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VISIVIA research project: set-up of the VISIT (Visual Inspection for Safety-deficit Identification and Triage) methodology and application on a prototype case on the road SS13 "Pontebbana".

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Abstract

The purpose of this work is to describe the development of the VISIT methodology (Visual Inspection for Safety-deficit Identification and Triage) and illustrate the first prototypal tests on a real case of the computerized inspection system. The tests were organized at the University of Udine – SPRINT-Lab Safety and Protection Intersectoral Laboratory, and took place on the SS13 "Pontebbana", a key connection road in the North-Est of Italy. This work illustrates how the new developed VISIT tools permit to acquire and manage the inspection data, in order to process and summarize them in a standardized way for a situational overview dashboard of the National Agency for Safety of Railway and Road Infrastructures (ANSFISA). The VISIT methodology aims to highlight the need for improving road infrastructures safety by the managing entities. The results of the prototype tests were positive. Therefore, the project moved on to the subsequent phases, which will allow the definition of the supervision and intervention request strategies in a contextualized manner, through a unique and innovative system. This system will support ANSFISA in its objectives of vigilance aimed at improving the levels of safety and regularity of road traffic on the Italian network.

Keywords: VISIT, Visual Inspection, Safety-deficit, Identification, Triage, Authority, Infrastructures supervision, Process audit, Operational supervision plans, Rapid and pragmatic objective technical evaluation

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1. Introduction

In recent decades, improving road safety has been a fundamental issue. According to the Global Status Report on Road Safety 2018 (WHO, 2018), the number of deaths due to road accidents is 1.35 million/year, representing the main cause of death for people between 5 and 29 years. Together with the behavior of drivers and the quality of vehicles, infrastructure represents one of the five pillars to be managed to ensure high levels of safety.

Much of Europe's road infrastructure has been in operation for several years and the costs associated with its maintenance amount to a high percentage of the construction budget. Costs are added to these costs in terms of traffic slowdowns which are due to closure times linked to inspection and maintenance works. Furthermore, over the last 30 years, the rate of deterioration of these infrastructures has increased due to increased traffic loads and the effects of climate change (Europe Commission, 2018). In 2017, the creation of an integrated policy for the future of transport infrastructure safety was included among the main European goals by the President of the European Commission, (Junker, 2017).

The European Directive 2019/1936/EC also stated that, among safety management strategies, road safety inspections (RSI) represent a tool to prevent the risk of accidents and reduce road accidents (Vaiana et al., 2021). In any case, the weakest element of Directive 2008/96/EC is the limited application to the trans-European road network and, after this directive was modified by Directive 2019/1936/EC, it was included in the scope of application of highways and other primary roads.

Since 1980, when the concept of infrastructure safety monitoring was born in the United Kingdom (Federal Highway Administration, 2006) several directives and mandatory procedures related to this topic have been published. However, despite having the same objectives and using similar methods, current inspection procedures range from visual inspections (VI) to destructive (DT) and non-destructive investigations (NDT) testing and structural health monitoring (SHM), and are still regulated at a national or regional level. This leads to a dispersion of energy on different approaches across Europe with a great disparity in terms of level of detail, frequency of inspections, competence of inspectors and methods of archiving inspection results (Turksezer et al., 2021).

In 2018, the Italian legislator established the Italian National Agency for Safety of Railway and Road Infrastructures (ANSFISA), entrusting it with the task of promoting and ensuring the supervision of the safety conditions of the national railway system, as well as road and highway infrastructures, on the basis of annual programs of activities of system audits, field inspections and random checks, thereby compelling the managing entities, who are responsible for their safe operation, to implement the necessary risk control measures and safety upgrading interventions if required. It is important to highlight the distinction in roles between the supervisory authority, i.e., ANSFISA, responsible for monitoring and notifying evidence of risk situations, and the managing entities, responsible for managing and ensuring the infrastructure safety. The role of the supervisory authority is to identify and classify any evidence of safety criticalities and, when necessary, notify the managing entities of the need to address or control these issues in a timely and appropriate manner, based on the identified situation. Thus, the supervisory activities require specific procedural tools and evaluation methods, distinct from those used by the managing entities or other organisms. Multiple managing entities exist within the Italian territory, and typically, different entities adopt their own methodologies for performing assessments and maintenance. Moreover, the same infrastructure may be managed and inspected by different entities for different scopes.

In fact in Italy, several laws are related to traffic safety management, mainly the "New Road Code" (1992), the "Guidelines for Urban Traffic Plans" (1995), and the "Geometric and Functional Rules for the Construction of Roads" (2001). Furthermore, Italy adopted a "National Road Safety Plan", which is called "Piano Nazionale per la Sicurezza Stradale" and moreover Directive 2008/96/EC was adopted through the Decree 35/2011. This legislative decree was followed, in September 2012, by the ministerial Decree 137/2012 which contains the guidelines for *network safety ranking* and describes step-by step how to undertake safety audits and inspections.

While inspection programs of the TEN (Trans-European Network) were launched in 2019-2020 pursuant to above mentioned Legislative Decree No. 35/2011, another approach based on the key protocols of the International Road Assessment Programme (iRAP) methodology (Persia et al., 2020, Derras et al., 2022, Murozi et al., 2022, Shokat et al., 2023) was adopted in the 2010 by "Automobile Club d'Italia" on some road sections in the Lazio Region by participating in the "Atlas of Road Safety" project, in the 2016 by ASTRAL (Azienda Strade Lazio s.p.a.) that published infrastructure safety studies for each of the roads under its jurisdiction and in the 2019-2021 by ANAS that participated in the SLAIN project, coordinated by EuroRAP (Daidone et al., 2023).

Furthermore, to overcome the barrier posed by the formal interpretation of the two Directives 2008/96/EC (on the safety management of road infrastructures) and 2004/54/EC (on tunnels), which do not allow road safety inspections to be carried out inside of the tunnels, the Ecoroads project was launched (Adesiyun et al., 2016).

In this context, despite the existence of multiple approaches to road safety assessments, ANSFISA specifically needed a methodology for supervisions, aimed to check the safety situation (or more precisely, the absence of evidence of unsafe conditions) rather than evaluate the specific methods by which individual entities achieve the required safety outcomes. The supervisor's methodology must be global, consistent, and applicable across all activities and entities, to ensure a standardized comparison between different infrastructures or infrastructure components, without being tied to approaches adopted by a particular operator. ANSFISA, as a supervisory authority, also needs to have an overall picture of the assessment outcomes for a relatively extensive and diversified set of assets, managed by multiple third parties. Therefore, it requires evaluative synthesis tools that allow for comparative assessments based on uniform logic, with a sufficient level of detail to frame the type and severity of the identified issues. The evaluations should be structured in a way that defines the necessary treatment, following a pragmatic evaluation logic that aims to promptly activate actions for their resolution, rather than detailed evaluations or the construction of indices, which are typical of analyses and management strategies used by the managing entities.

To answer to the aforementioned needs, the researchers of the SPRINT laboratory at the University of Udine, which is also UNESCO Chair on Intersectoral Safety for Disaster Risk Reduction and Resilience, and the ANSFISA experts started the Safety Inspection Visits of Road Infrastructure project (in Italian VISIVIA). In the following, section 2 illustrates the principles of the VISIVIA project, followed by an overview of the Visual Inspection for Safety-deficit Identification and Triage (VISIT) methodology, which has been specifically developed for the ANSFISA surveillance purposes. Finally, the implementation of the VISIT methodology on a real case test is illustrated and commented. The paper ends with some final consideration of the further steps of the project.

2. The VISIVIA project

To adequately fulfil its mandated responsibilities, ANSFISA needs to meet the following requirements:

- Having pre-codified inspection methodologies specifically designed for supervisory purposes, to support the inspection activities of roads and highway infrastructures;
- Having a centralized framework that provides a comprehensive overview of the situation, summarizing inspection outcomes, appropriately processed and synthesized. This aims to highlight the need for safety improvement interventions, differentiated by severity and urgency, and support context-based supervision strategies;
- Integrating the data acquired from safety inspections of infrastructure networks with the centralized framework. This provides a comprehensive view useful for informing context-based strategies and intervention requests, as well as an updated overview of the safety status of road infrastructures.

Moreover, inspection methodologies require trained inspectors to visually assess the various assets, capturing any evidence of unsafe situations and recording associated judgments on the basis of predefined indicators. Hence, the need arises to develop an objective and uniform evaluation methodology, ensuring objectivity in the judgment metrics during inspections (Bennetts et al., 2018). Taking into account all the issues above mentioned, ANSFISA identified, as a reference approach, the "Visual Inspection for defining Safety Upgrading Strategies" (VISUS) methodology (Grimaz & Malisan, 2016, 2020), developed by SPRINT-Lab researchers and adopted by UNESCO for safety inspections of educational infrastructures (Grimaz & Malisan, 2023). The VISUS methodology involves multiple inspectors who adopt a common and pre-defined visual inspection method to collect substantial information. This information is elaborated through the automatic application of pre-codified rules and criteria for achieving the safety evaluation of the situation, ensuring uniformity in the judgment metric. This approach thereby facilitates the subsequent planning of safety upgrading strategies. For this reason, the principles and visual evaluative approach underlying VISUS were assumed as a starting point for the development of a methodology to be applied in the context of inspection of road infrastructures and supervision purposes, in the VISIVIA project, which has the following objectives:

- Develop a visual investigation methodology for conducting on-site inspections, adapting the principles of the VISUS methodology to the specific context of road infrastructures. The methodology, calibrated to ANSFISA's specific needs, is tailored to homogeneous elements of investigation (segments, singular points, critical points), considering the different environmental contexts in which they are located. This led to the Visual Inspection for Safety-deficit Identification and Triage (VISIT) methodology described in section 3.
- Design a prototype "dashboard" for monitoring and planning purposes. The dashboard has to provide decision-makers at ANSFISA with an overall view of the key indicators deemed relevant for managing the inspection outcomes of road infrastructures under ANSFISA's oversight. The characterization with these indicators aims to capture the "safety situation", "types of intervention needs", and the "status of work" in relation to the actions undertaken by the managing entity, concerning individual road system elements/structures.
- Implement a prototype and adaptable IT tool for using the VISIT methodology on tablets/laptops to collect safety data and judgments, and automatically process the data to construct graphical indicators to be represented on maps and the dashboard. This prototype, aimed at testing engineering processes and algorithms in an iterative way, will serve as the reference basis for the subsequent development of an application by specialized software developers.

In borrowing the VISUS methodology for developing the methodologies for surveillance inspections at the base of the VISIVIA project, two guiding metaphors were referred to: the first is "medical triage", and the second is "doctoral supervisor". Just as in the VISUS methodology, the triage approach was assumed as a decision-making support method under conditions of time and resource constraints, aimed at optimizing the treatment of critical situations according to a priority logic while differentiating the nature of the treatment (Grimaz et al., 2016). Additionally, the metaphor of the doctoral supervisor guided the type of supervision depth, which aims to sensitize the responsible subject to take action if deviations from the expected standards within their sphere of responsibility are identified, and to activate reinforced supervision protocols, if necessary, based on the types and severity of the identified deficits. The metaphor of the doctoral supervisor highlights the proactive and positive purpose that the supervising authority exercises over the responsible subject (managing entities), serving as a kind of assistance to perform their tasks better, rather than a logic of opposition or dispute.

Considering the mentioned aspects, the purpose of the methodology is not to certify the safety level, create a safety ranking, or optimize maintenance operations conducted by the managing entities. It has been specifically implemented for performing surveillance action that, through visual inspections, enables the activation of awareness procedures for the responsible individuals in case of deviations from specific reference situations, by reporting the identified evidence of deficit. At the same time, it triggers a specific treatment protocol. Additionally, the outcomes of the methodology have to allow to obtain an overall picture of the situation. This requires defining uniform logics and criteria for assembling the results of the various inspections performed on different assets, even when the infrastructure operator or the inspectors are different. As a result, the VISIT methodology has been conceived, implemented, and tested as described in the following sections.

3. VISIT Methodology

In order to ensure uniform evaluation of various assets, the SPRINT-Lab researchers have developed the Visual Inspection for Safety-deficit Identification and Triage (VISIT) methodology that draws the analogy with medical triage examinations, where the patient is analogous to the asset, and the various parts of a body are the different districts of the asset. Additionally, experience in the definition of decision-making support tools was borrowed from Grimaz et al. (2021, 2022), which propose graphical indicators for a comprehensive outcome overview of multi-parameter assessment. Due to space constraints, more information will be provided in upcoming papers, after the finalization of the VISIT manual; this work aims to outline the framework of the VISIT methodology (Fig. 1).

VISIT inspections are carried out with reference to a section of infrastructure (e.g., a segment of road), which typically contains multiple assets of different types. The first part of the VISIT application requires inspectors to perform a preparatory desk work activity in which they identify the segment and the different assets to inspect.

VISIT uses different procedures customized for the different assets, but all of them adopt uniform criteria for judgment formulation. For each asset (roads, bridges, tunnels), the VISIT methodology pre-identified the various semeiotic parameters, that could refer to specific functions or identify as a portion of the infrastructure (in the following called "districts"). Examples of districts are: in roads: platform conditions, cognitive supports, external adversities, etc.; in bridges: elevation structures, horizontal structures, accessories etc.; in tunnels: tunnel structure, fire services, ventilation system, etc. For each district, "Significant Observational Elements" (referred to as EOS) have been specifically pre-codified to support inspectors in recognizing and classifying the presence of safety deficits.

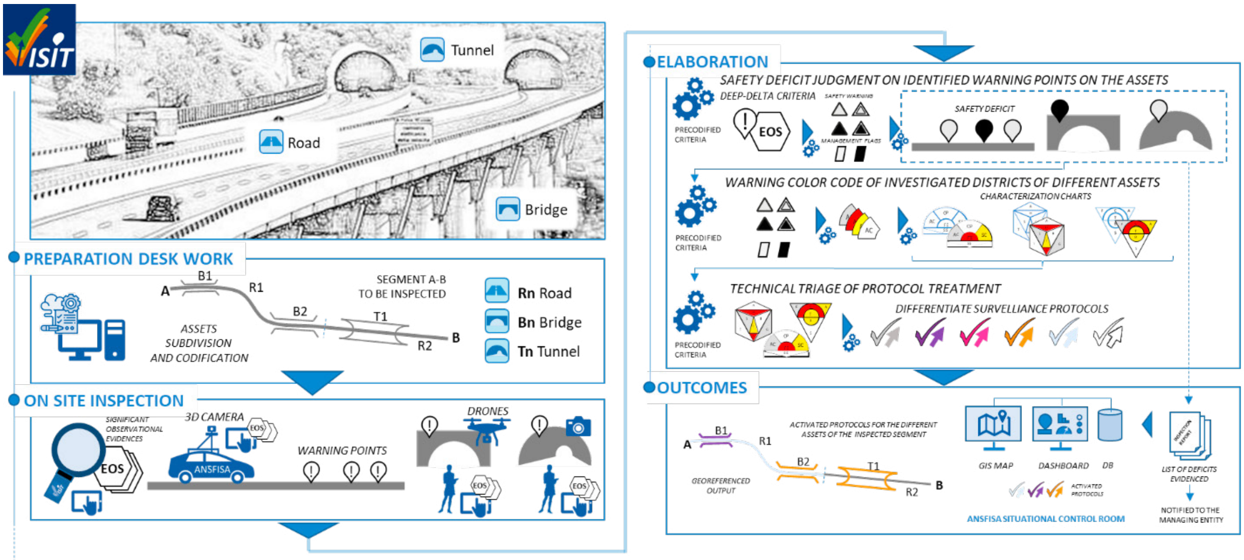

Fig. 1. Framework of the VISIT methodology.

EOS identification can be done according to different modalities, for example travelling on a specifically equipped vehicle or using various devices such as drones or technical cameras to acquire evidence of safety deficits. The classification of the identified evidence is obtained by applying the "deep-delta method", a criterion based on the degree of deviation from a pre-defined reference situation. In particular, the identified evidence of safety deficit is classified both in terms of its intrinsic effect on user safety and as an indirect indicator of management-related deficiencies by the managing subject. This mode of recognition and classification ensures both consistency of judgment among different inspectors tasked with the same inspection and coherence of judgment metrics when comparing different assets or inspections. The type of deviation also serves as a warning for reporting to the managing subjects, in order to address the identified deficiency. The set of deficiencies encountered for each district allows for the assignment of a warning color code to the district itself, using pre-coded algorithms.

The set of districts for each asset (roads, bridges, and tunnels) is visually represented through specific "characterization charts" that provides an overview of the inspection that allows for the identification of the deviation level for each district and serves as a sort of technical triage for summarizing the situation for treatment purposes.

Once the EOS have been inspected, identified, and classified, and warning color codes have been assigned to the various districts for the representation of the asset's characterization charts, the subsequent step consists of the application of technical triage criteria to assign a surveillance protocol code to the individual asset and the infrastructure as a whole. Six surveillance protocols have been pre-coded using the nature and magnitude of the identified deficits, and address the analyzed cases towards a specific treatment protocol. If no deficiencies are found, the standard protocol is maintained. The presence of warning situations with a red code in main districts determines focused field inspections with reduced timeframes, to verify the removal of reported deficits by the managing subjects. The presence of management-related deficits, on the other hand, directs the focus towards audits on the safety management system (Renzi et al., 2023). A specific protocol addresses the case when inspectors identify regulatory and documentary deficits, even in the absence of significant substantive deficiencies. An additional protocol is applied when the inspection does not cover all the districts specified by the VISIT methodology, but focuses only on some of them.

Finally, SPRINT-Lab researchers have developed a specific procedure that automates both the creation of summary reports, as well as the integration of inspection results and surveillance protocols to generate a georeferenced map within a GIS environment. This map is interactive and can be queried for information; it permits to access the specific inspection report of each asset and provides an overview of the analyzed network, distinguishing the protocols and displaying infographics. Inspection data and outcomes are stored in an organized database that can be queried and used to create a dashboard, not only for statistical purposes but also as support for defining surveillance strategies.

4. Prototype application on the SS13 "Pontebbana" road

The VISIVIA project was structured following a Rapid Application Development (RAD) approach (Martin, 1991; Yen & Davis, 2019) based on a first phase of conception and prototyping, and in a subsequent recursive process of experimentation, and refinement. This design approach permits iterative developments to enable necessary upgrades and customization. Moreover, by adopting RAD user-centered principles, each iteration allows for closer alignment with end-user needs. The initial phase of conception and prototyping was carried out by SPRINT-Lab researchers. ANSFISA experts were involved in the experimentation of the first prototype on a real case study, in order to provide feedback functional for the subsequent refinement phase led by SPRINT-Lab researchers.

In particular, a preliminary prototype of the assessment methodology for each asset was engineered for the acquisition and processing of data during inspection. This prototype version was developed after various tests (both simulated and in real cases) performed by the SPRINT-Lab researchers in different situations and assets. Prototype version of the inspection tools was developed using an IT tool for data collection, elaboration, and result sharing, specifically developed for rapid and easy customizability (Grimaz et al., 2023a). Once this initial calibration was completed, more complete experimentation on a real case study was jointly conducted by SPRINT-Lab researchers and ANSFISA experts.

The prototype test area covered the section of SS13 "Pontebbana" from km 177+200 to km 184+500, in the province of Udine, that was chosen because it allowed for the inspection of the road, comprising a tunnel and a bridge. Additionally, there were three more bridges in the area where the VISIT methodology could be tested without causing traffic disruptions (Fig. 2.a). The activities took place from July 18th to July 21st, 2022.

To support inspection activities, basic instructions for the VISIT procedure has been developed, and was divided into sections that include an explanation of the criteria underlying the VISIT methodology, graphical examples (photographs of real cases) to support inspections, with separate sections for the analysis of road segments, bridges, and tunnels. ANSFISA experts were trained on VISIT methodology and then, jointly with the researchers of the University of Udine, applied the methodology for performing the inspection of the assets in the area selected for the experimentation.

Experts from the Italian National Fire Corps were also involved in the prototype testing activities to investigate the use of drones to support inspections of bridges (Grimaz et al., 2023b). Field activities (Fig. 2.d) enabled the testing and experimentation of the design solutions of the evaluation methodology, particularly to verify the effectiveness of the engineering processes and tools developed for both field assessments and the automated representation of results. Specifically, methods of data collection using 360° cameras and the use of drones were tested.

During the two days of activities, on-field surveys were conducted to verify the effectiveness and efficaciousness of the survey support tool during the real-scale test, also adopting actual modalities of the survey. This means that for road segments, the analysis was conducted with the surveyors sitting in an instrumented car and proceeding at a velocity that would not affect traffic on the road. Evidence findings were acquired through a compact and economic 360 camera (Insta360 ONE X2 camera, Insta360, 2021) installed on the car of surveyors, and continuously recording the video (Fig. 2.b). Simultaneously, the surveyors on board used a specifically developed app to acquire the coordinates of warning points and recorded an audio synchronized with video to better illustrate the situation, for potential post-elaboration needs. The inspection of the tunnel required closing one way (Fig. 2.c).

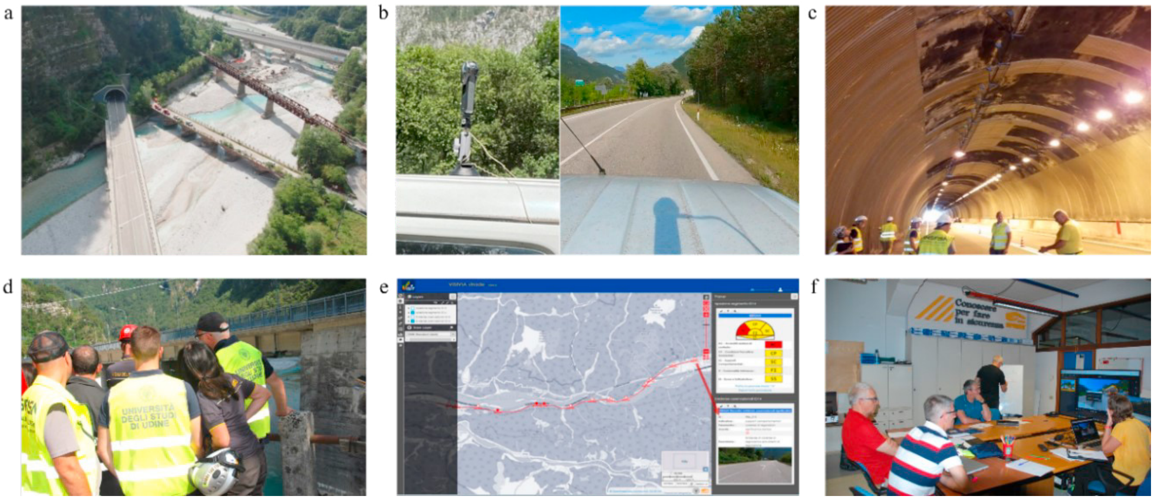

Fig. 2. (a) aerial view of the inspected area showing the road, bridge, tunnel (to the right), and three additional bridges nearby.; (b) view of the vehicle used for the road inspection. A compact 360 camera is installed on the vehicle roof; c) inspection of the tunnel by foot; (d) inspection of bridges; (e) example of web-GIS map defined in real-time during the test; (e) debriefing activities.

The debriefing activities that followed the fieldwork (Fig. 2.f) not only highlighted the successful outcome of the activities (comprising the real-time creation of webGIS maps with outcomes, Fig. 2.e), but also allowed for the identification of specific areas and aspects that require further attention in the ongoing activities. The results of the debriefing evidenced that the prototype tests were positive and suggests important considerations for the following steps of the project. The importance of training inspectors to understand the principles of the VISIT methodology and to adopt the pre-codified metric of judgment has been identified as a crucial element to consider in the next steps. The applications confirm the opportunity to proceed with separate specialties (roads, bridges, tunnels) with their respective VISIT approaches defined within the unique framework of the VISIVIA project.

5. Conclusions

A customized methodology for surveillance purposes of ANSFISA, called VISIT, has been developed thanks to a joint research project with the University of Udine (VISIVIA Project). The first test of the prototype version of the methodology in a real case application produced positive results and important suggestions for further improvements. The methodology, designed on the basis of the rapid application development approach, has already permitted to proceed with the suggested refinements that emerged from the prototype application. The central point of attention is now the training for inspectors. For this reason, the research group is currently focused on developing a specific manual of instructions and supporting tools for rapid training purposes. It is worth noting that, at the current stage, VISIT has been developed exclusively for road infrastructure. However, its conceptual framework allows for the possibility of extending the application of the methodology to other assets under ANSFISA's competence through appropriate customization.

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