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Work Package 2

Reference Model

Task 2.4
Choice of basic sound propagation models

Deliverable 14 of the Harmonoise project

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Contents

1 Introduction

The objective of Work Package 2 (WP2) of Harmonoise is to develop an accurate reference model for the calculation of environmental noise from roads and railways. The development of the reference model consists of the following tasks:

- definition of the physical problem (task 2.1)
- overview of the state of the art in sound propagation modeling (task 2.2)
- benchmark tests with state-of-the-art sound propagation models (task 2.3)
- selection of most useful sound propagation models for the reference model (task 2.4)
- combination of these models into the reference model (task 2.5 and 2.6)
- testing and validation of the reference model (task 2.7 and 2.8)
- final implementation of the reference model (task 2.9).

The first three tasks have already been executed and reported ([1][2][3]). A short description of these tasks is given in chapter 2 and the main results are summarized in chapter 3.

The results of these previous tasks are used for the selection of the basic sound propagation models for the reference model (task 2.4) in chapter 4.

The selection of the basic models has implications for the structure of the reference model and for the situations that the reference model will be able to handle. The basic steps of a calculation with the reference model are described in chapter 5 and the set of situations that the reference will be applicable to is defined in chapter 6.

2 Description of previous tasks

Three tasks have been carried out as a preparation for the development of the reference model. These tasks are described below.

Task 2.1: Definition of physical problem

In this task, the physical problem to be solved in WP2 is described in general terms. It is meant as a basis for the work to be done in WP2. The structure of the Harmonoise project and various aspects of the reference model to be developed in WP2 are presented.

Task 2.2: State of the art of modeling

An overview of the state of the art in sound propagation modeling is given. Various propagation models are described that are used by the WP2 partners and/or are known from scientific literature:

- Linearized Eulerian model (EULER),
- Boundary Element Method (BEM),
- Meteo-BEM (METBEM),
- Parabolic Equation method (PE),
- Generalized Terrain Parabolic Equation method (GTPE),
- Fast Field Program (FFP),
- Straight-ray model for a non-refracting atmosphere (SRAY),
- Gaussian beams method,
- curved-ray model for a refracting atmosphere, using a linearized sound-speed profile (CRAYL), and
- various statistical scattering models (STAT).

Furthermore, three general modeling aspects that are relevant for sound propagation modeling are described: meteorology, impedance models, and Fresnel zone interpolation.

Task 2.3: Benchmark cases and modeling approximations

Benchmark calculations are performed with the propagation models described in task 2.2. The benchmark tests consist of the following elements:

- three source heights (0.05 m, 0.5 m, and 5 m),
- three horizontal source-receiver distances (20, 200, and 2000 m),
- four types of surfaces (rigid, grassland, porous asphalt, and porous concrete),
- transitions from one type of ground surface to another,
- eight different atmospheric conditions (including range-dependent sound-speed profiles and turbulence),
- four barrier types (rectangular barrier, trapezium, T-shaped barrier, and tilted barrier),
- four terrain profiles (ridge, trench, elevated road, and depressed road), and
- a forest or a city.

In addition, various modeling approximations are tested to investigate if they are useful for the reference model:

- coupling of models,
- two-dimensional approximation for oblique propagation over a barrier, and
- Fresnel-zone interpolation for heterogeneous ground.

3 Results of previous tasks

The results of tasks 2.1, 2.2, and 2.3 have been recorded in three technical reports [1][2][3]. In this paragraph the main results are summarized.

Task 2.1: Definition of physical problem

The structure of the Harmonoise project is shown in Fig. 1. The reference model to be developed in WP2 will compute the noise indicators L_{den} and L_{night} in a two-step approach:

Short-term noise levels are calculated by combining source spectra with propagation attenuation spectra.

Combination of the short-term noise levels with meteorological statistics yields the levels L_{den} and L_{night}. The meteorological statistics consists of statistical weights of a limited set of meteorological conditions.

For the calculation of the short-term noise level from a stream of cars or trains along a road, the concept of an incoherent line source will be used in the reference model. The incoherent line source will be approximated by a finite number of incoherent point sources on the line. Therefore, the calculations in the reference model will consist basically of a set of calculations of sound propagation from a point source to a receiver.

WP1 will deliver source descriptions in terms of point sources. Each point source will be specified by the height of the point source and by a 1/3-octave band sound power spectrum, which is a function of the speed of the vehicle and possibly a function of emission direction.

WP3 will develop an engineering model. The accuracy of the output of the engineering model will be evaluated by comparison with the output of the WP2 reference model.

In WP4 measurements will be performed that will be used for validation of the results from WP1, WP2, and WP3.

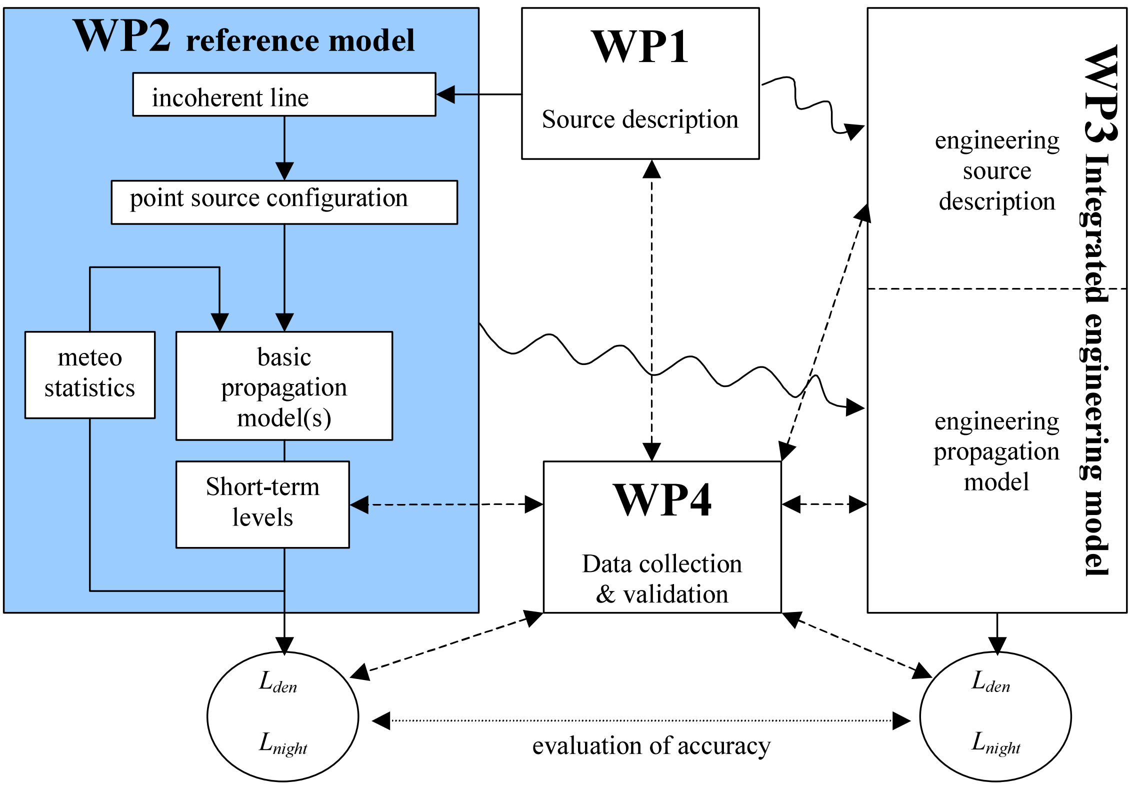

Fig. 1. Structure of the Harmonoise project.

Tasks 2.2 and 2.3: State of the art of modeling & Benchmark cases and modeling approximations

The state-of-the-art sound propagation models are evaluated on three items: accuracy, applicability, and computational effort (see Table 1). Accuracy is based on deviation from the 'true' solution. Applicability refers to limitations of the set of situations the model can be applied to. Computational effort refers to computing times and memory.

Table 1: Appreciation of the sound propagation models.

model	accurate in …	applicability	computational effort
EULER	most cases	no limitations, except for an approximate representation of ground impedance	very large
BEM	most cases	limited to a nonrefracting atmosphere	large
METBEM	many cases	(presently) limited to linear sound speed profiles	large
PE	most cases	limited to axisymmetric cases, maximum propagation angles between 35 and 70 degrees, forward propagation, rectangular obstacles, and a flat ground	large
GTPE	most cases	see PE, but applicable to arbitrary terrain profiles with a maximum local slope of 30 degrees	large
FFP	many cases	limited to axisymmetric cases, a layered atmosphere, no obstacles, and a flat homogeneous ground	large
SRAY	many cases	limited to a nonrefracting atmosphere, dimensions of obstacles and distances to diffraction edges that are large compared to wavelength, and obstacles that consist of flat surfaces	small
CRAYL	some cases	see SRAY, but not limited to a nonrefracting atmosphere	small
STAT	indeterminable	limited to a nonrefracting atmosphere and randomly distributed scattering objects that are small compared to wavelength	small

Results of the tests of the modeling approximations show that:

- Hybrid models (SRAY+PE and BEM+PE) are accurate in cases investigated. A disadvantage is that refraction in the source region is neglected.
- The accuracy of the two-dimensional approximation for oblique propagation over a screen varies with the angle between the source-receiver line and the normal to the screen. For most traffic noise cases, integration over the angle results in an error les than 1 dB.
- The Fresnel zone interpolation is accurate in some of the cases investigated, but inaccurate in other cases.

4 Selection of basic propagation models

The results of the previous tasks are used for the selection of basic sound propagation models for the reference model (task 2.4). The basic propagation models that provided accurate results in most benchmark cases are EULER, BEM, and the PE methods (PE and GTPE). Of these basic models, only the EULER and PE methods can handle situations with realistic meteorological conditions. The use of the EULER model in the reference model is (presently) too ambitious, i.e., demanding too much computational effort. This also holds for the use of the PE method for three-dimensional calculations. Therefore, **the two-dimensional PE method will be used as the basis for the reference model, and sound propagation will be calculated in the propagation plane**, i.e., the vertical plane through each point source and the receiver (or image source and/or image receiver).

In situations in which the PE method cannot be applied and in which refraction may be neglected, SRAY or BEM will be used. In principle, BEM could be used in all of these situations, because the applicability of BEM is larger than the applicability of SRAY. However, because of its smaller computational effort, SRAY will be used instead of BEM in situations where SRAY is applicable and accurate.

Scattering models for forests and cities will be excluded from the reference model, because of their indeterminable accuracy. In the future, three-dimensional EULER may be used as a reference model for propagation in the complex geometries of forests and cities. The applicability of three-dimensional EULER has been shown in a demonstration [4], but presently three-dimensional EULER demands too much computational effort to perform calculations for the propagation distances that the reference model should be able to handle.

Thus, the reference model will be a combination of the following basic propagation models:

- Parabolic Equation methods (**PE** or **GTPE**)
- Straight ray model (**SRAY**)
- Boundary Element Method (**BEM**)

For traffic noise situations, it is natural to divide the geometry in the propagation plane into two regions:

- a source region, and
- the region outside the source region.

The source region roughly encompasses the (rail)road, possible noise barriers and descending or ascending slopes (steeper than 30 degrees) at the sides of the (rail)road.

<u>Source region</u>

Depending on the geometry, we will use **PE, SRAY** or **BEM** in the source region. PE can handle situations with realistic meteorological conditions, but cannot handle large elevation angles and complex geometries. In cases with a large elevation angle, SRAY or BEM will be used. SRAY and BEM can deal with more complex geometries than PE, but assume a non-refracting atmosphere. Therefore, it is not possible to deal with a realistic atmosphere and a complex geometry simultaneously. An approximation has to be made: either the atmosphere in the source region is approximated by a non-refracting atmosphere, or the complex geometry is approximated by a more simple geometry with a flat ground and possibly a straight noise barrier. Which approximation is the best choice, depends on the geometry.

<u>Region outside the source region</u>

For flat ground, **PE** will be used. For non-flat terrain, the generalized-terrain PE method (**GTPE**) will be used.

When SRAY or BEM is used in the source region, it will be coupled to the PE method in the region outside the source region. Thus, hybrid models (SRAY+PE or BEM+PE) will be used in the reference model.

5 Basic steps of a calculation with the reference model

In this section, the basic steps of a calculation with the reference model are described. The approach is based on the fact that the two-dimensional (or axisymmetric) PE method will be used as a basis for the reference model.

Step 1. Approximation of the traffic flow by a number of incoherent point sources.

Step 2. For each point source, the *propagation planes* are selected.

Case a) No reflections from vertical surfaces.

In this case there is only one propagation plane for each point source: the vertical plane through the point source and the receiver (see Figs. 2 and 3).

Case b) Reflections from vertical surfaces (buildings, screens).

In this case there are several propagation planes. In some cases, the number of propagation planes is infinite (see for example Fig. 4 in which two of these propagation planes are shown). In these cases, a practical choice is required for the number of propagation planes that are included (this number depends on the situation).

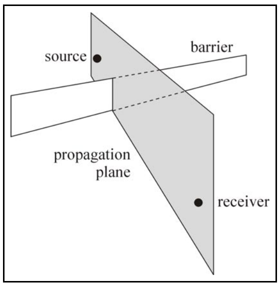

Fig. 2. Propagation plane.

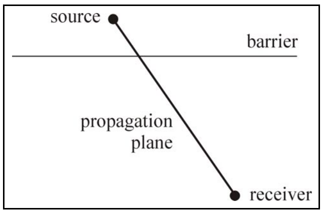

Fig. 3. Top view of Fig. 1.

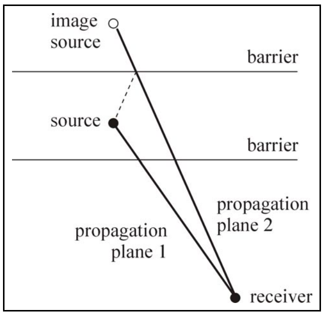

Fig. 4. Top view with two propagation planes.

Step 3. For each propagation plane, sound propagation *in* the propagation plane is calculated.

Case a) 'PE case'

A PE model is used for the calculation of sound propagation in the propagation plane.

Note. Reflection in the upper barrier in Fig. 4. can be calculated with PE using a complementary Kirchhoff approximation.

Case b) 'Hybrid-model case'

An SRAY or BEM model is used to generate a transition vector of complex pressure values in the propagation plane, and a PE model is used for further propagation in the propagation plane.

Note. If a three-dimensional ray model is used, sound rays are not completely confined to the propagation plane (diffraction rays follow from Keller's law).

Step 4. For each propagation plane, sound propagation along paths *outside* the propagation plane is calculated.

If the propagation plane crosses a finite obstacle, *e.g.* a building, sound diffraction along the (vertical) edges of the obstacle outside the propagation plane is calculated. The results may be used as a correction[*)] to the results from the previous step.

If there is an obstacle just outside the propagation plane, it may be necessary to perform a correction to the result calculated in the propagation plane (a Fresnel zone approach may be useful here).

Step 5. Summation of results.

The results from steps 3 and 4 are summed over all propagation planes (possibly taking into account a coherence loss between propagation planes).

*) Diffraction around an obstacle will either be included by an approximate approach or will be neglected.

If the obstacle only partly screens the traffic road (see Fig. 5), sound at the receiver is dominated by the unscreened sources on the road; in these cases, diffracted sound from the vertical edges of the building may be neglected. If the obstacle screens the traffic road completely, diffracted sound from the vertical edges may be included as a correction to sound that travels within the propagation plane (*i.e.* sound diffracted from the top of the building).

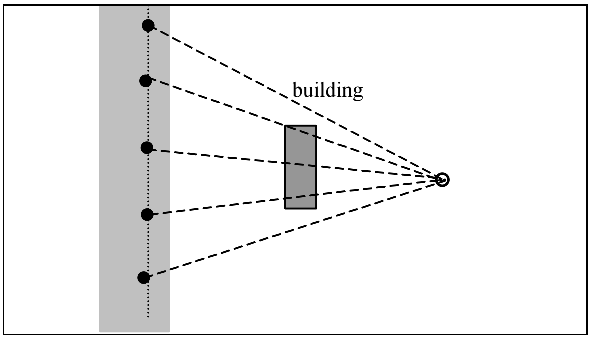

Fig. 5. Top view of an example of a situation in which diffraction around an object may be neglected.

6 Definition of situations

The reference model as it is described in chapters 4 and 5 will be applicable to a limited set of situations. This set of situations is defined in this section. The propagation planes play an essential role in the reference model. Therefore the geometry in the propagation plane is used for the definition of the set of situations that the reference model can handle.

6.1 Elements in the propagation plane

Elements of the geometry in the propagation plane are:

- source
- receiver
- atmosphere.
- ground surface
- barriers and obstacles

<u>Source and receiver</u>

The traffic flow is represented by a number of incoherent point sources. The traffic flow may be along a more or less arbitrarily curved path.

Source and receiver heights are between zero and 50 m (see report task 2.1).

Point source – receiver distances are between 5 m and 10 km (see report task 2.1).

(line source – receiver distances are between 5 m and 2 km).

<u>Atmosphere</u>

The wind and temperature profiles depend on the ground surface and the barriers.

DLR will propose a CFD method to be used in the reference model for situations in which the range dependence of the meteorological profiles needs to be taken into account.

<u>Ground surface</u>

The ground surface is characterized by the ground impedance and the terrain profile.

The ground impedance may vary (discontinuously) with position.

The terrain profile is restricted to arbitrary profiles*) with a maximum local slope of 30°.

*) current GTPE code is limited to circle segments.

<u>Barriers and obstacles</u>

The surface of a barrier or obstacle is characterized by the impedance. Figure 6 presents examples of barrier shapes (in the propagation plane).

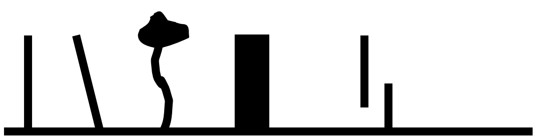

Fig. 6. Examples of barrier shapes.

6.2 Possible geometries in the propagation plane

Source region

The source region roughly encompasses the (rail)road, possible noise barriers and descending or ascending slopes (steeper than 30 degrees) at the sides of the (rail)road. The ground surface of the (rail)road is flat. There may be zero, one, or two barriers in the source region (including earth berms with slopes steeper than 30 degrees). The barriers may have an arbitrary shape. In section 6.1, examples of barrier shapes are given. Figure 7 presents examples of source region geometries.

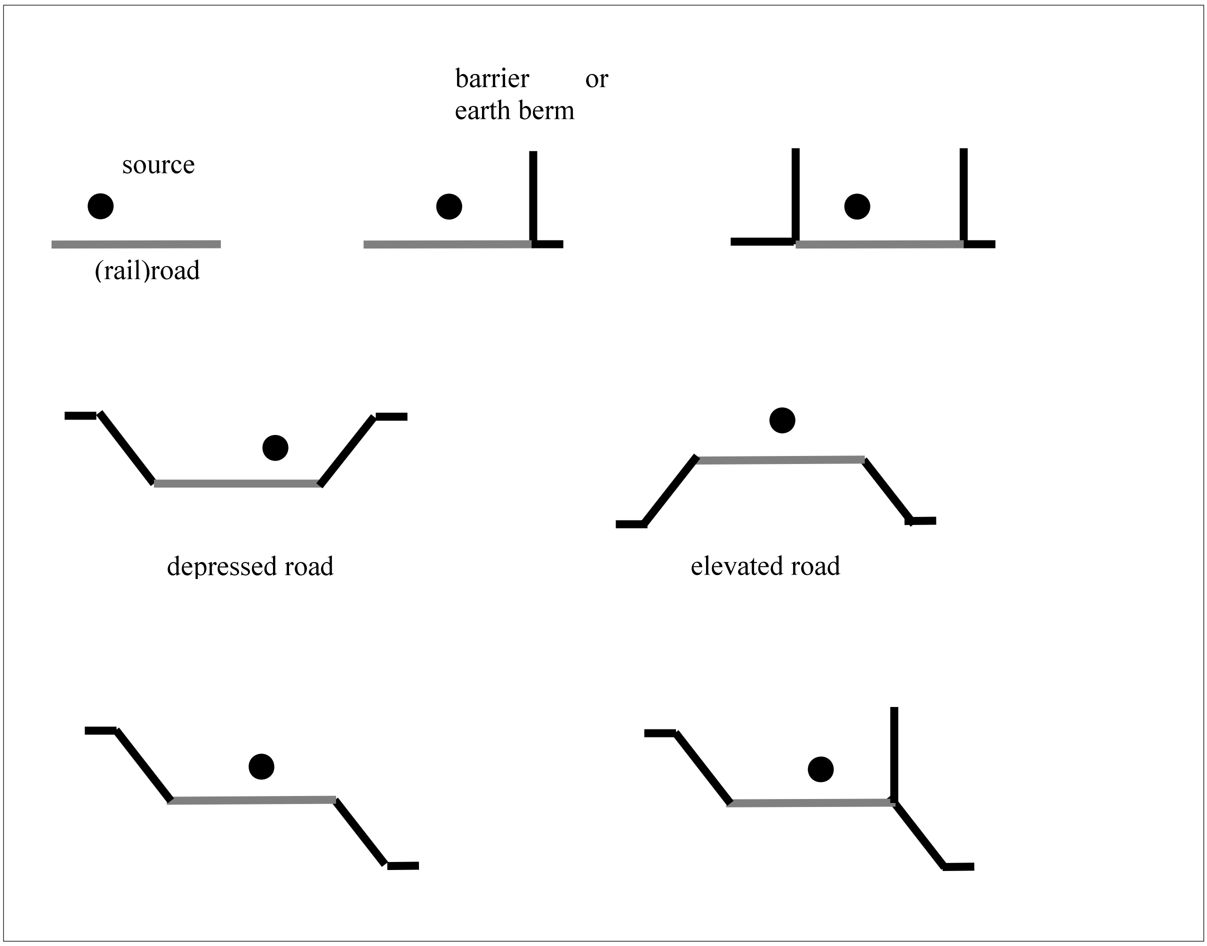

Fig. 7. Examples of geometries in the source region.

Region outside the source region

The region outside the source region may have:

- zero or one barrier or obstacle

- a terrain profile with a maximum local slope of 30 degrees.

(so smooth hills or berms can be modeled as part of the terrain profile).

The shape of the barrier or obstacle has to be rectangular, or such that it can be modeled by a rectangle. The barrier or obstacle has to be acoustically hard and flat.

The angular limitation of PE (PE is accurate only for elevation angles less than typically 45 degrees) puts restrictions on receiver positions behind obstacles.

6.3 Examples

Figure 8 gives some examples of situations that the reference model will be able to handle using the approach described in the previous sections.

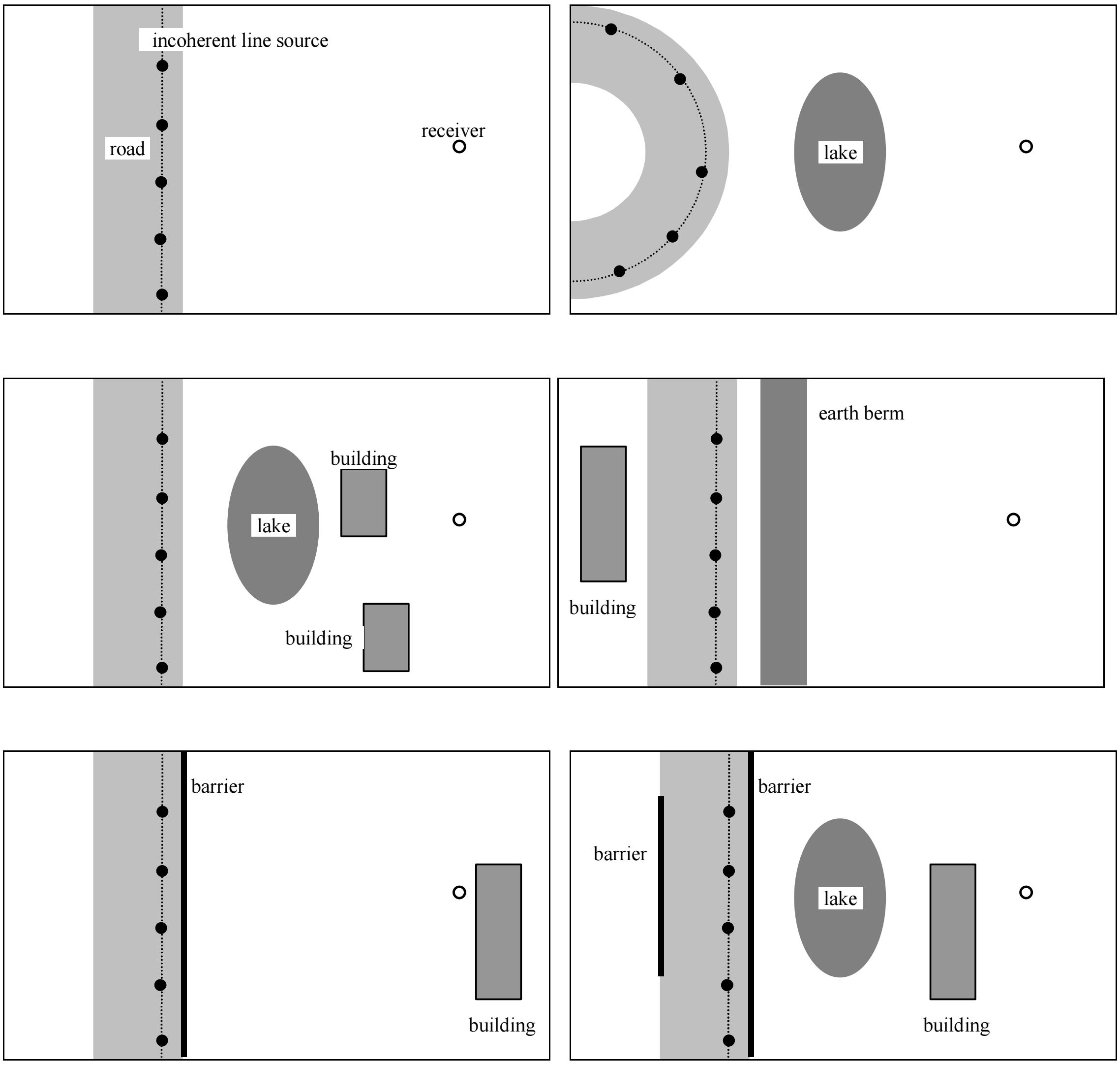

Fig. 8. Top view of examples of situations that the reference model will be able to handle.

7 References

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[2] WP2 team, “Task 2.2. State of the art of modeling,” HAR22-TR020220-TNO10, October 2002.

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[4] D. Heimann, “Propagation through a strip of trees – LE model simulations,” HAR23-MO021002-DLR02, October 2002.