Assessing the Relative Sustainability of Long Parallel Noise Barriers and Related Noise Reducing Devices for a Motorway in Italy

Crina Oltean-Dumbrava[1]; Mark Richards[2]
[1]University of Bradford, BCSE, UK
[2]TOBIN Consulting Engineers (UK) Ltd

ABSTRACT

Noise barriers and related devices for noise impact mitigation are more and more used along road and railways. They are expensive civil engineering works with environmental and social impacts, but are still selected looking only at the price and few conventional technical parameters. This work presents a model for assessing the relative sustainability of road noise barriers (RNB), taking into account technical, environmental, economic and social factors. There are many types of RNBs available, ranging from the use of timber panels through to photovoltaic panels. This makes it difficult for stakeholders to make informed decisions with regards to the sustainable design and procurement of RNBs. This paper provides an account of the novel research carried out to assess and rank the relative sustainability RNB types using preference functions, pair wise comparisons and Multi Criteria Analysis (MCA) techniques. The model consists of using primary criteria and makes it possible to obtain a sustainability ranking for each noise reducing device, throughout its life cycle. A worked example is presented and discussed, related to the selection of long parallel noise barriers for an existing motorway in Italy.
Keywords: Multicriteria analysis; sustainability; noise barriers, 52.3.

1. INTRODUCTION

As a result of climate change and current agendas such as ‘Agenda 21’ run by the United Nations, for sustainability, every discipline (including acoustics and transport) and sector of society has to play a role in order to achieve the global position of being sustainable. This becomes particularly true if we take into account the scale of typical noise barrier projects, which have to incorporate the complexities of the designing task, the enormity of construction work as well as the resources required to maintain and eventually remove Noise Reducing Devices (NRDs) once they have reached the end of their life cycle (Oltean-Dumbrava C. et al, 2010a).Thereby, it becomes evident that NRDs use as much resources and have as much of an impact on the built environment as any other large built structure.

A framework for the overall sustainability of noise barriers across their whole life cycle and a practical tailor made decision system for decision makers, transport engineers, urban/transport planners and other relevant stakeholders, has been developed within Work Package 6 of QUIESST, a project co-funded by the European Community's Seventh Framework Programme that began on November 1st, 2009. The paper presents the testing of the QUIESST methodology and its application to four different noise barriers that were selected to find the best alternative from the point of view of sustainability, by applying a Multi-criteria Decision Support Method (MCDM).

2. DEFINING A PROPER SET OF CRITERIA AND KEY PERFORMANCE INDICATORS

Given the definition of sustainability as: “the optimal consideration of technical, environmental, economic and social factors during the design, construction, maintenance and repair, and removal/demolition stages of NRDs projects” (Oltean-Dumbrava C. et al, 2010b), a set of criteria and indicators have been developed for four noise barriers. The four noise barriers analysed were:

- CORTEN STEEL and GLASS
- CORTEN STEEL and PMMA

- ALUMINIUM and GLASS
- ALUMINIUM and PMMA

The company chosen to provide reliable information for the data collection was CIR Ambiente SpA, Italy, because of its previous collaboration with the QUIESST project. CIR Ambiente SpA is an Italian leader in the production and installation of mufflers for road and railway applications and together with the group company Ausilio SpA, are offering consultancy related to the noise impact, phonometric, monitoring, data processing, acoustic design and testing. CIR Ambiente SpA has always been committed to the issue of environmental compliance and it has collaborated with Certificazione e ricerca per la qualità (CERMET), an independent body that carries out environmental assessment and offers certification of environmental performances for goods, services and systems.

CERMET has already assessed the environmental performances of a corten steel & glass barrier and an aluminium & PMMA barrier for CIR Ambiente SpA. The corten steel & glass barrier has also been analysed by QUIESST WP6 researchers for its sustainability and was used as a benchmark for comparison reasons. The four noise barriers design solutions mentioned above, which will be assessed for their sustainability, are very similar to each other in dimension and shape, but substantially different from the point of the materials used. The sustainability assessment will consider social, technical, environmental and economic factors, like the QUIESST sustainability assessment method.

2.1 Materials Used for the Four Noise Barriers

The main characteristics of the principal materials used for the four noise barriers are described below.

Corten Steel

Weathering steel, best-known under the trademark “COR-TEN” steel often used without the hyphen as "Corten steel", is a group of steel alloys which were developed to eliminate the need for painting, and form a stable rust-like appearance if exposed to the weather for several years. COR-TEN derives the name from the main characteristics of this steel: high corrosion resistance (COR) and high tensile strength (TEN).

"Weathering" refers to the chemical composition of these steels, allowing them to exhibit increased resistance to atmospheric corrosion compared to other steels. The corten steel utilized for noise barriers is commonly referred to as phosphorus corten and has a resistance to atmospheric agents from 5 to 8 times that of carbon steel.

Aluminium

Aluminium is ductile metal silver. The panels of CIR Ambiente SpA use an alloy of aluminium i.e. Aluminium 3105 and Wrought aluminium-manganese. It is essentially an alloy of aluminium pure to 98%, with some additions to make it resistant. It has excellent corrosion resistance; formability and workability of welding are excellent. The 3105 alloy is then powder coated on the entire surface with a polyester resin. The polyester powder coatings are the products of choice for the application on external finishing elements because they have a good resistance to UV rays.

Layered Tempered Glass

Layered glass, or laminated glass, is made by joining two or more layers of ordinary glass alternating with a sheet of milky colour plastic, usually polyvinyl butyral (PVB). The tempered glass is obtained via a heat treatment (quenching). Tempered glass is about six times more resistant than float glass. It is also considered a "safety glass" since, in addition to being strong, has a tendency to break into small less dangerous pieces. The end of life for laminated glass provides for the separation of the intermediate layer of plastic and then crushing and recycling of glass.

PMMA

The polymethyl methacrylate (abbreviated to PMMA) is a plastic material formed from polymers of methyl methacrylate. Normally it is very transparent, more than glass, to the point that it possesses characteristics similar to the optical fibre for qualities of transparency, and with the property of being more or less shatterproof, depending on its compound.

2.2 Barrier Description

The assembly of the described materials is very similar for all four noise barriers. The elements that compose the barriers, of 5m height with the highest meter being transparent and 3m of interaxis are listed below:

- a concrete foundation creates the ground anchor for the barrier, resisting wind actions;
- a HEB200 metallic profile 5300mm high post is repeated every 3m of interaxis.
- a 40mm thick base plate, four stiffeners and anchor bolts connect the post to the concrete foundation;
- a steel cladding covers the post. This element, called carter, is repeated on the highway side and on the receptors side and it is 0,8mm thick;
- eight metallic cassettes with the dimension of 3000x500mm cover 4m in elevation. The surface exposed to the highway noise is drilled and the cassette contains the sound-absorbing element. The lateral faces are sealed with polypropylene ends;
- a rock wool internal layer constitutes the sound-absorbing element;
- a metallic steel profile connects the lower cassette to the concrete foundation;
- a transparent panel with a metallic frame completes the barrier, with the dimension of 3000x1000mm.

A selection of site independent criteria has been made, resulting into the final list of criteria that was used for the sustainability assessment. The indicators, which provide the metrics or the possible ways of measuring each sustainability criteria, were determined by the QUIESST researchers/expert working group. A combination of private interviews and group meetings were conducted to discuss each criterion in turn to bring to the fore and debate potential ways of providing indicators. Existing research and available indicators was also used, where possible, and the guidelines and screening process promoted within BS ISO 21929-1 were adopted for developing indicators.

Since precise indicators are now outlined, the qualitative or quantitative nature of the criterion can be specified together with their rank, their sustainability factor, the type of criteria and the indicator used to evaluate each criterion.

2.3 Data Collection and Information Generation

Most of the information required to start the analysis was obtained from the noise barriers manufacturer: CIR Ambiente SpA, Italy. This important stakeholder was asked to provide both quantitative, objective data and qualitative judgments about the four noise barriers types compared. Another source of important information was the QUIESST partners who, because of their in-depth knowledge of the acoustic barriers market, could provide unbiased opinions to mitigate the manufacturer's assertions Oltean-Dumbrava, C., et al 2012a). The data collection for the four sustainability factors is described below.

2.3.1 Social Data Collection

A questionnaire was submitted to CIR Ambiente SpA, asking them to give a 1-10 rating score to the four noise barriers solutions being analysed, for each one of the site independent social criteria selected, where 1 reflects a very poor performance and 10 the best possible performance. The results were then discussed together with the aforementioned QUIESST partners in order to verify their reliability. Table 1 below details the score obtained by the different barrier types.

Table 1 Selected NRD solutions' social scores

Social criteria	Scores (1-10 rating) Corten +Glass	Corten +PMMA	Alum. +Glass	Alum. +PMMA
Possibility of sicknesses due to NRD type	7	7	7	7
Resistance of the materials to vandalism	7	8	6	7
Shading impacts for road users	4	4	4	4
Possibility of work related injuries due to NRD type	7	8	7	8
Architectural design of NRD type	6	6	6	6
NRD type visual impacts	6	6	6	6

2.3.2 Economic Data Collection

Economic values were mainly obtained from the questionnaire submitted to the manufacturer, but the collected information was also discussed with the QUIESST partners in order to verify their reliability and to gain a final validation. Table below details the costs necessary for the different barrier types.

Table 2 Selected NRD solutions' economic scores

Technical criteria	Indicator	Scores Corten +Glass	Corten +PMMA	Alum. +Glass	Alum. +PMMA
Ex works cost	€/m^2	120	105	125	110
Transportability cost	€/m^2	5,4	5,3	6,3	6,2
Labour cost	€/m^2	24	18	24	18
Equipment hire cost	€/m^2	8	5	8	5
In-situ civil works required by barrier type	€/m^2	30	30	30	30
Maintenance cost	€/m^{2}year	7	2,3	7	2,3
Removal/demolition cost	€/m^2	35	25	35	25

2.3.3 Technical Data Collection

Technical values were mainly obtained from the questionnaire submitted to the manufacturer but the collected information was also discussed with the QUIESST partners, in order to verify their alignment to data tabulated per NRD type and to gain a final validation. Table 4.4 below details the score obtained by the different barrier types.

Table 3 Selected NRD solutions' technical scores

Technical criteria	Indicator	Scores Corten +Glass	Corten +PMMA	Alum. +Glass	Alum. +PMMA
Glare of materials	yes/no	no	no	no	no
Use of recycled materials	% mass	10	0	30	20
Sound insulation	dB	32	30	26	26
Sound absorption	dB	15	15	15	15
Structural elements service life	years	25	25	25	25

Acoustic elements service life	years	20	20	20	20
Impact of maintenance tasks	1-10 rating	6	8	6	8
Maintenance frequency	n°/life cycle	8	3	8	3
Intrinsic buildability/constructability	m^2 built/day	105	180	105	180
Intrinsic removability at the end of life	m^2 removed /day	210	270	210	270
Ability to change existing noise barrier as required	1-10 rating	5	5	5	5

2.3.4 Environmental Data Collection

The environmental assessment of the four selected barriers was not based on questionnaires or debates, since its criteria require very precise and technical values the manufacturer is not aware of. This factor was then analysed through the use of an analytical tool which conducts an Environmental Life Cycle Analysis (E-LCA). The software utilized for this purpose is SimaPro 7.3.3 Multiuser. Once the analytical tool was chosen, the chain of materials and processes that constitute a span of 3m for each barrier was uploaded into SimaPro, divided into six main components. Applying each of the described methods to the four NRD solutions detailed earlier in this report, we obtained the following results.

Table 4 Selected NRD solutions' environmental scores

		Scores			
Environmental criteria	**Indicator**	**Corten +Glass**	**Corten +PMMA**	**Alum. +Glass**	**Alum. +PMMA**
Loss of land	m^2/m	0,55	0,55	0,55	0,55
Ecotoxicity of soil	m^3/m^2	61,5	60,9	427,9	427,3
Total waste production	kg/m^2	135,06	130,50	108,27	103,71
Hazardous waste	% mass	0,0082	0,0084	0,1170	0,1221
Radioactive waste	% mass	0,0038	0,0038	0,0067	0,0069
Waste for energy recovery	% mass	7,29	12,33	8,30	14,14
Recyclability potential	% mass	92,70	87,67	91,71	85,86
Re-use potential	% mass	24,89	21,47	14,14	9,85
Global warming potential	$kgCO_{2eq}/m^2$	226,0	245,7	263,69	283,43
Global warming potential	$kgCO_{2eq}/$ Tkm	0,68	0,67	0,78	0,77
Acidification potential	$kgSO_{2eq}/m^2$	0,79	0,87	1,05	1,12
Dust and particulate matter	kg/m^2	0,79	0,79	0,69	0,69
Materials that trap or deflect pollution	yes/no	no	no	no	no
Ozone layer destruction	$kgCFC\text{-}R11_{eq}/m^2$	1,07E-05	9,66E-06	1,41E-05	1,33E-05
Embodied water content	l/m^2	5057	5271	5879	6093
Ecotoxicity for water	m^3/m^2	19756	19896	38515	38655
Use of primary energy resources for transport	MJ/Tkm	11,20	11,03	12,94	12,77
Use of primary energy resources	MJ/m^2	2937	3320	3382	3765
Renewable energy production	MJ/m^2	0	0	0	0

3. MCDM TOOL SELECTION

A decision maker (DM) assessing the sustainability of a project will often deal with multiple, usually conflicting, criteria (Elghali L.et al, 2008; Hwang, C.L., et al 1981; Janic, M., et al 2002). Munda (2004) postulates that it is impossible to optimise all the objectives of sustainability simultaneously due to their many overlapping dimensions. The WP6 research team has purposefully selected using a multi-criteria analysis (MCA) approach to primarily assessing the sustainability of NRDs over adopting the 'rating concept' utilised by other discrete sustainability assessment methods and tools (e.g. CEEQUAL, BREEAM, LEED).

The MCA approach begins with defining the overall decision goal, i.e. 'sustainability assessment' and the definition of criteria which best represents achieving the decision goal. A multi criteria decision making (MCDM) tool has been then selected to assess the multiple sustainability criteria in relation to one another in an equitable way.

There are many potential MCDM tools and methods that could be used by the DM. Typically, this can be summarised as the compensatory vs. non-compensatory debate/approach to assessing multiple selected criteria (Oltean-Dumbrava C. et al, 2011 and 2012b).

The Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) was selected among a list of available and reliable MCDA methods (Mareschal, B., 2013). The PROMETHEE and Gaia method helps decision makers find the alternative that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, identifying and quantifying its conflicts and synergies and highlights the main alternatives and the structured reasoning behind.

A PROMETHEE analysis operates through pair-wise comparisons of alternatives to establish a rank order. Alternatives are evaluated according to the selected set of criteria, which have to be maximized or minimized.

3.1 PROMETHEE Rankings

The PROMETHEE I Partial Ranking is based on the computation of two preference flows:

Phi+ (positive or leaving flow) is a measure of strength;

Phi- (negative or entering flow) is a measure of weakness.

Both Phi+ and Phi- can be used to rank the actions. However they do not always provide the same ranking, because of the conflicting aspect of a multi-criteria problem. PROMETHEE I evaluates the two rankings induced by Phi+ and Phi- and only includes the preferences that are confirmed by both rankings. Incomparability is interesting because it emphasizes actions that are difficult to compare and thus helps the decision-maker to focus on these difficult cases (Mareschal B., 2013).

The PROMETHEE II Complete Ranking, instead, is based on the net preference flow (Phi), less informative, but more immediate to understand than the Partial Ranking.

3.2 PROMETHEE Diamond

The PROMETHEE Diamond is an alternative two-dimensional joint representation of both PROMETHEE I and II rankings and has been used in this analysis. The square corresponds to the (Phi+, Phi-) plane where each action is represented by a point. The plane is angled 45° so that the vertical dimension gives the Phi net flow.

A 45° cone is drawn for each action. The tip of the cone corresponds to the action preference flows values. When one cone is on top of another one, that action is preferred to the other one in the PROMETHEE I partial ranking. When two cones overlap, the corresponding actions are incomparable in PROMETHEE I. The vertical positions of the tips of the cones with respect to the diagram running up the middle of graph gives the PROMETHEE II complete ranking/Phi net flow.

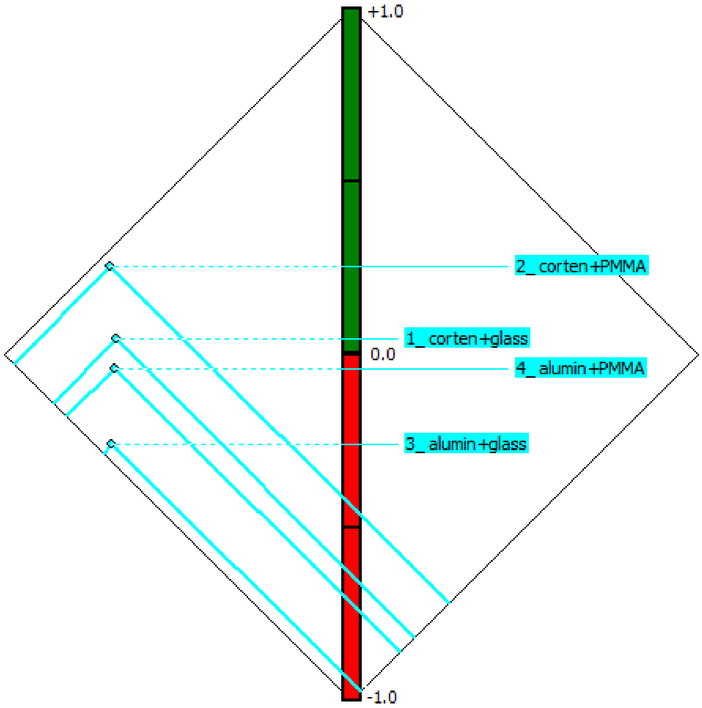

Figure 1 PROMETHEE Diamond

Figure 1 shows that the CORTEN STEEL and PMMA noise barrier is relatively the most sustainable solution and should be the client's preferred option. Since the cones of the projected lines formed within the PROMETHEE Diamond diagram do not overlap, the required comparability between solutions/options does exist and a clear sustainability ranking between the four noise barriers has been obtained. The ranking from the relatively most sustainable solution to the least sustainable solution is:

- CORTEN STEEL and PMMA
- CORTEN STEEL and GLASS
- ALUMINIUM and PMMA
- ALUMINIUM and GLASS

4. CONCLUSIONS

The sustainability assessment carried out in the present work, clearly detailed the highlights of the methodology developed within the QUIESST project and emphasises even more its validity as a sustainability assessment method. Applying this method to the four selected barriers demonstrated that solution 2, with corten steel and the transparent panels in polymethyl methacrilate is the most sustainable one. The reasons are that it performs the best in the technical, social and economic behaviour of PMMA compared to glass and in the best environmental behaviour of corten steel compared to aluminium. The result provided by PROMETHEE Diamond, the selected MCDM tool, is consistent with this rationale and the Sensitivity Analysis performed (not presented in this paper) confirmed its reliability and provides a useful example for end users to conduct their own sustainability assessments. In the future this method could become a universal approach to assessing the sustainability of NRDs projects with the view to complying with and supporting the transport and overall global sustainability agenda.

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6. REFERENCES

1. Elghali, L., Clift, R., Begg, K.G., & McLaren, S. (2008). Decision Support methodology for Complex Contexts. Institution of Civil Engineers.161. pp, 7-22.
2. Hwang, C.L., & Yoon, K. (1981). Multiple Attribute Decision Making: Methods and Applications. Berlin/Heidelberg/New York: Springer – Verlag.
3. Janic, M. & Reggiani, A. (2002). An Application of the Multiple Criteria Decision Making (MCDM) Analysis to the Selection of a New Hub Airport. EJTIR, 2, no. 2, pp. 113 – 145.
4. Mareschal, B. (2013). Visual PROMETHEE 1.4 Manual [PDF]. VPSolutions. Available at: www.promethee-gaia.net.
5. Munda, G. (2004) Social Multi – Criteria Evaluation (SMCE): Methodological Foundations and Operational Consequences. European Journal of Operational Research.
6. Oltean-Dumbrava C., Miah, A., Watts, G., Brero, G., Clairbois, J-P., Padmos, C., Auerbach, M., Hans, J., and Schiopa. (2010a). State of the art review and report on the sustainability of noise reducing devices. QUIESST Project. European Community's Seventh Framework Programme (FP7/2007-2013).
7. Oltean-Dumbrava, C., Miah, A., Watts, G., Brero, G., Clairbois, J-P., Padmos, C., Auerbach, M., Hans, J., and Schiopa. (2010b). Relevant Generic Sustainability Criteria and Indicators for NRDs. QUIESST Project. European Community's Seventh Framework Programme (FP7/2007-2013).
8. Oltean-Dumbrava. C., Miah, A., Watts, G., Brero, G., Padmos, C., Chuddalla, M., Grannec, F. (2011). Relevant methods for assessing the overall sustainability of NRDs. QUIESST Project. European Community's Seventh Framework Programme (FP7/2007-2013).
9. Oltean-Dumbrava. C., Miah, A., Watts, G., Brero, G., Padmos, C., Chuddalla, M., Grannec, F. (2012b). Evaluation of methods for assessing overall sustainability using two noise barrier case studies. European Community's Seventh Framework Programme (FP7/2007-2013).
10. Oltean-Dumbrava.C., Miah, A., Watts, G., Brero, G., Padmos, C., Chuddalla, M., Grannec, F. (2012a). Data Collection and Information Generation for the Measurement of the Sustainability Generic Relevant Criteria and Indicators for Existing NRDs. QUIESST Project. European Community's Seventh Framework Programme (FP7/2007-2013).