APPLICATION OF LOW-TECH AND LEAN-TECH CONCEPTS TO ROAD TUNNELS FOR GREATER ENERGY EFFICIENCY

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ABSTRACT

Our planet is facing a major climatic challenge, which is becoming increasingly acute and critical.

The need for underground communications infrastructure, to be maintained or created, remains strong in all countries to meet the needs of trade, travel and development.

These infrastructures can be money pits with a high carbon footprint. Simply optimising a system, is not enough to meet the challenges. The usual reliance on technology and the development of new systems in the hope of reducing the energy balance, while relevant in some cases, can be a headlong rush or an illusion with no guarantee of overall savings.

In this context, a different, holistic approach seems necessary in terms of design, operation and maintenance, and even use. The entire life cycle of the structure is concerned, particularly the design and operation phases:

- The design phase is totally structuring even if it is one of the shortest. It obviously involves a series of technical choices dictated by regulatory requirements, but which must also meet the specific constraints of operation and maintenance and the level of service expected of the structure, a level that is often poorly defined. It also deals with the criteria for choosing and procuring supplies, which are often neglected for lack of a suitable analysis tool.
- The operating phase, which is intended to be as long as possible, is crucial. Beyond the ‘established regime’, this phase includes major maintenance and renewal stages that must be taken into account right from the design stage.

This article looks at the practical implementation and convergence of different approaches:

- Low-Tech: using solutions technologically “sober” in terms of natural resources and energy consumption
- Lean-Tech: using technology as “leanly” as possible
- Design for Maintenance (DfM): maintenance/maintainability-oriented design
- Reliability Maintainability Availability Safety (RAMS) of “systems”

Keywords: low-tech, lean-tech, avoid, reduce, offset.

1. INTRODUCTION

The design of a road tunnel must take into account numerous parameters, including economic and social function, regulatory requirements, the environment surrounding the structure, traffic characteristics, operating and maintenance resources, and investment and operating/maintenance budgets.

The equipment systems used are increasingly numerous and sophisticated in order to offer unrivalled levels of safety and service, at the risk of increasing energy consumption.

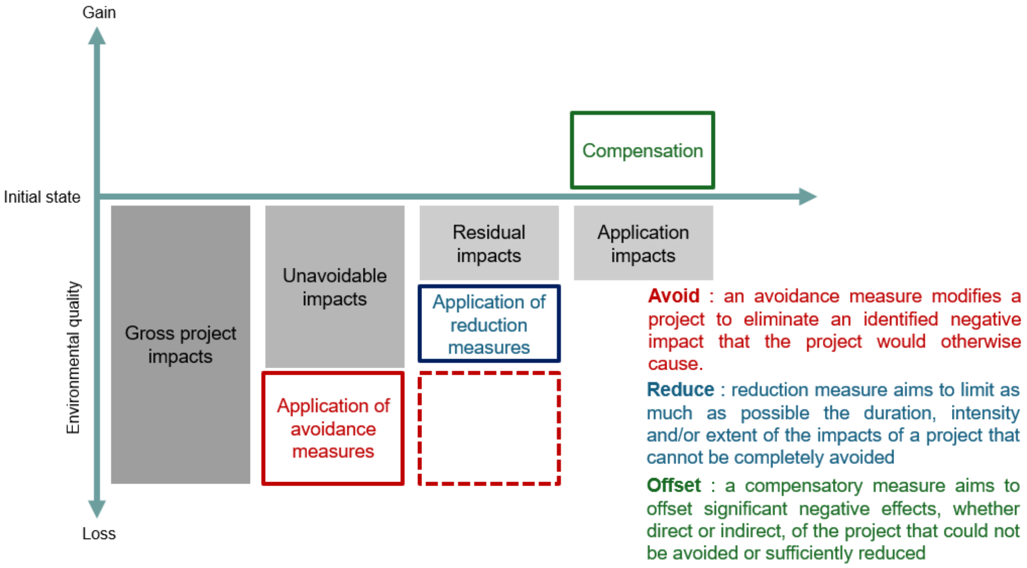
In this era of energy efficiency, beyond the usual levers for action on direct consumption specific to structures, it seems worthwhile to promote eco-design approaches such as low-tech or lean-tech and to highlight their similarities with more well-known approaches such as DfM and RAMS.

In terms of eco-design, road tunnels have multiple direct and indirect impacts and interactions with seven commonly identified environmental themes:

Figure 1: Environmental themes

Faced with the major climate challenge facing our planet, one of the basic principles is to avoid or reduce environmental impacts as much as possible (1), or where necessary to offset them, taking into account the entire life cycle of the structure. This ‘ARO’ (avoid, reduce offset) approach is illustrated below.

(1) *ensuring that improvements in one area do not significantly harm others.*



Avoid : an avoidance measure modifies a project to eliminate an identified negative impact that the project would otherwise cause.

Reduce : reduction measure aims to limit as much as possible the duration, intensity and/or extent of the impacts of a project that cannot be completely avoided

Offset : a compensatory measure aims to offset significant negative effects, whether direct or indirect, of the project that could not be avoided or sufficiently reduced

Figure 2: 'ARO' approach

The aim of this article is therefore to encourage design offices, project managers, contractors and operators of road tunnels to place eco-design at the heart of their concerns, with particular emphasis on energy and resource efficiency, the circular economy, carbon neutrality and pollution control. To this end, the authors list a number of concrete solutions, propose avenues for reflection, open up new perspectives and share their questions. A methodology and recommendations are then suggested, before concluding.

The list of examples of solutions and avenues for consideration is structured around the first three phases of the project life cycle and some of the environmental themes. The contribution of each example to the ARO approach is indicated by a symbol. A R O

2. DESIGN PHASE

2.1. Energy efficiency

- R Ensure economical design of the structure:
  - The layout (curves) impacts CCTV systems (and any associated automatic incident detection) and signalling systems.
  - the longitudinal profile (gradients, low points and high points) impacts drainage, lighting, fire protection, signalling, ventilation and video surveillance systems (and any associated automatic incident detection)
  - the cross-section (height, width, section) impacts lighting and ventilation systems
- A Prioritise passive systems such as:
  - sunshades like those in the Jenner Tunnel (Le Havre, France), which replace supplementary lighting
  - gravity-fed firefighting and sanitation networks
  - buildings designed to limit heat gain and/or promote ventilation rather than air conditioning (Rtherm walls and doors).
- A Eliminate redundancies that are not fully justified by the level of service or safety required and that prove to be energy-intensive, such as transformers and their no-load losses.
- R Limit the need for electrical tracing (depth, insulation, circulation) related to sanitation and fire protection systems.
- R Reduce the volume of effluent to be collected (intermediate collection, watertightness) from the sewerage network.
- R Optimise lighting design criteria (exposure, environment, head treatment, road characteristics, provided that this does not involve transporting materials from too far away or negatively impacting the environment, permitted speed).
- R Pay particular attention to the intrinsic efficiency of equipment and the optimisation of Joule losses, in particular:
  - efficiency of pumps and the delivery network (diameter and length of pipes, relay tanks)
  - efficiency of pumps and the fire protection network (diameter and length of pipes)
  - efficiency of inverters and variable speed drives of all kinds
  - efficiency of light sources and photometry of lighting fixtures
  - pooling of servers (virtualisation) required for supervision systems, networks, radio communications, emergency call networks, etc.

    This particular focus on efficiency, combined with the use of only the strictly necessary equipment, makes it possible to limit the resources required to equip the structure initially, then losses at source and therefore ventilation and/or air conditioning requirements, and finally the impact of GER works when they occur.
- R Prioritise natural ventilation over forced ventilation and air conditioning.

2.2. Resource efficiency

- A Negotiate with the emergency services the possibility of providing fire suppression pressure using their fire engines rather than specific fixed installations (savings in installation, servicing, testing, maintenance, major maintenance renewal and associated easements).
- ? Consider the choice of battery type for uninterrupted power supply and chargers (scarcity of metals/rare earths).
- ? Which type of cable should you choose? Copper or aluminium? The following table looks at energy costs and CO_2 emissions, but does not mention the medium- or long-term availability of resources, their recycling rates, etc.

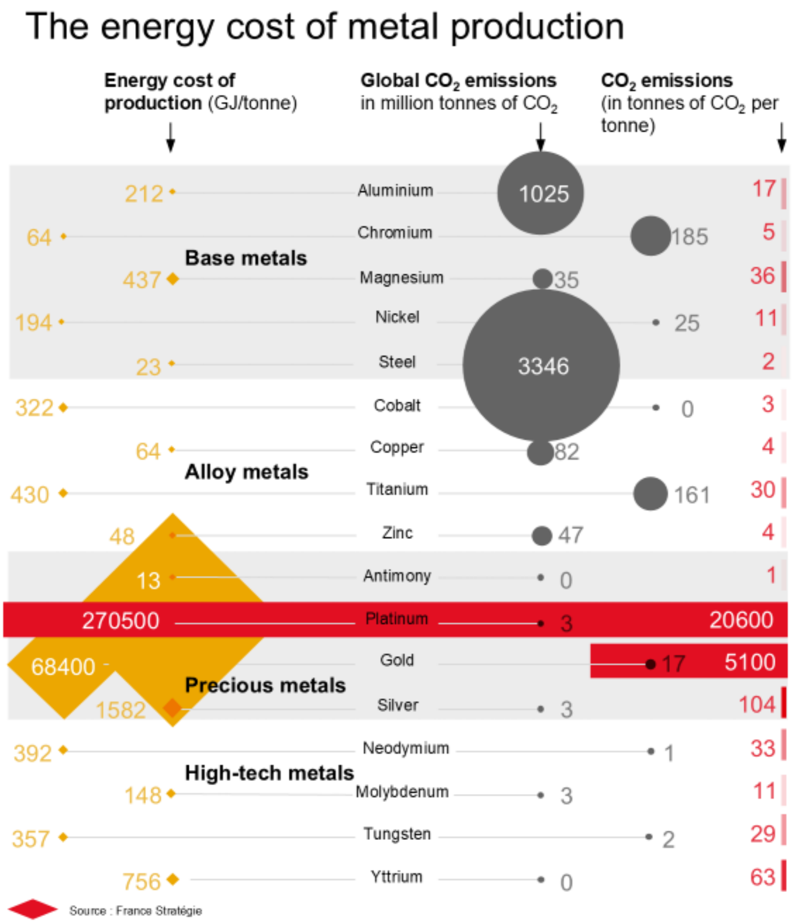


Figure 3: Energy cost of metal production

- R Avoid unnecessary equipment that is rarely or poorly used, as may be the case with the following systems:
    - linear fire detection in tunnels
    - extinguishing systems in technical rooms or tunnels

  In general, only install what is strictly necessary (in terms of equipment) and avoid compensating for weak civil engineering design with additional equipment: passive safety measures are always preferable to increased ventilation, a safe route is preferable to increased lighting and signage, etc.
- R Group equipment as much as possible on a limited number of technical sites – i.e. avoid isolated pockets of equipment.
- R Prioritise a robust design that is tailored to the specific context of the project.

R • Avoid corrosive materials and pay close attention to galvanic couples to ensure greater durability of sanitation, fire protection, ventilation, signalling and lighting systems, etc.

R • Require that repairs be possible and that components be replaceable rather than the entire piece of equipment or even the entire system (repairability index).

R • Respect the natural hydrological balance of the mountain ranges crossed, which may justify a roof-shaped longitudinal profile rather than a single slope.

O • Utilise surface water (separate network) for firefighting, filling siphon manholes or cooling premises.

2.3. Circular economy

R • Use recyclable or recycled materials that are abundant and easy or less difficult and energy-intensive to extract, produce or refine (steel rather than plastic, for example).

2.4. Carbon neutrality

A • Exclude SF6 from high-voltage equipment

A • Exclude (as far as possible) outdated technologies such as internal combustion engine generators.

R • Pay particular attention to the choice of heat transfer fluids for transformers and air conditioners, as well as the choice of acoustic insulation (for ventilation) and thermal insulation (for technical rooms).

R • Where possible, use renewable energy sources (solar, hydraulic, wind) for the needs of main technical rooms, for example.

R • Opt for a conventional heating system for technical and operating rooms rather than reversible air conditioning.

2.5. Pollution control

R • Limit gradients to reduce pollution from heavy vehicles.

A • Favour natural fluids in submerged transformers.

R • Choose paints carefully or limit their use.

2.6. Biodiversity

O • Provide wildlife crossings and other animal protection measures (toad tunnels, etc.).

3. IMPLEMENTATION PHASE

3.1. Energy efficiency

R • Ensure that the luminance meters and twilight sensors in the lighting system are correctly adjusted (including orientation) and, more generally, that all types of sensors are correctly calibrated.

3.2. Carbon neutrality / Circular economy

R • Consider the geographical origin of materials and equipment and promote reuse.

3.3. Biodiversity

- R Limit waste on the construction site and avoid polluting the natural environment.
- R Limit noise and light pollution, particularly at certain times of the year (breeding season, migration, nesting, etc.).
- O Respect or restore the various plantings.

4. OPERATION AND MAINTENANCE PHASE

4.1. Energy efficiency

- R Optimise functionalities, particularly self-tests (periodic testing of thermal engine backup groups, fire boosters, fans and accelerators).
- R Optimise operating times:
  - for signalling (lane assignment lights, variablemessage signs) used ‘just in time’ (which also has the advantage of better ‘engaging’ users)
  - for lighting
- R Limit the volume of data stored and data flows from supervision systems, video surveillance (and any automatic incident detection), emergency call networks, etc. to what is strictly necessary.
- R Enforce more virtuous use of the infrastructure by, for example, reducing the maximum speed allowed. This can have a significant impact on lighting and ventilation, two of the most energy-intensive systems.

4.2. Resource efficiency

- R Ensure regular maintenance and preventive maintenance in accordance with manufacturers' requirements to prolong the life of equipment while guaranteeing its performance.
- ? Do not clean structures (less water, fewer pollutants, no paint) at the risk of irreparably clogging the piers and degrading the luminance?

4.3. Circular economy

- R Use recycled equipment or materials that some suppliers are beginning to offer.

5. METHODOLOGICAL ELEMENTS

The approach must be proactive, cross-functional/comprehensive and long-term. It is based on:

- Systematic questioning of each element of the ‘tunnel system’, in both civil engineering and equipment. This involves targeting all systems, obviously the large consumers, both occasional and permanent, but also the small permanent consumers.
- Analysis of equipment systems and their interactions (with each other and with the infrastructure).
- Consideration of the life cycle of the installations.

According to ADEME (The French Agency for Ecological Transition), ‘The low-tech approach involves questioning needs with a view to retaining only what is essential, reducing technological complexity, and maintaining what already exists rather than replacing it.’ The questioning can validly be based on the Avoid-Reduce-Offset criteria of the ARO approach, just as the RAMS approach requires questioning each of the criteria of Reliability, Maintainability, etc.

It may be useful to break down the ‘systems’ in order to better address their specific effects and be more comprehensive:

- sensors >>> quality (accuracy, reliability), adjustment
- operational part >>> functionalities (normal and degraded modes, self-tests, etc.)
- actuators >>> efficiency

It is also essential to consider ‘systems’ both as such and in the specific context of the project.

Taking into account the life cycle of installations (infrastructure and equipment) should make it possible to assess the environmental impact of specific equipment during the following phases:

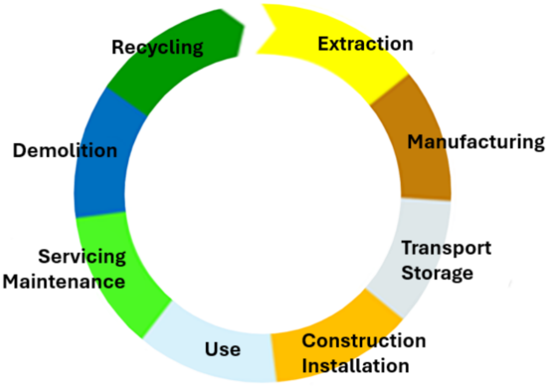


Figure 4: Life cycle

There are many ‘lean’ methods, often adapted to the context and modified over time. They generally aim to improve activities and products. Three of them seem likely to provide useful and effective support for reflection:

- the 5S method, which can be extrapolated to the design and maintenance process.
- the reduction of waste, including overproduction, overstocking, unnecessary transport, overprocessing, defects and scrap.
- ‘total productive maintenance’ with its concepts of planned maintenance and maintenance-oriented design.

In fact, there is a clear convergence between ‘low-tech’ and ‘lean-tech’ approaches, methods and concepts and the more common RAMS and DfM approaches. All aim to ensure the efficiency of activities (operation and maintenance) and the availability of facilities, and therefore of infrastructure, the primary motivation for which, it should be remembered, is to improve an economic or social function. The objectives of repairability, sustainability, standardisation, scalability, simplicity, etc. are therefore common to all.

6. RECOMMENDATIONS

Given the environmental challenges we face, the systematic questioning mentioned in the methodology section is no longer an option: it is a moral obligation before it becomes, perhaps in the near future, a regulatory or legal obligation in the same way as safety and RAMS objectives.

Firstly, it is necessary to clearly define the level of service (1) expected from the infrastructure of which the tunnel is a part. Although this step is fundamental, it is rarely explained in detail. This often results in oversizing due to the reproduction of unsuitable designs, which could be avoided by analysing needs (low-tech) and reducing waste (lean-tech).

(1) *There are many criteria, including safety, availability, reliability, predictability (journey time, traffic information, etc.), comfort, cost, etc.*

When it is not possible to completely eliminate energy consumption, the aim is to reduce requirements as much as possible and optimise existing systems. To this end, it is recommended to:

- accurately characterise consumption by implementing sufficiently sophisticated measurement and monitoring tools;
- ideally, focus on the most impactful parameters of each system;
- at a minimum, carry out the simplest and quickest optimisations;
- address the causes rather than their effects as a priority.

Efforts can also be made to optimise servicing and maintenance operations by avoiding systematic replacements that are too early and favouring scheduled operation. The latter option aims to limit unplanned interventions, which generate additional costs for operating services and also for users who are unable to organise themselves in advance.

Generally speaking, the principle of 'keep it simple' (2) seems as relevant in an ARO approach as it is in an RAMS or DfM approach. 'Technological escapism' should be avoided at all costs, and any increase in complexity must be firmly justified by necessity.

(2) *Albert Einstein proposed the following variation: 'Everything should be made as simple as possible, but not simpler.' In other words, the design of a system should be as simple as possible, to the point of reaching a minimal form.*

Finally, it should be emphasised here that none of these recommendations are in any way contrary to compliance with regulatory and fundamental safety requirements – quite the contrary. In other words, these requirements cannot justify a lack of concern for the environment, which, as we have seen, converges with the RAMS and DfM approaches.

7. SUMMARY AND CONCLUSION

The few examples listed show that most avoidance and reduction measures can be decided (1) during the design phase. However, there are also options during the construction and operational phases.

(1) *To be more precise, it should be said that they 'must be decided during the design phase' because postponing them may make them difficult or even impossible to implement later on. As such, calls for tenders and works contracts should/must include selection criteria during both the selection phase and the detailed design phase.*

Furthermore, it should be noted that most measures consist of reducing environmental impacts, rather than avoiding them entirely, which is more difficult to achieve. Compensation measures are also possible; these are obviously important but are not the primary objective. In any case, concrete and relatively simple measures are possible for many equipment systems!

You (readers) may have thought, 'I already do some or all of this.' Well, that's great! There is no doubt that there are many Mr Jourdains of eco-design and that, thanks to them, to you, environmental concerns will be better taken into account because, when it comes to environmental issues, every action counts, big or small! ARO measures must therefore be encouraged, developed and systematised wherever possible, in all areas and throughout the entire life cycle of facilities.

Faced with the major climate challenge facing our planet, the eco-design approach is no longer an option, especially since:

- It is fully compatible with regulatory safety requirements.
- It converges with RAMS, DfM and cybersecurity approaches.
- It does not preclude making the most of Intelligent Transport Systems (which could revolutionise mobility and contribute to safety) or Artificial Intelligence (enabling optimised management of certain processes).
- It is essential for meeting infrastructure resilience requirements.
- It can help control overall construction, operating and maintenance costs.