LEANTECH IN ROAD TUNNELS

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ABSTRACT

Due to historical developments and the desire to provide road users with the safest possible infrastructure, today's practice results in complex and cost-intensive electromechanical equipment in road tunnels. The Swiss Federal Roads Office (FEDRO) initiated the LeanTech research project aiming at reducing the system and operating costs by streamlining the specifications without reducing noticeably aspects relating to safety, availability, and maintenance.

The currently applicable requirements on the operating and the electromechanical equipment in road tunnels were critically examined in a systematic process. In terms of LeanTech, the question was whether and how requirements can be optimised with neither reducing the safety of the road users nor the availability of the infrastructure.

A total of 2182 requirements were identified that could be optimised without affecting compliance with the minimum requirements for tunnel safety. The applied multiple-step analysis concluded that the optimisation potentials of 2113 requirements were too small to allow for an in-depth investigation in this research project. From the remaining requirements, 41 were examined in detail. This resulted in 9 adaptation proposals with major impacts in terms of LeanTech, which can be implemented easily and promptly. In addition, 12 recommendations for action were proposed for more thorough investigations.

Keywords: LeanTech, requirements on electromechanical equipment, cost reduction,

1. INTRODUCTION

Due to historical developments and the desire to provide road users with an infrastructure that is as safe as possible, road tunnels today are characterized by complex and cost-intensive electromechanical installations. The constantly increasing cost pressure (investment, maintenance, and replacement) and the changing socio-legal-economic context make it necessary to critically scrutinize the existing requirements on road-tunnel equipment as well as current practice in planning and implementation. Therefore, the LeanTech research project [1] was initiated by the Swiss Federal Roads Office (FEDRO). LeanTech is aiming at streamlining the current specifications with only marginal impact on safety, availability, and maintenance. To do so, the following tasks had to be performed:

- Recording and presenting the reference system (existing requirements).
- Analysis and evaluation of the reference system (existing requirements).
- Identify recommendations and implementation strategies for improvements, considering usual European standards [2].
- Develop specific suggestions for improvement and demonstrate their feasibility.

One of the difficulties in implementing the project objective is to reduce the requirements on the equipment without compromising the required level of safety. This applies both to road users (the public) and stakeholders within the FEDRO and emergency services (police, fire-fighters, etc.).

To achieve the project objectives, the following four steps were performed:

1. systematic processing of the current requirements
2. selection of requirements with optimization potential
3. detailed analysis of the selected requirements with optimization potential
4. assessment of the remaining requirements with optimization potential

The approach was transparent and comprehensible. Consequently, it was deliberately refrained from developing a multi-dimensional model of the interaction between requirements, technical implementation variants and results in terms of safety, availability, and maintenance, including all dependencies.

Parallel to the systematic analysis and processing of the requirements, the opinions of international experts on the topic were obtained. This allowed the topic of LeanTech to be expanded and enriched from an international perspective.

2. STATE OF RESEARCH AND NEEDS

The currently valid standards, FEDRO guidelines and technical manuals to be used for the design and implementation of electromechanical equipment are driven on one hand by research findings and on the other by major fire incidents. The desire for safety is a major factor and tends to result in increased complexity and costs of the electromechanical systems.

From the point of view of the Swiss Tunnel Research Working Group, the time has come to critically review and, if necessary, revise the requirements on the electromechanical equipment in road tunnels. In this way, the systems can be reduced to what is strictly necessary and less effective systems as well as redundancies that are not sensible or insufficiently thought through can be modified or even eliminated.

The current guidelines and specifications regulate the requirements on individual systems and components. These can and should be scrutinized (e.g. need of redundant power supply, and optical guidance lighting versus safety lighting). The interaction between the individual systems and the superordinate relationships between several systems must also be considered. In this respect, for example, both the emergency exits, and the ventilation of the traffic space have a direct influence on self-rescue in the event of a fire. Nevertheless, there is currently no direct dependency between the relevant requirements. However, it is prescribed that deviations from the core requirements in the FEDRO guidelines must be assessed in a cost-benefit context by means of a risk analysis [7], [8].

By critically scrutinizing the meaningfulness, usefulness, and timeliness of the applicable requirements, it seems possible to make substantial savings regarding investment, operation, and maintenance without causing a noticeable reduction in the safety level or availability of the system.

The basic questions for the selection and evaluation of the possibilities for simplifications of the equipment in road tunnels are the following:

- Which functions are to be fulfilled and to what extent?
- How efficiently are the requirements implemented by the equipment?
- What mutual influences are there between the individual functions and the associated systems?
- What redundancies are necessary and how are these implemented?

- What is the possible/acceptable scope for simplification?
- What are the consequences (advantages and disadvantages in terms of safety, availability, maintenance, and costs) of the simplifications?
- How can the simplifications be implemented?

In principle, the questions are aimed at new installations to be built. However, there is also potential for simplification in forward-looking replacement planning (e.g. standardized open communication systems).

It makes sense to compare and review the design philosophy and/or the equipment standard with international standards (guidelines, planning manuals, etc.) and international research results to determine the minimum equipment required. This can also provide more clarity as to where redundancies are necessary or appropriate. In addition, the assessments of optimization potential by international experts should be obtained and used in the project.

3. METHODOLOGY

Two distinct approaches are available for the elaboration of requirements: top-down and bottom-up. The top-down approach is based on a high degree of abstraction or a global view. Step by step, the problem is increasingly concretized. An overall problem is divided into sub-problems, which may then be subdivided into further sub-problems. In the bottom-up approach, delimited, detailed sub-problems are solved first. These are then used to tackle the next larger problems above them and so on until the overall problem can be solved at the end.

Within the LeanTech project, both approaches were applied in parallel, the interviews with the international experts can be regarded as top-down, whereas the systematic classification and analysis of the requirement framework was a bottom-up approach.

3.1. Systematic classification and analysis

The hierarchy of guidelines, standards, etc. defined by FEDRO was used for this purpose. This ranking and the considered project perimeter are shown in Figure 1. Requirements of higher priority than FEDRO guidelines (e.g. the FEDRO instructions) were considered a priori to be irrevocable, as these are outside the sphere of influence of the research activities. Consequently, the FEDRO instruction [1], which defines the minimum safety requirements for tunnels in the national road network, was excluded from the project perimeter. This implicitly means that the requirements stated in the EU directive on minimum safety requirements for road tunnels [2] must be complied with.

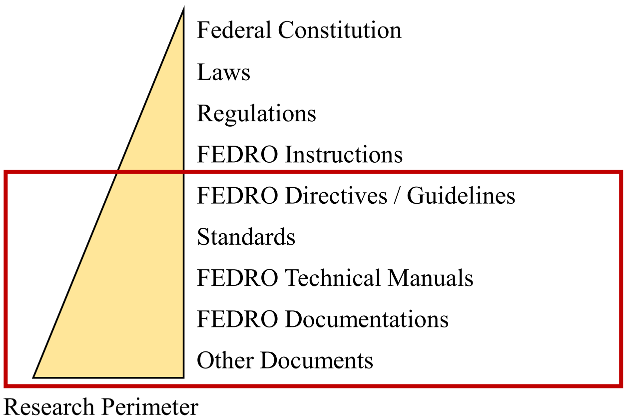

Figure 1: LeanTech Research Perimeter

The bottom-up approach based on existing regulations was considered advantageous, as the research perimeter is clearly defined. The requirements to be scrutinized are clearly structured and prioritized. Moreover, the analysis and any optimizations relate directly to existing requirements.

The systematic analysis revealed requirements relevant to the LeanTech project contained in

- 18 FEDRO directives and guidelines
- 5 national standards
- 69 FEDRO technical manuals and documentations

In order to determine the requirements that have the most potential in terms of LeanTech, the following sequential steps were applied:

- Step 1: Compliance with minimal safety requirements
- Step 2: Complexity- and/or cost-driving
- Step 3: Preliminary evaluation
- Step 4: Detailed evaluation
- Step 5: Selection for LeanTech

As a results of the first step, it was concluded that 2182 requirement could be optimized in terms of LeanTech without violating compliance with the minimum safety requirements.

In the second step, the impact on system complexity and/or cost (installation and maintenance) was analysed (minimal influence, relevant influence, uncertain influence). 366 of the initially identified 2182 requirements were judged to have adequately large influence on the system complexity and/or costs. Requirements with minimal influence were discarded.

The third step evaluated three aspects of the impact of any modification (simplification) of the requirement i.e. in terms of:

- tunnel safety (safety for the tunnel user),
- availability of the infrastructure (for the tunnel user), and
- maintenance (maintenance effort, maintenance intervals)

For each aspect, the impact was assessed potentially to be:

- positive (increase in terms of tunnel safety, increase of the availability, eased maintenance),
- neutral, or
- negative (reduction of tunnel safety, decrease of availability, increased maintenance).

If two of the above-mentioned aspects were judged to have a negative impact, it was decided not to pursue adjustments of the requirement. 265 requirements remained for subsequent scrutiny.

In step 4, it was concluded that 102 of the 265 remaining requirements had adequate financial potential to justify a more detailed analysis. Moreover, it was assessed if the details of the requirements could depend on tunnel length and/or traffic (type and quantity), as this could either allow for more general adjustments or more simplifications based on specific tunnel characteristics.

For the final selection, the results of the methodology were considered together with specialist and expert assessments also taking the suggestions and proposals of the international experts (see chapter 3.2) into account. This resulted in a selection of:

- 41 requirements for detailed analysis, and further,
- 28 requirements for an overall potential assessment.

3.2. Expert survey

The international experts were asked the following question:

> *Which requirements for electromechanical equipment in road tunnels should be adapted and in what way to reduce costs (or complexity) without having to accept any real negative impact on safety, availability, and maintenance*?

An open question was deliberately posed to allow for a variety of feedback. No reference to the conditions in Switzerland was requested. The expert's feedback was analysed considering the constituency of each expert and therefore the expert's natural frame of reference.

This question was asked at the beginning of the research project. The feedback was therefore useful for the detailed analysis of the requirements with optimization potential.

4. RESULTS

4.1. Expert survey

A total of 38 international experts were consulted, and the feedback received exceeded expectations. The feedback can be summarized as follows:

- 23 specific adaptation proposals for individual equipment types or installations,
- 12 specific adaptation proposals based on considerations of multiple installations,
- 3 high level adaptation proposals.

The full list of proposals can be found in [1]. The proposals are deliberately not affiliated to a certain expert, as it was desired to obtain honest and perhaps controversial responses. Specific proposals are for example: reduction of requirements on material qualities, renouncement of cross-passage ventilation, simplification of the surveillance (anemometers, CO-measurements) and detection equipment (incident detection) or general simplification of control systems (general renouncement of touch panels, limitation of data points and limitation of PLCs). The proposals based on consideration of multiple installations are mainly aimed at simplifications according to the principle of "one system for one purpose".

In addition, the opinion was also expressed that no adjustments to the current requirements are possible or appropriate.

4.2. Systematic classification and analysis

As presented in chapter 3.1, the full number of catalogued requirements were processed. From the total number of 2182 requirements having passed evaluation step 1 (compliance with minimal requirements), a total of 41 requirements emerged as being interesting in terms of LeanTech (optimisation possible, sufficient impact in terms of cost, specific optimization proposal possible) and were examined in depth. For each FEDRO equipment type, Table 1 presents number of requirements with LeanTech potential after each evaluation step.

Table 1: Summary of the number of requirements with LeanTech potential per evaluation step and equipment type

Evaluation step	**Total number**	**Superordinate requirements**	**Energy supply**	**Lighting**	**Ventilation**	**Signalization**	**Surveillance and detection**	**Communication & Controls**	**Cables**	**Auxiliary installations**
Step 1: Compliance with minimal requirements	2182	7	183	254	519	291	179	333	222	194
Step 2: Complexity- and/or cost-driving	366	4	17	42	262	10	14	8	0	9
Step 3: Preliminary evaluation	265	3	7	26	190	10	14	8	0	7
Step 4: Detailed evaluation	102	0	4	10	55	10	14	8	0	1
Step 5: Selection for LeanTech	41	0	4	10	14	5	6	1	0	1
Requirements for further analysis	28	0	0	0	17	1	6	4	0	0

In the end, 9 specific adaptation proposals were elaborated, which can easily and promptly be implemented whilst still having a major impact in terms of LeanTech. In addition, 12 recommendations for action were made for more in-depth investigations and further 28 requirements with optimisation potential were subjected to a higher-level analysis.

The 9 specific adaptation proposals concern the following:

1) Power supply from two independent power grids,
2) Determination of the total required energy supply,
3) Life-time requirements on batteries for uninterrupted power supply (UPS),
4) Reduce the temperature requirement on axial fans,
5) Lower minimal permissible under-pressure in ventilation ducts along the traffic space,
6) Permit to determine anti-recirculation measures at tunnel portals using a detailed analysis and not simply require a certain staggering in direction of the road axis,
7) Omit the requirement for fixed installed control panels locally for intervention on site of control units. However, certain local control panels are required to activate tunnel closure,
8) Increase the required minimum lifetime of LED in traffic signals,
9) Constrain video detection (CCTV) to halted vehicles, wrong direction vehicles and occupation of laybys.

The 12 recommendations for further in-depth analysis relate to:

1) Base the dimensioning of the UPS on the estimated required power requirement and duration and not on the nominal power of each consumer,
2) Combination of optical guidance lighting and safety lighting,
3) Increase of the required maintenance factor of luminaries from 0.80 to 0.85,
4) Requirements on luminaries to increase efficiency and longevity; reduce maintenance,
5) Reduce the requirements on material quality according to the findings in the soon to be published research project AGT 2014/004,
6) Refine requirements on civil measures to minimise flow short circuit at tunnel portals,

7) Detailed method to determine the minimum distance between two following tunnels to ensure that they are aerodynamically independent,
8) Rethink the redundancy requirements on the ventilation of egress tunnels so that one ventilation station is basically deemed adequate,
9) Re-define the necessity and functionality requirements on air locks in egress tunnels,
10) Maintain local HMI for equipment enabling cross overs at tunnel portals,
11) Consider if linear heat detectors can be omitted in certain (typically short) tunnels and/or be replaced with temperatures sensors in smoke detectors,
12) Maintain the currently specified bundling of equipment to different local control units.

4.3. Exemplary optimisation proposal

According to [4], [5] and [6], tunnels in general and especially the traffic space respectively escape-route ventilation equipment needs to be powered (medium voltage level) by two independent local power grids. Furthermore, an uninterruptable power supply (UPS) must be installed (no need to account for ventilation equipment).

For certain tunnels, a supply from two independent power grids is only possible at great expense (tunnels in remote areas or city tunnels). In addition, grid outages have become a rarity these days. Currently, the most common cause of grid interruptions is maintenance work; disruption-related grid outages that cannot be predicted or immediately compensated have become rare events. Interruptions are usually rectified by the energy supplier/grid operator within less than 60 minutes. The probability of a simultaneous failure of the two independent grids is very low. The UPS system cannot fully compensate for a power failure; it only supplies parts of the installations such as the control systems, emergency lighting and signalization.

If a tunnel would be powered by only one power grid, this would mainly impact the availability. However, the effects are highly dependent on the tunnel length and amount of equipment. For a network-wide coherent implementation (standardization of the considerations to be carried out), it may be advantageous to introduce a form of tunnel classification that clearly defines under which conditions two independent, local power supplies are mandatory or when deviations from this are possible.

Therefore, the following proposal was formulated:

For tunnels which have a traffic-space ventilation system and/or an escape-route ventilation system, power supply from two independent sources must be provided.

- Normally, power should be provided by two independent, local power grids.
- If this is not practical for economic reasons, power must be provided by at least two supplies from the medium-voltage grid.

For all other tunnels, energy supply from only one power grid is permitted, provided the following conditions are met:

- Due to safety considerations, it is admissible to continue operating the tunnel despite a complete blackout (normal network and UPS system); with or without additional measures such as traffic-speed reduction, personnel on site, etc.
- In the event of planned interruptions to the power supply (e.g. during maintenance work on the power grid), the tunnel's power supply can be guaranteed.

5. SUMMARY AND CONCLUSION

Due to historical development and the desire to provide road users with the safest possible infrastructure, today's practice results in complex and cost-intensive installations (electromechanical equipment) in road tunnels.

The research project LeanTech in road tunnels was initiated and financed by the Swiss Federal Roads Office FEDRO. It addresses this issue and aims at reducing both the system costs and the operating costs (costs on the part of the operators for maintenance and operation) for road tunnels by streamlining the specifications without having to reduce noticeably aspects relating to safety, availability, and maintenance.

Using a systematic approach, the existing requirements on electromechanical equipment were catalogued, categorized, and evaluated in terms of their LeanTech potential. A grand total of 2182 requirements were identified that could be optimised without affecting compliance with the minimum requirements for tunnel safety. From those, a total of 41 requirements were examined in depth. This resulted in 9 specific adaptation proposals, which can be implemented easily and promptly whilst having a major impact in terms of LeanTech. In addition, 12 recommendations for action were made for more in-depth investigations and further 28 requirements with optimisation potential were subject to a high-level analysis.

6. REFERENCES

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