the help of any number of computer applications. Simulation of any scene and changes to that scene are readily possible. Geographical information systems (GIS) and relational database methods can be combined as a means of studying the visual characteristics of any landscape. Simulation and imaging techniques for the landscape are well known (16 and 17) and, when combined with GIS and relational database techniques, provide the potential to study a sequential view of a landscape--a corridor landscape as seen by a moving viewer (see SIMULATION AND COMPUTER TECHNOLOGY below).

In another area of environmental design, urban design, we found an extensive body of work related to urban streets, including their use, the perception of them, and user behavior in them. This research has focused on streets with relatively slow movement and comparatively complex landscapes. Little work has been done that relates directly to roads in non-urbanized areas. However, some of the concepts and researchable questions for urban streets are relevant to highway settings. These include the following:

- Concepts that relate the perception of the person moving in the landscape: structure, rhythm, and complexity may be translated and applied to the road. Additionally, concepts on environmental cognition: sequential versus spatial mnemonic and orientation systems are useful. Rapoport, the major theorist in this area, synthesized empirical research with theoretical work in psychology, anthropology, and geography (18 and 19). The relationship between the roadside and the driver has been recognized and hypothesized for more than 30 years (20, 21, 22), but the actual perceptual relationship has not been studied.
- Issues of interactions among different modes of transportation within the same landscape: pedestrians, drivers, mass transit riders (23).
- Issues of interaction among transportation modes and different land uses, as well as with specific design elements of the landscape: crosswalk design, building setback, street furniture, and landscape elements.

HIGHWAY RESEARCH

Relevant studies were found in the areas of hazard surveys, physical elements research, and driver behavior studies.

Hazard Surveys

Hazard survey studies have indicated that highway characteristics such as geometry, operations, environment, and driver behavior are related to accidents. A body of literature, mainly in the form of guidebooks or manuals, has outlined methods to survey highways to locate hazards along them. For example, one manual explained a subjective method, "positive guidance," for hazard inventory in terms of violations of driver "expectancy." (24) According to the underlying concept for this method, positive expectation decreases reaction time. Thus a roadway can either help or hinder the driver by providing expected information at the appropriate time or by failing to do so. The study focused on signage; however, reference was made to the fact that if a line of trees or poles runs tangent to the road and then veers off, driver expectations may be violated. What is important in hazard research is that elements in the non-paved area, or non-operational variables such as "distance to last event," are thought to be relevant to hazard.

Most often road geometry is confined to a description of the paved roadway, but sometimes other aspects such as gradients, sight distances, the presence of roadside obstacles, edge-markings, curbs, footpaths, and roadside development are included as elements of "geometry." Correlation of road geometry and accidents is a familiar method of measuring hazards along the roadway (25), and similar methods could be used for roadside landscape elements. For example, the typical aspects of a geometry correlation study translated to a landscape elements survey could be as follows:

1) Describe the road geometry (the shape and form of the landscape) at a sample of known accident sites.
2) Identify geometric elements (landscape elements and character) common to all the sample sites.
3) Identify the locations of these elements in entire highway system.
4) Determine correlations between accidents and these elements in the entire system.
5) Classify the locations of these geometric elements (landscape elements) as hazardous.
6) Develop landscape designs or criteria to reduce the hazard.

<u>Physical Elements Research</u>

Physical elements research has focused on the visibility of individual physical factors, the hierarchy of perceived elements or the visual complexity of what is seen. A Michigan study that examined the relationship between color in signs and detectability is typical of research on individual factors. (26) From such studies we may be able to learn about color in the landscape, although only one highway sign color is in an earth tone. The hierarchy in the visual decision process has been studied in the Netherlands (27) and could help us understand what is more important visually, the perception, the preview, the characteristic objects, or the circumstances of vision.

Research has generally suggested that complex scenes degrade visual performance, although the research has involved typical non-urban roads and has not focused on roadside landscape elements. This work has referred to signal detection or signage and has measured complexity in a target-to-surround method, as in signal studies of noise factors such as density of noise, proximity of noise to target, and heterogeneity of the surround. Recognition depends both on the target and the surround. Studies on signage have limited application to visual complexity in roadside landscape scenes. Some exceptions have dealt with scene instability, such as work by Gallagher (28), who set out to produce a simple model of scene instability as an objective measure of scene complexity. This study looked at where and how subjects get overall path information, the "signal," and how to measure the amount of noise in the surround. Gallagher assumed that some sequential processing is possible, that all information is sampled from a narrow cone along the foveal line-of-sight, and included roadway objects and roadside foliage, utility poles, build lines, and other elements. These are all redundant cues to path. The studies on physical elements are not terribly helpful, but they do suggest that studies of physical elements of the roadside (landscapes individually or as seen sequentially) could be productive.

Driver Behavior Studies

Driver behavior studies include those that deal with erratic driver behavior or eye movement studies. The former do not identify elements along the roadside except for a sign, and the reaction studied is some sort of erratic maneuver. For example, Hanscom explained a simple use of the "comparative erratic maneuver" technique. (29) This method uses stop-action, overhead photography to count weaves, partial weaves, hesitations, and stopping/backing drivers performed at some location of interest in reaction to new diagrammatic signs. A computer program analyzed the photos, counting the number of maneuvers that were comparably erratic. The result was some indication of driver response to the sign. This photo-computer study technique is more relevant to the mission of our study than the results of the erratic drivers behavior study.

Eye movement studies are a type of driver behavior study that uses apparatus to follow and record where drivers look and for how long, during the driving experience. This method has been used to study lane changing behavior, conspicuity of signage, and the effectiveness of signs. Although the results of eye movement studies are interesting, they do not yet combine into any meaningful set of concepts for driver behavior related to roadside landscape elements.

ENVIRONMENTAL PSYCHOLOGY

The perception by the viewer in motion has been studied in the field of environmental psychology. Theories of driver-environment relations focus on several processes that are known to be affected by the environment. These include attention/alertness, vehicle speed, focal/ambient vision, arousal/expectancy theory, stress and emotional responses, and ability to navigate successfully.

Attention/Alertness

Attention studies have indicated that skilled drivers adopt visual scanning techniques different from those of learners. Inexperienced drivers spend more time looking straight ahead than do experienced drivers, who spend almost 100 percent of their time looking far ahead of their vehicles at or near the "point of expansion" or "the stationary point in the visual scene from which fixed elements appear to radiate outwards as we approach them." (30) Skilled drivers depend more on looking in the distance with central vision for directional information, and they use peripheral vision, rather than central vision, to tell them where they are with respect to the lane position. They use their central vision more to cope with unexpected events and for directional information.

Vehicle Speed

One of the most important aspects of driving is vehicle speed. Exceeding the speed limit is a major contributing factor to accidents. Interestingly, drivers' perception of their speed does not match actual measured speed (30). Studies show that when drivers are asked to cut their speed by half, they consistently underestimate how fast they are going (e.g., they only cut speed by about a third); conversely, when asked to double their speed, they consistently overestimate how fast they are going. The researcher noted that such behaviors have important implications for the design of highway entrances and exits, where inappropriate speeds can be potentially dangerous.

Focal/Ambient Vision

The visual system can also be divided into focal and ambient vision. Focal vision provides high resolution, detailed vision for identifying and evaluating important information, such as hazards. Ambient vision is peripheral and provides information on motion, location, and locomotion -- it serves as a kind of early warning system. If something catches our attention from the ambient system, we turn our eyes to focus on its details. What the visual system of someone moving at 55 mph through the environment detects is different than that detected by a person who is strolling or sitting. Furthermore, the driver's vision is much more limited, because of the car, than the vision of a person walking through the environment. A walker can see something of the surroundings over a visual angle of about 180 degrees. A driver sees only about 20 percent of the scene.

Arousal/Expectancy Theory

Arousal relates to expectancy and is assumed to be related to performance in an inverse U curve; that is, it can be detrimental when it is either too high or too low. According to Reason (30), environmental features associated with excessive arousal include too many signs, too many intersections, little or no predictability in the environment, high levels of traffic, fast moving traffic, poor driving conditions, and other drivers who are not behaving appropriately. Conditions associated with under-arousal are predictable and monotonous surroundings, uneventfulness of the drive, night driving in low traffic conditions, and possibly expansive open views of the horizon. Another condition related to under-arousal that is associated with predictable and monotonous environments is "highway hypnosis" (31).

The basic premise of expectancy theory is that drivers cannot simultaneously process all of the information reaching them, so they take cognitive short-cuts. Thus, what drivers expect or do not expect to happen will have a major impact on their behavior. Expectancy refers to the readiness to respond to configurations and conditions that are in accordance with and/or reinforce drivers' expectations. It helps them to respond quickly and efficiently to information (32). Expectancy can be assessed at three levels: control (involving the driver and car); guidance (involving the car and road); and navigation (response to the surrounding environment). Expectancy theory is especially applicable to landform and environmental elements that create a pattern that may lead the driver to see the roadway incorrectly and thus make driving errors.

Stress and Emotional Responses

Several investigators have suggested that the best way to measure the impact of the environment is to assess its impact on emotional response (33). These studies note that the stress and the gradual accumulation of petty irritations may trigger emotional blow-ups, potentially dangerous to driving.

Ability to Navigate Successfully

The ability to navigate well seems to be related to many factors, some mentioned previously, such as "positive guidance." A survey of the highway research literature revealed no studies that have looked at landscape elements as navigational aids or impediments.

SIMULATION AND COMPUTER TECHNOLOGY

Simulation of an actual road setting is a basic need for any study of the perceptual relationships between the driver and the roadside. Currently, three types of simulation exist.

Real World, Full Scale Mock Up

In this case, an actual intersection, off-ramp, or road segment could be altered with various planting or other landscape elements, and actual drivers' reactions to varying study conditions could be observed. The benefit of this simulation type is reality; the limitation is that only a few relationships and only a limited situation (e.g., an off-ramp) can be studied at any one time. Further, the creation of such a study setting would be intricate operationally.

Scale Model of Road System

This type of table top model is used successfully for hydrological modelling in river studies and has been used a great deal in landscape architecture for a variety of study objectives. The benefit of table top models is that an entire system can be studied at once and repeatedly. The weakness is that the model elements must be very carefully crafted to seem real as photographed. Unlike the hydrology models, in which water is actually put into the table top version, a photo technique is used in the landscape models to simulate one's presence within the landscape. The labor intensive model preparation that results in a video image is now thought to be less useful than a video of a landscape that is altered photographically by computer techniques (see below).

Computer/Video Simulation

Boeing's technique for creating a full-scale, real-time computer situation for training pilots is well known. The same type of facility has been created for Mercedes Benz, Fiat, and Ford. Perhaps one of the existing facilities could be used for studies recommended in this report. If not, another, likely less costly, and clearly more accessible system is possible. For example, to study the correlation between occurrences of accidents and the landscape, the following steps could be taken with existing data.

1) Process WSDOT accident data by way of ASCII text files, then transfer the data into a spreadsheet program on the Macintosh computer. The formula cell function within the spreadsheet program can be used to isolate significant areas within the road segments where accidents occur but no obvious contributing factors seem to exist.

2) Once areas of accident significance have been identified along the study route, select study sites as segments of the video tape (existing WSDOT data) and digitally transfer these to a desktop image processing system. The video can

be captured with a software/hardware package on the Macintosh computer called The Video Spigot. The tape can be reviewed with a regular VCR, or displayed in real time directly on the computer terminal's screen. The image sequences can be saved directly into a format accessible by the image processing software.

3) The images in the image processors can be graphically edited and returned to the video sequence. In other words, we could alter the real scene to create controlled scenes to test various conditions and to test these as a driver would see them sequentially along a real road. This simulation could be used to sample motorist perceptions.

4) The video sequence can be sliced into individual frames at a yet to be determined interval and transferred individually into a geographic information system. Each slice, or snapshot of the road view, could be quantified spatially and compared to other slices. For example, the data from one slice could contain the following set (25 percent foreground vegetation, 20 percent road, 10 percent right of way, 10 percent tree cover). The data would represent relative area measurement of a potential driver's viewshed, and these viewsheds could be compared in many ways.

DISCUSSION

First, this study did not find a body of research in any discipline that addressed the driver/landscape relationship, except for fragments of studies that have been done in environmental psychology. From the fields surveyed (environmental design, highways studies, and environmental psychology), we hoped to find some agreement on the descriptive terms for landscape elements in the roadside that could be analyzed and some overlapping concepts that could be used as a researchable base. In environmental design, we found agreement that descriptions of the landscape are adaptable to fit the scale and function of a roadside and some theories regarding streets that might be translated to a roadside scale, but we found no descriptive terms for the roadside landscape in the other disciplines. In highway literature, we did find some references to the physical context off-the-road in studies relating to hazard, road geometry, and driver eye movement, but no one proposed a classification system for these elements. Our conclusion is that the first task for future research should be to categorize landscape elements as they relate to the visual perception of a moving observer.

We found slightly more leads in our search for overlapping concepts. We found references to "visual clutter" from environmental psychology, which relates to the environmental design term, "complexity." Environmental psychology studies of expectancy and navigation have used concepts that are also assumed in highway studies proposing methods to survey hazards along roads. Thus, the highway research concept of "positive guidance" can be used as one means of organizing the study of relationships between known accident areas along a road and roadside landscape elements. Expectancy theory from environmental psychology explains the concept of positive guidance and is especially applicable to landform and environmental elements that create a pattern that may lead the driver to see the roadway incorrectly and thus make driving errors. While no clear directions exist because no correlation studies have been done, the overlap of positive guidance and expectancy/navigation ideas, along with an existing method to survey highway hazards, is sufficient to be combined into a first lead for future research. Thus, our conclusion is that the initial research direction should be a study to determine whether any correlation exists between the occurrence of accidents and certain landscape variables once other known hazard variables have been eliminated. The most compelling conclusion of this study is that basic research on the driver's perceptual responses to landscape elements of vegetation, landform, and roadside structures is desperately needed. We have no basic knowledge about the driver's perception of the landscape as we do about signs. If we did, then the designs of these elements could be informed to enhance both safety and cost effectiveness.

One of the clearest connections between the disciplines is the common technologies -- film records (photographic/video) and various simulation methods for depicting the real world. All disciplines have used these tools for research. Moreover, a visual record for most highways already exists and provides a ready data source that can be captured and analyzed by existing, off-the-shelf computer technology. Another conclusion is that the existing video highway data and incident database provide ready means for both categorizing roadside landscape elements and proceeding with initial correlation studies between accidents and roadside landscape. A related conclusion is that existing film records could be graphically manipulated to provide a changing simulation of roadside views, and these simulations could be used as a means to study the basic driver responses to landscape elements.

RECOMMENDATIONS

Almost no information exists concerning what a moving viewer or driver sees in the roadside landscape, nor the driver's reaction to this visual information. This lack of knowledge is astounding, given two application needs: a) the likelihood that these landscape variables relate to safety, and b) the increasing amount of money being spent on landscape designs to satisfy public demands. Basic research on the driver's perceptual responses to landscape elements (vegetation, landform, and structures) is clearly needed. If we had the same level of knowledge about the driver's perception of the landscape as we do about signs, then the design of these elements could be informed to enhance both safety and cost effectiveness.

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