New Tools for Evaluating Underground Infrastructures according to Sustainable Development Concepts

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1. Introduction

As far as sustainable development is concerned, important issues are related to the use and management of underground space and to the adequate integration of a tunnel in a given infrastructure project whatever the mode of transport can be. Construction sites of underground infrastructures are liable to have significant economical and environmental effects. However, in a certain extent, both these kinds of effects can be offset by the protection of the surface and by the global optimization of the infrastructure design itself.

The CETU is now working on the best way to take into account the concepts linked to sustainable development. To aim this goal, the CETU is carrying out the development of new tools for decision support and for evaluating a given tunnel project at different stages: from the justification of the initial choice of an underground infrastructure to its final design, construction and operation.

A first stage consists in identifying and quantifying the various contributions of a tunnel in an infrastructure project, thanks to specific tools like multi-criteria grids of evaluation. Thus, the adaptation of the French grid RST02 to the field of tunnels is currently being studied through its application to a real project. This grid of evaluation has been developed within the scientific and technical network of the French Ministry of Ecology for several years.

At a further stage, i.e. when the tunnel is taken as granted in the infrastructure project, the choice of technical solutions is concerned. Although, tunnel infrastructures are usually strongly constrained by both economical and geological considerations, environmental impacts can be limited when considering the entire life cycle: i.e. construction, operation and “end of life” phases. The CETU is actually applying Life Cycle Analysis (LCA) to “materials” of civil engineering in order to compare the environmental potential impacts of technical solutions for excavation, support and lining.

2. Strategic challenges and the role of the CETU

2.1. General context

The Ministry of Ecology, Energy, Sustainable Development and the Sea (MEEDDM) has been created in 2007 by grouping two ministries: the Ministry of Ecology and Sustainable Development and the Ministry of Transport, Infrastructures, Tourism and the Sea, and the annexation of the part of the Ministry of Industry dedicated to energy. This Ministry was created to meet the challenges of sustainable development both now and in the future, and in particular to monitor the implementation of the decisions reached by the Environment Round Table (Grenelle de
In order to give a very significant impulse, the Ministry has been divided into five dedicated Directorates-General and two transverse entities.

Transportation, which is addressed by one of the Directorate-General, is a key player in the economic vitality and development of the territory. However, it represents 27% of greenhouse gas emissions. Hence, meeting the demand for mobility while minimizing environmental impacts, requires a number of guidelines.

2.2. The missions of the CETU

The Centre d’Études des Tunnels (CETU) is one of the technical services attached to the Directorate-General of Infrastructure, Transport and the Sea (DGITM) of the MEEDDM. The CETU contributes to improve the technical quality and safety of tunnels through its involvement in numerous projects. Beyond the statutory advices it regularly provides for projects belonging to the « State » road network, the CETU is increasingly called upon to intervene either in support or advice to tunnel owners and operators. As far as environment is concerned, expectations of tunnel owners and operators are becoming more numerous. For example, important issues are related to finding solutions to optimize the management of excavated materials, while respecting the technical and environmental constraints. Expectations also include questions related to the treatment of air at the extremities of tunnels in order to reduce concentrations of pollutants especially when tunnels are located in urban areas. The CETU is also requested by tunnel owners to develop and support methodologies for assessing how sustainable development can be taken into account in large underground projects. If this assistance meets the expectations of the owners of tunnels under the state responsibility, it also meets a real need of local communities, tunnel owners and operators for other tunnels than road tunnels.

Therefore, the CETU is expected to play a leading role to support the decision making and it meets the expectations of the MEEDDM.

2.3. Establishment of strategic research at the CETU

A new tunnel is always a construction project characterized by very heavy consequences in terms of economic and environmental impacts: large volumes of materials used, high energy consumption, various pollutions or harmful effects, etc. Moreover, the operation of the tunnel raises other issues linked to safety, mobility and environment. However, it enables to preserve the surface area and offers opportunities for better use of the underground. The new research project defined by the CETU aims to establish a hierarchy of issues related to the way to account for sustainable development within the process of making and operating a tunnel. For each phase, either at the design stage or during construction and operation periods, the CETU purpose is to be able to clarify key issues, to assess methods and appropriate tools, and to determine and evaluate technical alternatives to ensure the structure function and to satisfy requirements for preserving the planet.

On this basis, targeted actions will be undertaken. The CETU will be better trained to relay these issues and concerns within the profession.

2.4. The development of new assessment tools

As it was already mentioned before, the main expectations of tunnels owners and operators are related to the availability of objectives and reliable assessment tools. These tools should gain wide acceptance within the profession. Some of these tools already exist and require few if any adjustments. Others are still to be developed. These tools are of course not equivalent. It will probably be necessary to consider combining these different tools according to the stage of the project. Indeed, this is not necessarily the same tools that are relevant to various stages of design and construction or during the operational period. One of the ways to develop new tools or to
adapt existing tools and to validate them, consists in identifying projects that could serve as support for practical analysis. Finally, other questions are linked to the way to account for sustainable development considerations into contracts.

Hence, adequate tools should be available for decision makers to objectively justify their choice on the basis of considerations related to sustainable development.

3. Tunnel and sustainable development

3.1. Upstream stage: Why imagine a tunnel in the infrastructure project?

3.1.1. Identification of need

The first point we can underline, is that the tunnel should be considered as one element of the global infrastructure. Hence, the tunnel can not be dissociated from the infrastructure at the very early stages of a project studies. The whole project has to be evaluated and compared with other kinds of solutions. At this stage referred to as "upstream" stage, the problem is for the CETU to assess the specific contribution of the tunnel in terms of sustainable development by considering the economical aspects as well as the social and environmental ones. We also easily can imagine the importance of developing modular tools that can be subsequently integrated into more global tools.

The French circular dated January 7, 2008 fixed the terms and conditions of elaboration, instruction, approval and evaluation of investment operations on the state road network [1]. This circular and in particular the draft Annex 1 (phases of design and execution, orders and breakpoints) enables to better identify the role of different actors throughout the process that involves major stages of consultation or debate. The process is punctuated by successive decisions which lay down the choices. The complete study and work stages are illustrated in Figure 1. This simplified description allows us to locate the "upstream" stage at the opportunity study.

3.1.2. Existing assessment tools: Applying the RST\textsubscript{02} grid

The RST\textsubscript{02} grid is a multi-criteria assessment grid. It has been developed within the scientific and technical network of the French Ministry of Ecology for several years [2]. It enables to analyze a given project, to question it regarding sustainable development and to identify possible improvements. The RST\textsubscript{02} grid can be considered as unbiased as far it is based on the principles of the Rio Declaration of 1992. It consists of 29 criteria to review. There is an equivalent number of criteria for each dimension and interface (usually 4, except for the governance for which they

Figure 1: the major phases of a project [1].
are 5) (see Figure 3). These criteria are of equal importance. Projects can be of various natures. They may be related to a development plan, a program of actions or even a contractual project.

The first work of the CETU consisted in evaluating the relevance of the grid $\text{RST}_{02}$ for tunnel projects. This has been done in collaboration with the Centre d’Etudes sur les Réseaux, les Transports, l’Urbanisme et les constructions publiques (CERTU) and the City and Territories Department of the Centre d’Etudes Techniques de l’Equipement de Lyon (CETE), by applying the grid to a "support" project: the LINO (north link of the city of Dijon). The ongoing project is an infrastructure one which includes a tunnel and a cut and cover (See Figure 2). The LINO will connect the ends of the eastern bypass (N274) and the A38 motorway. It will also serve the surrounding areas. This project is long of 7.5 km. It includes 13 bridges or viaducts, a tunnel of 600 m long and a cut and cover of 300 m.

A team composed by the owner, its assistant (the CETU) and the project managers has been gathered to proceed to the test. Question guide and general recommendations are available to guarantee that each criterion is considered in the project. Social, economical and environmental criteria have been defined like for example: cultural identity, solidarity between generations, economic consistency, preservation of natural resources, impacts on health and safety, etc. Governance is also addressed by 5 specific criteria like management and consultation and participation. Each criterion is receiving a score between -3 and 3 depending on the quality with which it has been considered. An average score is then calculated for each dimension and interface and for the governance. Typical scores are given in Figure 3 in the form of a diagram called radar profile of sustainable development. The representation of sustainable development is also given in Figure 3. It is important to remember that this grid must be used within a project team bringing together the actors and different sensitivities. Using this grid is an opportunity to compare different points of view, to generate reflection and stepping back. The $\text{RST}_{02}$ grid may require adjustment. Questions can be reformulated and the criteria reviewed. Currently the grid is available in trades such as water, transport, urban planning and housing.
3.1.3. Encountered difficulties

Applying the grid to a real project has enabled to define the relevance of criteria and questions. Even if it depends to some extent on the nature of the project, this relevance can be questioned.

The essential difficulty lies in the distinction between the infrastructure project and the tunnel one. We aimed to assess the contribution of the tunnel in the infrastructure project, but it was difficult for the team to constantly reposition itself on the ongoing project and confusions appear between the different stages: design, construction and operation. Answers can strongly differ depending on the point of view. The very knowledge of all the project issues can not be provided by a single person, hence the need to build up a team around the project. One thing has to be understood and team should feel comfortable since there is no one right answer to each question, but several relevant answers.

Besides, the grid revealed itself to be too complex and to heavy to use, particularly when it is not already known by the members of the team. Many superfluous elements appeared in the answers to the numerous questions because of fuzzy boundaries between dimensions and interfaces. Questions are sometimes too general and not specific enough to talk to team members.

3.1.4. Future developments

In a second step, we could have considered the possible reformulation of criteria and / or questions, for a specific application to tunnels. This practice is actually already done in other areas. The challenge would have been to keep the main features of a general grid with changes in the expression of criteria and questions according to the "trades" which are considered. This solution was not retained. We decided to follow the advice of the CETE de Lyon which ensured the animation of the test. Another grid has been selected. It is also developed by the MEEDDM for the assessment of projects in the field of land use planning. This grid is also well-founded. It is the result of a consensus and it is based on the main objectives of the National sustainable development strategy: climate change and clean energy, sustainable transport, sustainable consumption and production, conservation and management of natural resources, public health, social inclusion, demography and migration, global poverty and sustainable development challenges. Several additional questions deal with levers and strategic tools. This new grid will also require the reformulation of questions to adapt it to tunnels and the implementation of a grading system to enhance the readability of results. However, it seems easier to use. This work will be done in 2010 along with a new experimentation on a real project.
3.2. Downstream stage: How to optimize the technical choices when the tunnel option is acquired?

When the "tunnel" is taken for granted in the infrastructure project, the problem lies in the assessment of potential impacts on the environment by adopting an approach like Life Cycle Assessment (LCA). This implies a good knowledge of the technical aspects of the project like methods of excavation, support, lining, equipment, as well as that of the operating phase. Therefore, even though located at the stage of the design studies (see Figure 1), this approach could be qualified as "downstream", i.e. orientated to the construction and to the operating phases. This approach has also to be completed by socio-economical considerations. Accounting for these latter aspects can be done through the development of specific indicators for tunnels (Harmful effects of noise for local residents during the construction phase and during the operating one, for example).

3.2.1. Geological hazards and economic consequences

Potential impacts of tunnels on the environment are usually determined by technical choices and structure design which can themselves depend on site conditions (geological considerations, presence of water, etc.), economical aspects and constraints linked to the construction phase. Thus, the flexibility to limit potential impacts on environment may not be as great as it could be due to the strong technical and economic constraints associated with this type of structure. Nevertheless, considering the priorities of most governments about global warming and preservation of natural resources, it seems to be of great importance to graft a new set of environmental criteria for choosing a technical solution.

3.2.2. Life Cycle Assessment (LCA) applied to tunnels

The LCA method was selected to assess potential impacts of tunnels on environment. The standards NF EN ISO 14040 and NF EN ISO 14044 [3,4] are describing respectively the "principles and framework" of LCA and the "requirements and guidelines". As it was stated before, the main assumption which is made here is that the "tunnel" is considered as granted in the infrastructure project. We are then interested in the potential impacts on the environment of its design, construction and operation. The economical aspects are also taken into account by using an assessment tool developed at the CETU. The idea is to compare technical solutions whose choice may be determined not only by geological and economic considerations, but also by environmental considerations. This has to be done by taking into account the entire life cycle of tunnel.

LCA is already applied in France to construction products and building constructions. Its application to civil engineering structures will address the potential environmental impacts throughout their life cycle: from production to end of life without forgetting the construction phase as well as the operating one. We use the well-known expression: "from cradle to grave". The LCA method enables to assess the interactions between technological processes and their effects on the environment. It consists of 4 phases described in [3]:
- Definition of objectives and scope of the study,
- Life Cycle Inventory (LCI),
- Assessing the impact of the life cycle and
- Interpretation.

In our case, the "functional unit" will be for example "the transition to another valley through a tunnel". The "product system" will be the tunnel itself. It will be linked to its environment by incoming and outgoing elementary flows. The elementary flows include the use of resources and emissions to water, air and soil.

Regarding tunnels, we can represent their life cycle by describing the various steps that constitute the design and construction of civil engineering, the design of equipment (lighting, ventilation,
general survey, etc.) and the maintenance of the structure and its equipments over time. These steps are summarized in Figure 4. In particular, the methodological question of defining the “end of life” of the tunnel arises obviously. Tunnels have not really what we could call an “end of life” as it is the case for an ordinary building. Whereas civil engineering remains in place, the model we finally chose to represent the “end of life” of the tunnel will be characterized by the end of the operating phase, dismantling and recycling equipment: lighting, cable tray, ventilation systems, etc.

Figure 4: Life cycle representation of a tunnel.

3.2.3. First results and main conclusions

The first part of the work consisted in applying the LCA method to "materials" of the civil engineering structure. This has been done on the basis of the description of technical solutions. It is therefore a first attempt to use LCA for tunnels [5]. The results are expressed in terms of environmental impacts. They are provided for one meter of a given profile. The different profiles we defined correspond to the most commonly encountered ones (from the lightest to the heaviest support) (see Figure 5). A software has been developed by the CETU in the framework of the research priority theme "Control of costs and delays". It enabled establishing the balance of quantities of "materials" used for each type of profile which can be chosen for the current section of the tunnel. Then, the use of the LCA software TEAM (developed and distributed by Ecobilan/PricewaterhouseCoopers) has allowed quantifying the potential impacts on the environment of one meter of tunnel depending on the selected type of profile. A critical analysis of the simplifying assumptions which were made and the relevance and reliability of environmental data which were available has been done. Indeed, a question of size remains: the availability of environmental data on so many building materials (waterproofing complex, cementitious materials, steel elements, fire protection, etc.).

We were also wondering about the importance of the impacts of the operating phase compared to those of the design and the construction ones. This could be accentuated by the great lifetime of the structure and could lead to dash and discourage our efforts for optimizing the choice of materials and construction techniques (at least from the environmental point of view). Therefore, we have also introduced data linked to the power consumption of electrical equipment (lighting and ventilation). Whatever the lifetime of the tunnel (50, 75, 100 or even 150 years) it appears that the environmental impacts of "materials" are far from being negligible compared to the consumption of electrical equipment. For the indicator of climate change for example, the contribution of power consumption is ranging from 10 to about 40% compared to that of materials (civil engineering only), depending on the duration of operation (see Figure 5).
3.2.4. Further studies

Further developments are planned for 2010. They concern the sensitivity analysis of LCA applied to "materials" of civil engineering with improvements to implement in the description of concrete types and steel elements. The phase of construction will also be modelled. Finally, the LCA will also be applied to ventilation systems. Moreover, economic data which were not presented here need more refinements and will be provided and completed along with LCA studies.

4. Conclusions and perspectives

Facing a challenge as to better account for all the impacts of choices linked to the design process, the construction and the operation of a tunnel, these first studies can be considered as exploratory ones. To effectively progress in the field of assessment, relying on existing tools and adapting them to the case of tunnels has appeared to be a relevant and an appropriate method. Assessment grids and LCA are part of these tools. All of them are certainly not equivalent but often complementary. They offer either a qualitative evaluation of the whole system or a quantitative evaluation of several components. These methods can often be applied to different stages of the project and should be used to justify a tunnel or very specific technical choices. As far as appropriate tools of assessment will be available, they should be discussed with the profession to receive the widest consensus. They also will enable identifying key issues in tunnel projects and highlighting the critical choices with respect to sustainable development.

References


