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Barriers and opportunities towards monitoring and asset management of EU transport infrastructure

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Abstract

Recent technological developments have clear potential to support paradigm shift from corrective maintenance towards risk-based/predictive maintenance through data-informed decision-making. The most promising developments are already taken up by local communities. Acknowledging that successful development, roll-out and implementation of standardisation is only possible with thorough understanding of the full context, the H2020 CSA IM-SAFE project evaluated the main barriers and opportunities that need to be overcome to enable well-functioning monitoring and maintenance of transport infrastructure. As the European countries have different political, economic and social situations, the analyses have been performed on the national level, and the outcomes have been aggregated to identify main barriers at EU level. This paper presents the outcomes of the analysis of PEST barriers and SWOT analyses and discusses the connection between the barriers and the limitations in the existing EU monitoring standards and opportunities for the national implementation. Finally, the article highlights the importance to consider different scenarios and their potential environmental constraints in order to ensure that the exploitation opportunities are successful and sustainable in the long-term.

Keywords

PEST analyses, SWOT analysis, standardisation, Transport Infrastructure, barriers, best practices, monitoring, asset management, bridges, scenarios

1 Introduction

Transport infrastructure plays an important role in everyday life, particularly road and railway infrastructure, which carries the majority of passenger and goods transport. However, this infrastructure is aging, and more than half of the bridges and tunnels have exceeded their designed service life, creating a risk to safety. The lack of maintenance due to insufficient budgets exacerbates the problem, and there have been close to 30 major failures of transport infrastructure in the past two decades [1], [2], [3].

Recent technological developments have clear potential to support paradigm shift from corrective maintenance towards risk-based/predictive maintenance through data-informed decision-making. The most promising developments are already taken up by local communities and have been identified as major trends for the future. Acknowledging that successful development, roll-out and implementation of standardisation is only possible with thorough understanding of the full context, the H2020 CSA IM-SAFE project evaluated the main barriers and opportunities that need to be overcome to enable well-functioning monitoring and maintenance of transport infrastructure, in particular road and railway bridges and tunnels and other relevant transport infrastructure assets.

The paper aims to identify and assess these barriers and opportunities based on different factors in eight European countries (Austria, Germany, Italy, Norway, Poland, Portugal, Spain, The Netherlands), and then aggregate them at the European level to enable optimal maintenance supported by timely and accurate information obtained from structurally implemented monitoring of transport infrastructure. Finally, the article highlights the importance to consider different scenarios and their potential environmental constraints in order to ensure that the exploitation opportunities are successful and sustainable in the long-term.

2 Description of the methods and approach followed in this paper.

The prioritisation of main barriers and opportunities has been done through the study of PEST (Political, Economic, Social and Technological) and SWOT (Strengths, Weakness, Opportunities, Threats) analyses as well as several workshops performed with some IM-SAFE partners. PEST analysis identifies external political, economic, social, and

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technical factors that impact the safety and functionality of a system. In general, a PEST-analysis may include both positive and negative factors, however, in IM SAFE project focus was put on the negative barriers. In contrast, SWOT analysis considers both internal and external factors to identify strengths, weaknesses, opportunities, and threats to the system. The study also involved workshops with partners and experts to collect inputs from a wide range of sources. The full description of PEST and SWOT analyses performed in the project can be found in the project reports [4], [5]. Paper presents a summary of these factors.

3 Barriers for harmonised standards adequate monitoring, safe operation and optimal maintenance transport infrastructure

3.1 Need for standardisation

The IM SAFE project emphasizes the need for standardization in monitoring infrastructure to gather relevant information for evaluating the condition of structures and assessing their performance. Condition- and risk-based maintenance strategies should be embedded in infrastructure management systems to maximize safety, availability, and cost-effectiveness over the lifetime of infrastructure. The project aims to harmonize rules between EU countries by identifying barriers to consensus and developing and implementing new harmonized standards. The new standards should provide guidance on analyzing and utilizing monitoring data, ensuring full availability of information, promoting long-term risk-based maintenance strategies, and guiding asset owners in using inspection, testing, and monitoring for risk management [6], [7], [8].

The new European standards should cover the following actions:

- provide engineers with guidance on the analysis and utilisation of the monitoring data for the safety assessment and for providing the necessary information for the risk management of infrastructure structures such as bridges and tunnels.
- enable full availability of the information gathered from inspections, testing and monitoring for the safety assessment.
- promote the implementation in the long term of risk-based predictive maintenance strategies for bridges and tunnels
- provide asset owners with guidance on the use of inspection, testing and monitoring for the risk management of bridges and tunnels

3.2 Political barriers

Political aspect of PEST analysis focuses on the areas in which factors such as e.g. (local, regional, national or international) government policy and/or changes in legislation may affect standardisation.

- Political involvement

The short-term nature of the political arena forces politicians to take actions that profit their voters now and not in 20 years, which may lead to sub-optimal solutions. Renovating a long-serving facility may go unnoticed. Even though the environmental awareness among voters is rising, there may be still more appealing the goal to launch new spectacular projects than to invest in the lifetime of an existing bridge or tunnel.

- Local, regional and national organisations

Public transport infrastructure is often owned by several local, regional and national organizations in a country and may be managed and maintained by other organizations such as consultancies and contractors. It could be a challenge to coordinate implementation of the same standards of monitoring among different actors, in absence of appropriate information systems and communication between stakeholders.

- Unclear jurisdiction over the asset

Another common issue, in some regions, is the unclear jurisdiction over the assets; in Italy, e.g., there are almost 1500 bridges whose control is parcelled out among provinces, municipalities or consortia. The difficulty of verifying the ownership of these infrastructures and the consequent fragmentation of the assets management are additional aspects that cause the interventions and renovation plans to advance slowly.

- Political changes

Elections are held regularly in EU member states as they are democratic countries. Quite often there is a political change with new political parties taking over responsibility that could change all the previous plans without giving continuity, affecting, among others, the infrastructure plans that need to be more medium and long-term plans.

- Laws and regulations

Current technical regulations in EU members states do not impose any obligation to use monitoring systems as part of infrastructure maintenance. Lack of precise laws, regulations, and standards put a lot of pressure on the individual engineer that are to make decision on difficult problems that have large impact on regional economy and safety for the users of transport infrastructure.

3.3 Economic barriers

Economic aspect of PEST analysis target past, current, and future economic issues, e.g. cost, financing (both public and private), insurance, taxes, economic growth, inflation and recession.

- Aging infrastructure

A lot of Europe's infrastructure facilities was designed and built following guidelines that were developed when the economy and cost for maintenance labour was quite different from today's situation. This means that solutions that had low investment cost were favoured over solutions with increased service life. In today's situation this results in high maintenance costs. A lot of the infrastructure has now already reached its design-life but are still in daily use and are still a valuable part of the infrastructure.

– Short perspective in contract with private companies

The duration of a contract between private road operator and infrastructure owner may influence the perspective of the private company, that size the economic investments plan according to the time it must be guarantor of the asset's safety and service performance.

– Long term contracts

Some maintenance is contracted in long term contracts that might be difficult to renegotiate and implement new ways of monitoring or maintaining infrastructure. If a district has a wide range of contracts type this might have a negative effect on the efficiency of the asset management.

– Value and cost is separated in time and between different stakeholders

Infrastructure performance is perceived by the users more relating to periodically occurring closures (need for interventions, maintenance) or serious structural failures than the time in which infrastructure assets provide safe and standard usage.

– Knowledge of the real situation could be hard to handle when available budget is inadequate to support interventions

If the budget prevents large rehabilitation project it might be tempting to avoid inspections that will highlight severe problems related to the transport infrastructure. However, this strategy will be problematic from a moral (and also legal) point of view.

– Economic corruption

The need of maintenance and monitoring interventions on infrastructures, both for the strategic importance in worldwide mobility and the direct impact of an incorrect management to the modern economy, is a sensitive objective for corruption strategies, that often occur in different fields of public investments. Many national and EU regulations and control systems are in place to prevent corruption and focusing on transparency.

3.4 Social barriers

Social factors that may be considered include socio-cultural elements such as attitudes and shared beliefs of end-users (society), policymakers and other stakeholders, and their resistance against changes.

– Risk awareness

When it comes to very rare incidents that are related to bridge failure with the corresponding large consequences, the risk awareness in the general population is over-stimulated. In the absence of these events the awareness of the risk is less than the real risk, after such an event the awareness is bigger than the real risk.

– Education of specialists and skilled workers

The education of engineers and skilled workers is not in balance with the current needsTo be able to take advantage of new methods for monitoring and asset management it will be necessary to increase education capacity for new engineers and skilled workers and also to focus on continuous education programs to increase knowledge among current employees.

– Administrative decision making could be too slow

In many regions the final decision to close infrastructure in dangerous condition is not made directly by the technical expert making the inspection. Since the decision could have large economic consequences the decision to close is taken by local, regional or national authorities.

– Difficult to learn from failures due to legal issues

Large failures with fatalities will most of the time be investigated, but the scope of the investigation will often be on the legal side to identify organisations or persons that could be blamed for the accident and to less extent is the focus on learning what happened and what could be changed to prevent future failures. This lack of openness about mistakes will prevent learning and unnecessary funding is spent repeating mistakes.

– Willingness to invest in research

Research funding for projects on maintenance of transport infrastructure has been relatively low compared to the big value of the infrastructure.

– Conservative organisations

People and organizations are in general not very willing to change the way they perform their work, and the infrastructure organisations are maybe more conservative than other industries (at least this is the general assumption).

3.5 Technological barriers

Technological component of PEST analysis considers the specific role and development of technologies, access to existing technological solutions, skills of professionals, research, innovation and emerging technologies.

– Variable and harsh climatic conditions

Europe has several regions with relatively harsh climatic conditions that often require extra maintenance for infrastructures. The challenge lies in prediction what infrastructure is more exposed to climate related extreme loadings.

– Number of assets makes it hard to keep them well tracked

The amount of infrastructure objects like tunnels and bridges in Europe is very high. Just the city of Hamburg by itself has almost 2500 bridges of varying size. A country like Switzerland have more than a quarter of the road network in tunnel or on a bridge.

Thus, the number of tunnels and bridges are quite high and make it difficult to keep a good control about the condition and to optimize the maintenance effort.

– Digitalisation of existing data

Meaningful data gathered from the inspections, structural monitoring and testing are necessary to identify and evaluate deterioration and systemic deficiencies of the key structural elements and materials, which –in combination with increased loads and resilient threats– make the structures vulnerable to catastrophic consequences of major failures or collapses.

Many existing bridges are not yet designed in a 3D model [9]. The data required for maintenance and repair is also usually only available in paper form and in various documents. Access to all the necessary data is therefore difficult and there is a risk of information being lost.

4 SWOT Analysis of Harmonising Standards for Adequate Monitoring, Safe Operations and Optimal Maintenance Transport Infrastructure

4.1 Strengths

This section reflects the benefits of harmonized standards for maintenance of transport infrastructure. Such standards can aid in the enforcement of laws and regulations for the sector, reduce infrastructure lifecycle costs by enabling preventive maintenance, and prevent catastrophic failures by promoting predictive maintenance. Standardized maintenance and monitoring can also help establish and improve lessons learned by collecting data and making it available to those involved in standardization. Further details can be found as follows:

- Contribute to the enforcement of laws and regulations for the sector. Harmonized standards can help working towards laws and regulations for maintenance of transport infrastructure.
- Enables reduction of infrastructure lifecycle costs triggered by the execution of preventive maintenance of infrastructures, which is made possible by continuous monitoring of their deterioration.
- Enables the prevention of catastrophic failures replacing reactive maintenance with predictive maintenance, promoted by data gathering from monitoring systems and thus not waiting for a failure or clear deterioration of the infrastructure.
- Standardized maintenance and monitoring will help establish/improve lessons learned. Collecting data, by monitoring systems, and decisions taken based on them and with information about the consequences of these, making this information available to the agents involved in the standardization of the system.

4.2 Weaknesses

Within this factor, challenges related to infrastructure maintenance and management are under discussion. These challenges include the separation of value and cost between stakeholders, lack of standardization in monitoring procedures across countries, resistance to change, difficulty in renegotiating maintenance contracts, varying characteristics of different types of infrastructure, lack of predictive modelling due to limited monitoring data, potential loss of detail in standardizing protocols, need for specialized staff to understand new regulations, and the difficulty of predicting maintenance needs. Further details can be found as follows:

- Countries have their own standards, experiences, culture and way of working. No common ground for monitoring standard(s) yet.
- People and organizations are in general not very willing to change the way they perform their work, and the infrastructure organisations are maybe more conservative than other industries.
- Each stakeholder has a unique economic and timeframe schedule. Related to the duration of maintenance contracts. It may be the case that the maintenance contract has been recently awarded and does not include this standard, making the financial offer inconsistent with new tasks required for the execution of the contract.
- Difficulty of harmonization for different types of infrastructures. The standards in place may not fully account for the varying characteristics of different types of infrastructure such as tunnels, viaducts, and roads.
- Difficult to predict due to lack of current references. Predictive modelling for infrastructure maintenance will be difficult until enough monitoring data is gathered.
- Standardizing protocols in different countries can lead to a loss of detail in each country's approach. As a general standard may not consider the specific needs of each country and infrastructure.
- Need for specialized staff to understand the new regulation. It would require hiring specialized personnel to implement the new standard or training existing personnel to be proficient in the new standard.
- Prediction is hard. Analysis of time series is not yet possible. No pictures available, hard to combine pictures

4.3 Opportunities

This section discusses the benefits of digitalization and standardized maintenance protocols for infrastructure maintenance. Digitalization allows for more efficient monitoring, integration of new sensor technology, automation, improved data collection, and prediction of infrastructure availability and weather impacts. Standardized protocols support appropriate budget allocation and help predict maintenance needs. Additionally, efforts to prevent corruption and increase research funding for maintenance projects are important. Overall, these developments can lead to more cost-efficient maintenance and improved infrastructure safety. Further details can be found as follows:

- Contribution to employment stabilization due to maintenance standardization. The possibility of predictive maintenance entails the knowledge of what maintenance will be needed in the next period; therefore, it is possible to know how much human intervention will be needed in each time.
- An increasingly important technical factor is the efficient use of digitalization. It is seen as an enabling technology for new ways of monitoring and data processing to get more detailed insights about the structural health of bridges for better and more cost-efficient maintenance.
- It allows the introduction of new digital traditionally considered unfeasible by the sector. The potential for

utilizing new sensor technology is identified as one important trend in IMSAFE project.
- It enables the integration process of the sensor technology to be more cost-effective and even quicker. Better and cheaper communication systems and sensors are being developed allowing the inspection of bigger targets and also simplifying the inspection of infrastructures. For example, the use of drones for the inspection of high-altitude bridges, where previously specially trained people were needed to climb the bridge towers.
- Enables automation of the entire process. Automation is feasible, less time consuming, cheaper in the end. The data can be stored and used for research, such as learning more about weather-dependent performance.
- It enables cooperation between different stakeholders and enables a common maintenance platform. Also enables to design of information platform for a variety of stakeholders. It is needed to manage cooperation, share information on a common platform. Is new for sector.
- Enables improved data collection (Data quality improvement). The increase in data collection by the infrastructure monitoring system will lead to an increase in both the quantity and quality of data collected.
- Standardized protocols on monitoring and maintenance procedures supports an appropriate budget allocation (Procedures are less sensitive to political changes or budget reduction). i.e. It will be possible to know where a maintenance action is needed, and how much will need to be invested. This will allow for proper economic planning by all stakeholders.
- Helps to predict the availability of infrastructure (I.e. forecasting jams due to construction works). Thus, by helping to predict the availability of assets and even assess when it would be best to perform maintenance, considering the annual user estimate demand.
- Can help predicting how climate change impacts on infrastructure. Due to the experience of the normal deterioration of an infrastructure during its life cycle (behaviour of materials), it will be possible through the monitoring system to detect anomalous behaviour attributable to unpredictable weather.
- To study in depth the effects of deterioration of materials and consider it to improve the prevention capabilities. Collect accurate information on the current state of the infrastructures and link with the status of materials which compose each infrastructure.
- While efforts are being made to prevent corruption in Europe, and it is generally limited, there may be some countries that resist implementation due to pressure from certain stakeholders. Increased transparency and strict enforcement of anti-corruption laws will continue to reduce the problem.
- Research funding for projects on maintenance of transport infrastructure has been relatively low compared to the big value of the infrastructure. It is necessary for infrastructure owners to influence on the budgets for research to be able to increase the effort.

4.4 Threats

This section deals with the challenges associated with standardizing monitoring and inspection of transport infrastructure in Europe. These challenges include political involvement, legal issues, lack of flexibility, uncertainty associated with material deterioration, and difficulties in creating a cohesive framework that addresses gaps with existing standards. Despite these challenges, standardization can lead to more efficient and effective monitoring and inspection, reducing the need for reactive maintenance and increasing safety. However, the unique nature of each structure and the uncertainty associated with unforeseen events may require more flexible and adaptive approaches to standardization. Further details can be found as follows:

- Citizens increasingly expect infrastructure owners to assess the situation, even if the budgetary situation does not always allow for quick action when negative situations are discovered.
- Political involvement in transport infrastructure management can be problematic due to, for example, lack of technical competence, short-term political objectives and ideological influences.
- Monitoring is always an individual decision and the possibilities for generalisation /standardisation are limited. Monitoring (and inspection) with the objective to acquire relevant and correct information about the structural integrity, requires a sequence of decisions about the type, location, timing of measurement, and decisions about data handling and analysis. These decisions are difficult to take and require multidisciplinary expertise.
- Ignorance of responsibility to advise in critical situations (When negative situations are revealed). A standardized system for monitoring and inspection in Europe would make it harder to hide behind the "we did not know about the problem" and make infrastructure owners responsible for the conditions. However, responsibility could be hide behind the new standard. Engineers faced with difficult choices could use the standards as tools to argue for better monitoring, enough budgets and better solutions.
- Reduction of maintenance budget due to the effectiveness of harmonization. The effectiveness provided by the standard through the harmonization of monitoring tasks can lead to a reduction in the budget because problems are detected before reactive maintenance is required, which generally has a higher economic and time cost. Therefore, public entities could decide to "adjust" their budget.
- Each country has a standard as a reference and could create its own ad-hoc standard. There is a possibility that, once this standardization has been completed, it may not meet all the expectations of the countries and they will adapt this regulation and create their own.
- Gap of the new standard with current related standards (including quality standards to be considered). It is important to address any gaps between the new standard and existing related standards to ensure that there is a cohesive and consistent framework for addressing the issues covered by the standards.
- Non-viability of standardization due to increasingly uncertain environments (Crisis, wars, inflation, technological disruption, etc.). Standardization can be a valuable tool for promoting efficiency, interoperability, and safety in various industries. However, in some cases, standardization may become non-viable due to

increasingly uncertain environments.
- Lack of flexibility of standardization in the case of unforeseen events (I.e. Natural Disasters). The observed and predicted climatic changes are likely to cause new challenges to the infrastructure especially caused by increased intensity of rainfall. The challenge lies in prediction what infrastructure is more exposed to climate related extreme loadings. In such uncertain environments, it may be necessary to adopt more flexible, adaptive approaches to standardization.

5 Main trends for future best practices

Regarding PEST and SWOT analysis, several key trends has been extracted: first trend unifies different scenarios in a "big picture" requires a broad agreement between a multitude of different actors, who must contribute their experience and knowledge to a joint vision that leads to a standard of standards. The second trend is related with technology, in which a wide range of measurement possibilities seems to be available for active infrastructure monitoring. This will be one of the main drivers on which new maintenance protocols will be supported.

Another important outcome of the dialogue with the local and Pan-European CoP's was the identification of trends for future best practices [6]. These are:

- Trend 1: Risk-based maintenance management and condition-based preventive
- maintenance strategies
- Trend 2: Risk-based inspection and condition survey planning
- Trend 3: SHM with novel (non-remote) technologies: distributed sensing, wireless
- and energy-efficient sensor technologies
- Trend 4: Autonomous sensing incl. drone inspections
- Trend 5: Remote sensing
- Trend 6: Implementation of IoT and data analytics

Given the wide variety of practices and different level of application of the trends, it would be beneficial to share lessons learned, share the knowledge and unify the criteria, methods and regulations in Europe to assure the resilience of the infrastructures and optimize the maintenance practices.

6 Potential Scenarios to foresee exploitation opportunities emerged after the implementation of a new related standard

The implementation of a new standard can create opportunities for exploitation, but these opportunities are not immune to environmental constraints. Several factors can affect the deployment and acceptability of these opportunities. Therefore, it is important to explore these circumstances using tools such as SWOT and PEST analysis. By building different operational scenarios, the various factors can be combined into hypotheses, allowing for the simulation of contextual conditions under which these exploitation opportunities could emerge. With this information, forecasting when and how to proceed with these opportunities will become significantly more accurate, reducing the risks associated with their deployment. It is important to consider these environmental constraints in order to ensure that the exploitation opportunities are successful and sustainable in the long-term. By doing so, businesses can adapt to changing circumstances and capitalize on emerging opportunities while minimizing potential risks.

After a comprehensive review of the potential factors that might impact upon all three scenarios, the most relevant ones considered for this analysis are included in *Table 1.*

In this regard, general description of Optimistic Scenario, Most Likely and Worst Scenario has been conducted in this section. As an example, the best scenario could be a great acceptance expected from all the actors involved in maintenance, a massive support from the political governments and economic prosperity in Europe among others features combined.

Table 1 Main factors considered for potential scenarios

Area	Most Relevant Factors
Political Factors	*Political involvement*
	Local, regional and national organisations
	Political Changes
	Transparency
	Laws and regulations
Economic Factors	*Aging infrastructure*
	Limited budget and sub-optimal use of funding
	Economic corruption
Social Factors	*Administrative decission making could be too slow*
	Conservative organisations
Technological Factors	*Variable and harsh climatic conditions*
	Number of assets makes it hard to keep them well tracked
	Digitalisation

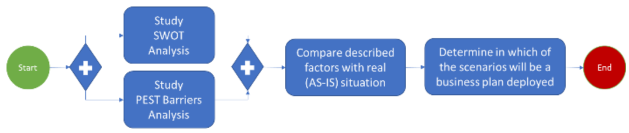

Figure 1 Steps towards (decision making leading to) the most optimistic, most likely and most pessimistic scenario

- The most optimistic scenario

Considers full support from the governments where it is established, the support of local administrations to adopt its solution, favourable laws and regulations, and political stability that outlines minimal changes over several legislatures. This scenario would also envisage a financial commitment to R&D and innovation in inspection tasks, a non-ageing infrastructure (with minimal upfront maintenance). On the other hand, it would be considered that the decisions of the administrations are agile and that the climatic conditions are stable and predictable. Also, it would consider that there is not a great variety of technological assets deployed and the state of digitisation allows for full integration with new solutions.

- The most likely scenario

Envisages partial support from the governments where it is established, partial support from local administrations to adopt its solution, favourable laws and regulations in some of the countries and changing political mandates (some long and some very short). This scenario would also contemplate a financial allocation for R&D&I in inspection tasks but with a high demand, a mixed infrastructure, some recently built and others more than 50 years old. On the other hand, it would consider that the decisions of the administrations are agile in the smaller EU countries (not in the larger ones) and that the climatic conditions are variable (for cycles of several years). It would also consider that there is no variety of assets deployed (with different state of technological maturity) and the state of digitisation is very diverse, being low for non-relevant bridges and high for newly built bridges.

- The most pessimistic scenario

Involves a resistance from the governments where it is established, the non-responsiveness of the authorities to adopt its solution, unfavourable laws and regulations in some of the countries and volatile (usually short or very short) political mandates. This scenario would also envisage an economic scenario with hardly any subsidies, an ageing infrastructure, most of which is more than 50 years old. On the other hand, it would consider that the decisions of the administrations are slow and that the climatic conditions are unstable, with intense cold/hot snaps. It would also consider that there is no asset deployed and the state of digitisation is practically non-existent throughout the infrastructure, despite its importance.

7 Conclusions

European standards should guide the monitoring strategy and data analysis for ensuring the safety of infrastructure structures such as bridges and tunnels. The implementation of a new standard can create opportunities for exploitation, but it is important to consider the potential environmental constraints that could impact their deployment and acceptability. By conducting a comprehensive analysis of potential factors using tools such as PEST and SWOT, businesses can build different operational scenarios and simulate contextual conditions to forecast when and how to proceed with these opportunities. This can significantly reduce risks and ensure their long-term success and sustainability.

Overall, it is important to consider these scenarios and their potential environmental constraints to adapt to changing circumstances, capitalise on emerging opportunities, and minimise risks.

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