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EVALUATION OF TRAVEL COMFORT OF PASSENGERS – RELATIONSHIP BETWEEN VEHICLE AND ENVIRONMENT

Lukáš MÁLEK[1]

Abstract

The aim of this paper is to present in more detail a part of the passengers' travel comfort evaluation method in a rolling stocks design. This paper deals only with an interaction between a VEHICLE and an ENVIRONMENT. Introduced part of the method is focused on a mathematical model design of acting environmental factors on the vehicle and their random behaviour. The selected environmental factors are noise, vibrations, light and heat. Definition of sources of the selected factors are designed, their manners of a propagation in a surrounding (energetic path tracing) and statistical complex evaluation of final intensity of the selected factors in a random critical point of the vehicle interior as well. The mathematical model design is a simulation of the vehicles interior, which is possible to parametrically impact by geometrical and material indexes of the vehicle design.

Keywords

passengers, travel comfort, design, interaction, mathematical model, noise, vibrations, light, heat, random behaviour, complex evaluation, intensity, vehicles interior, simulation, geometrical and material indexes

1 INTRODUCTION

The introduction of this paper is a reaction on the sustainable mobility topic in railway transportation. A service life of a rolling stock is designed on a base of a definition its service, usually it is cca from 30 till 40 years. During this time, a vehicle has to be sustainable and reliable and has to meet the needs of an operator and an end customer, alias passenger. By renovation and reconstruction, use of the old vehicle is possible to prolong its service life according to constructions´ options of the vehicle, valid regulations and needs of an operator.

Sustainable mobility is settled not only from an economic-political aspects and charges of traction energy. A huge part also is an attractive and effective mobility. On the one side a development of the vehicle is bound up with the specification of technical interoperability (TSI), whose aims are:

- safety,
- reliability,
- health protection,
- protection of mother nature and
- technical compability.

On the second side is required to regard with the sustainable mobility also from travel comfort point of view, because it is not defined in TSI. Is important to motivation of the end customers, passengers, to the utilization of public transport and by this fulfill the sense of the sustainable

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[1] **Ing. Lukáš Málek**, Czech Technical University, Department of automotive, combustion engine and railway engineering, Technická 4, 166 07 Praha 6. Tel.: +420 739 028 463, e-mail: selfeater.malis@seznam.cz

mobility. This is the possible way how to achieve energy savings and to reduce global and local exhalations in our surrounding as well.

The vehicle, which fulfills TSI, doesn´t need to be explicitly comfortable and a travel culture doesn´t need to be attractive. In order to be the vehicle correctly and appropriately designed is required to have a strategy in a system integration of components and to think of needs of a future transport, because this is socially necessary and useful.

From the end customer point of view are engended different groups of passengers by owing to offers of hi-speed, commuter, light and urban transport. These target audiences are variously exposed to travel process with culturally-traditional subtext[2].

From the vehicle design point of view there is a portfolio of offered products - rolling stocks. These products are mostly developed on a basis of platforms that are adapted according to individual needs of operators. Methods used for the vehicle development are grounded on available standards, TSI and UIC, legislations and customer requirements.

This study frame takes in a tracing of the base four factors that define a travel comfort quality and methods used for comfort evaluation of passengers in order to the vehicle design. The factors:

- noise,
- vibrations and accelerations,
- illumination and
- heat

are evaluated by specific methods from point of view of:

- audiometry,
- accelerometry,
- photometry and
- thermometry.

General design of mathematical model is constructed of four base parts:

- collectivization of information and integration of input parameters [5],
- simulation of the vehicle interior,
- comfort evaluation of the vehicle interior and
- setting of system reliability.

Completely the model is calculated by input parameters:

- the vehicle design parameters (material indexes, geometric indexes),
- the environment paramters (climatic indexes, ride indexes, information indexes) and
- the human parameters (ergonomic indexes, hygienic indexes).

The aim of this paper is a design of a principal of the part of mathematical model - simulation of the vehicle interior.

Behaviour of the traced factors in critical point is evaluated on energetic level, because the energy is their common denominator. Intensity and form of the energy are evaluated between their sources and critical point -> observer. Necessary element is an exposition of the energy. A time variable is a dimension of continuum and is required for dynamic analyses.

2 PHILOSOPHICAL DESCRIPTION OF PROBLEM

From the macroscopic point of view is a main idea based on a system balance between a human, a vehicle and an environment [1]. Geometrically is possible to present the system balance on the figure below. Well known variables are the subsystems itself:

- the environment ***E***,
- the vehicle ***V*** and

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[2] Culturally-traditional subtext means national diversity of population, urbanism, folclor, ecology, hygiene etc.

- the human ***H***.

Unknown variables of the system balance are penetrations between the subsystems:

- between the environment and the vehicle ***E-V***,
- between the vehicle and the human ***V-H***,
- between the human and the environment ***H-E*** and
- between the environment, the vehicle and the human ***P = E-V-H***.

Relationships of the penetrations of two adjacent subsystems are independent variables; the penetration of all three subsystems is dependent variable.

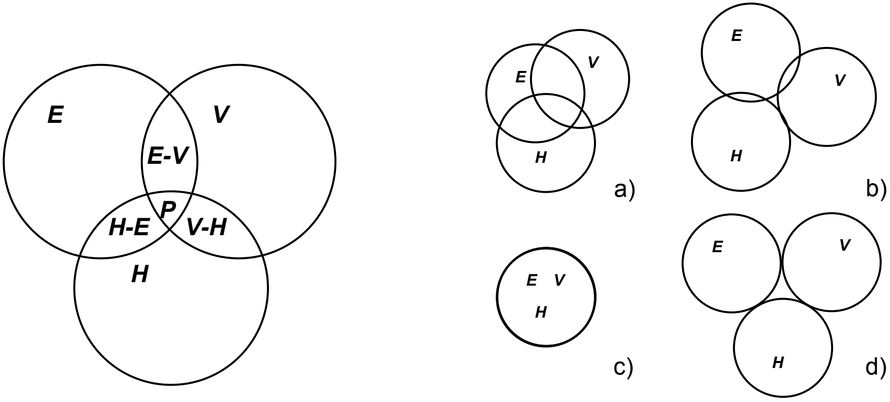

Fig. 2 System balance

E....................... Environment subsystem
V....................... Vehicle subsystem
H....................... Human subsystem
E-V, V-H, H-E.... Subsystem penetration
P = E-V-H.......... System penetration

As is shown on the figure above, is possible to predict examples of typical configurations of the system balance:

a) system compatibility is dominant from the environment point of view,
b) system compatibility is dominant from the environment point of view and the compatibility between the human and the vehicle is zero,
c) system stability and
d) system instability.

Relationship ***E-V*** expresses an interaction between the vehicle and the environment, where is the train operated. The interior environment is affected by the vehicle design itself.

The vehicle design is in the mathematical model presented like a boundary area between exterior and interior environment and is paramterized by own material and geometric indexes.

The reliability of the vehicle subsystem is given by relationship between the suitable critical components and the all layout components. That means the relationship between the suitable geometric/material paramaters of the vehicle and complete vehicle parameters package.

$$R_V = \frac{suitable\ critical\ components}{all\ layout\ critical\ components} \leq 1 \qquad (1)$$

Similar situation is for reliability of the environment subsystem. The relationship between suitable parameters and all layout environmental parameters leads to percentage of success - reliability of the environment.

$$R_E = \frac{suitable\ environmental\ parameters}{all\ layout\ environmental\ parameters} \leq 1 \tag{2}$$

Known reliability of the vehicle and the environment is a good step to calculate the reliability of interaction of both subsystems, as is shown on the figure below and formula (3).

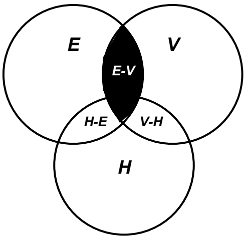

Fig. 3 Interaction between environment subsystem and vehicle subsystem

$$R_{E-V} = R_E \cdot R_V \leq 1 \tag{3}$$

How is possible to identify suitable parameters? For that is required to create a mathematical model of continuum, what describes the energy behaviour of traced factors. The behaviour of these factors is controled by the environmental and the vehicle parameters and affects the energy intensity and form from its source to the end point – observer.

3 DESIGN OF SYSTEM SIMULATION

By simulation of the interior vehicle environment is possible to achieve the relationship ***E-V*** according to relevant traced factors. Because the simulation is based on energetic description of these factors and approximates to their real behaviours is required to define:

- necessary conditions (energy conservation law),
- initial conditions (sources and environment) and
- boundary conditions (vehicle design).

3.1 Energy conservation law condition

By usage of 3D CAD systems is possible to simulate approximately the real 3D space. This space is defined by formula (4).

$$\Omega \subset \mathbb{R}^3 \tag{4}$$

By this way is possible to percept the vehicle subsystem ***V*** like geometry of boundary area ***dΩ*** of two different enviroments ($\boldsymbol{\Omega} = \boldsymbol{\Omega_e} + \boldsymbol{\Omega_i}$). The design of mathematical model of the interior vehicle description is based on the energy balance and complies with energy conservation law [2].

Stationary description of both environments in random place of the vehicle $\boldsymbol{X_e}$ and $\boldsymbol{X_i}$ and in time ***t*** is defined

$$u_e = u(\boldsymbol{X_e}, t),\ \ \boldsymbol{X_e} \in \Omega_{\mathrm{e}}, t \in \langle 0, T) \subset \langle 0, +\infty), \tag{5}$$

$$u_i = u(\boldsymbol{X_i}, t),\ \ \boldsymbol{X_i} \in \Omega_{\mathrm{i}}, t \in \langle 0, T) \subset \langle 0, +\infty). \tag{6}$$

Transfer of mechanical energy and radiation energy in the macroscopic scale is evaluated like a waving and is possible to consider in both cases general vector functions of the energy flow

$$\phi_{energy} = \phi(\boldsymbol{X}, t), \quad \boldsymbol{X} \in \Omega, t \in \langle 0, T) \subset \langle 0, +\infty). \tag{7}$$

Distribution density of sources in random place of vehicle ***X*** and time ***t*** is expressed

$$f_{sources} = f(\boldsymbol{X}, t), \quad \boldsymbol{X} \in \Omega, t \in \langle 0, T) \subset \langle 0, +\infty). \tag{8}$$

Construction of vehicle inclose the interior balance subarea

$$U(\Omega_i, t) = \int_{\Omega_{vehicle}} u_i(\boldsymbol{X_i}, t) d\boldsymbol{X_i}. \tag{9}$$

Energy flow transmitted in normal vector direction of vehicle boundary area is represented like surface integral of flow function

$$\phi_{energy}(\partial\Omega_i, t) = \int_{\partial\Omega_i} \phi(\boldsymbol{X}, t) \cdot \boldsymbol{n}(\boldsymbol{X}) dS. \tag{10}$$

For dynamic description is possible to express the evolution conservation law by step by step formatting in local differential form

$$\frac{\partial}{\partial t} u_i(\boldsymbol{X_i}, t) + \mathrm{div}\phi_{energy}(\boldsymbol{X_i}, t) = f_{sources}(\boldsymbol{X_i}, t). \tag{11}$$

Important is, that sources distribution function can be affected by interior and exterior stat of the vehicle

$$f_{sources} = f\big(\boldsymbol{X}, t, u_i(\boldsymbol{X_i}, t), u_e(\boldsymbol{X_e}, t)\big), \quad \boldsymbol{X}, \boldsymbol{X_i}, \boldsymbol{X_e} \in \Omega, \qquad t \in \langle 0, T) \subset \langle 0, +\infty). \tag{12}$$

3.2 Description of traced factors sources

Sources of energetic traced factors are defined into three groups:

- ambient sources,
- diffused sources and
- sharp sources.

Ambient sources are flat character, where a direction of emitted intensity is sagittal to plane element, for example: heat sources.

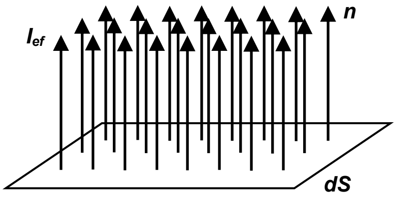

Fig. 3 Ambient source

Diffuse sources are point character, where a direction of emitted intensity is given by vector of emission and its space angle, for example: sound sources.

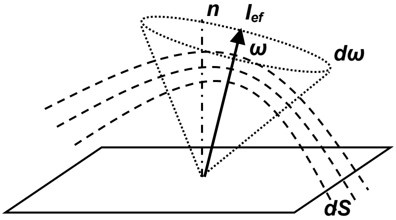

Fig. 4 Difuse source

Sharp sources are point character, where a direction of emitted intensity is given only by vector of emission, for example: light spot sources.

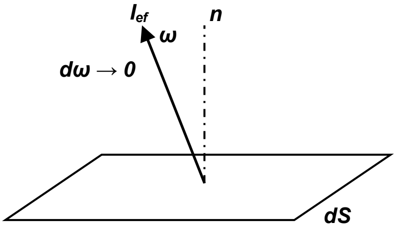

Fig. 5 Sharp source

The source description is one of the ***E*** and ***V*** subsystem parameter, because it has an influence on the energy propagation.

3.3 Description of energy behaviour in space

Energy powers related to the plane element are traced intensities on the boundary area of different environment. The energy expanding in the space has never expire, only can be reflected, absorbed, transformed or transmitted (emitted). These processes are called energy losses or gains.

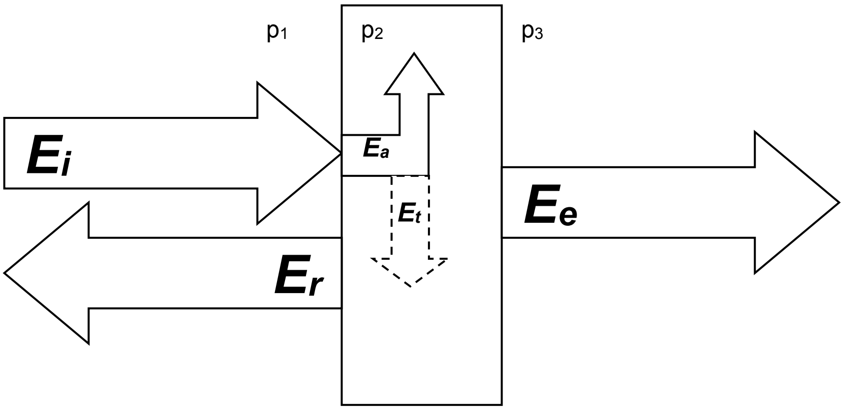

Fig. 6 Energy behaviour in space (schema)

E_i – Energy impacted
E_r – Energy reflected
E_a – Energy absorbed
E_t – Energy trasformed
E_e – Energy emmited
p_i – *where i=1,2 and 3 are different stationary environment*

Complete energy balance on an interaction interface is

$$\mathrm{E_i} = \mathrm{E_r} + \mathrm{E_e} + \mathrm{E_a} + \mathrm{E_t}. \tag{13}$$

Energy power is defined like an amount of work performed per time unit

$$P_{ef} = \frac{\partial A_{ef}}{\partial t}\ [W]. \tag{14}$$

For energetic description is better to use an intensity of traced factors. The intensity is the energy power related to the plane element ***dS***. Than is possible to express the intensity

$$\mathrm{I_{ef}} = \frac{\partial P_{ef}}{\partial S}\left[{}^{W}\!/_{m^2}\right]. \tag{15}$$

Following formulas express the effective intensities by specific effective variables for traced factors (sound, vibration and acceleration, illumination and heat)

$$I_{1/ef} = p_{ef} \cdot v_{ef} \cdot \cos(\varphi) \cdot \cos(\theta)\ \left[{}^{W}\!/_{m^2}\right], \tag{16}$$

$$I_{2/ef} = \frac{m \cdot a_{ef} \cdot v_{ef}}{S} \cdot \cos(\gamma)\ \left[{}^{W}\!/_{m^2}\right], \tag{17}$$

$$I_{3/ef} = \frac{\eta \cdot \phi_{ef}}{S}\ [lx], \tag{18}$$

$$I_{4a/ef} = \frac{\lambda \cdot T_{ef}}{d}\ \left[{}^{W}\!/_{m^2}\right], \tag{19}$$

$$I_{4b/ef} = \alpha \cdot T_{ef}\ \left[{}^{W}\!/_{m^2}\right], \tag{20}$$

$$I_{4c/ef} = \varepsilon \cdot \sigma \cdot {T_{ef}}^4\ \left[{}^{W}\!/_{m^2}\right]. \tag{21}$$

Now it is known how the factors expanding through the environment. The effective variables depend on the parameters of the environment. That means, that the ***E*** subsystem parameters like a humidity, an air speed, a day/night mode, a concentration of particles etc., can affect these effective variables.

How does it work on the boundary area of the vehicle ***δΩ***? In elementary scope is the energy transmission in the place ***X*** and direction ***ω*** from the normal vector ***n*** of the plane element ***dS*** shown in the figure below.

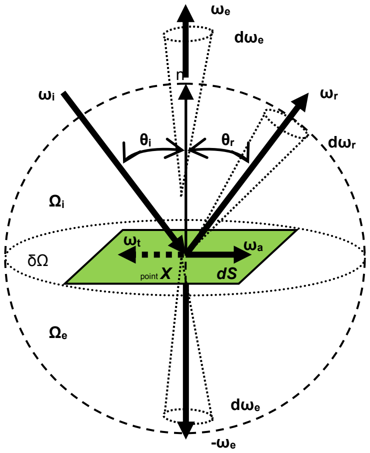

Fig. 7 Energy behaviour on boundary segment dS

Incoming intensity ***ωᵢ*** impacts the plane element ***dS*** under the vector angle ***θᵢ*** and in ideal case the intensity ***ωᵣ*** is reflected again under the same angle ***θᵣ*** into the surrounding. Outgoing intensity also depends on the space angle ***dωᵣ***, which is defined by ambient, diffuse or sharp character of the boundary area element.

These boundary area character is described by the vehicle ***V*** subsystem parameters like a material absorbtion, reflection, transformation and emission are. Also the energy behaviour on the boundary area depends on its position in 3D space and its global orientation of normal vector ***n***.

Intensity transmission related to the space angle is possible to express in following

$$I_i(X;\omega_i) = \frac{\partial^2 \mathrm{P}_i(X;\omega_i)}{\partial S \partial \omega_i cos\theta_i} = \frac{\partial I_i(X;\omega_i)}{\partial \omega_i cos\theta_\mathrm{i}} \left[{}^{W}\!/_{m^2 sr}\right], \tag{22}$$

$$I_r(X;\omega_r) = \frac{\partial^2 \mathrm{P}_r(X;\omega_r)}{\partial S \partial \omega_r cos\theta_r} = \frac{\partial I_r(X;\omega_r)}{\partial \omega_r cos\theta_\mathrm{r}} \left[{}^{W}\!/_{m^2 sr}\right], \tag{23}$$

$$I_e(X;\omega_e) = \frac{\partial^2 \mathrm{P}_e(X;\omega_e)}{\partial S \partial \omega_e cos\theta_e} = \frac{\partial I_e(X;\omega_e)}{\partial \omega_e cos\theta_\mathrm{e}} \left[{}^{W}\!/_{m^2 sr}\right], \tag{24}$$

$$I_a(X;\omega_a) = \frac{\partial^2 \mathrm{P}_a(X;\omega_a)}{\partial S \partial \omega_a cos\frac{\pi}{2}} = \frac{\partial I_a(X;\omega_a)}{\partial \omega_a cos\frac{\pi}{2}} \left[{}^{W}\!/_{m^2 sr}\right], \tag{25}$$

$$I_t(X;\omega_t) = \frac{\partial^2 \mathrm{P}_t(X;\omega_t)}{\partial S \partial \omega_t cos\frac{\pi}{2}} = \frac{\partial I_t(X;\omega_t)}{\partial \omega_t cos\frac{\pi}{2}} \left[{}^{W}\!/_{m^2 sr}\right]. \tag{26}$$

Power densities in investigated place ***X*** – integration:

$$I_i(X) = \int_{\Omega^+} I_i(X;\omega_i) cos\theta_\mathrm{i} d\omega_i. \tag{27}$$

$$I_r(X) = \int_{\Omega^+} I_r(X;\omega_r) cos\theta_\mathrm{r} d\omega_r. \tag{28}$$

$$I_{e+}(X) = \int_{\Omega^+} I_{e+}(X;\omega_{e+}) cos\theta_{e+} d\omega_{e+}. \tag{29}$$

$$I_{e-}(X) = -\int_{\Omega^-} I_{e-}(X;\omega_{e-}) cos\theta_{e-} d\omega_{e-}. \tag{30}$$

$$I_a(X) = \int_{\Omega} I_a(X;\omega_a) cos\frac{\pi}{2} d\omega_a. \tag{31}$$

$$I_t(X) = \int_{\Omega} I_t(X;\omega_t) cos\frac{\pi}{2} d\omega_t. \tag{32}$$

According to this is possible to define distribution functions:

$$\varrho_r(\omega_i \longrightarrow \omega_r) = \frac{I_r(\omega_r)}{I_i(\omega_i)\cdot\cos\theta_i\cdot d\omega_i} \leq 1\ [sr^{-1}], \tag{33}$$

$$\varrho_{e+}(\omega_i \longrightarrow \omega_{e+}) = \frac{I_{e+}(\omega_{e+})}{I_i(\omega_i)\cdot\cos\theta_i\cdot d\omega_i} \leq 1\ [sr^{-1}], \tag{34}$$

$$\varrho_{e-}(\omega_i \longrightarrow \omega_{e-}) = \frac{I_{e-}(\omega_{e-})}{I_i(\omega_i)\cdot\cos\theta_i\cdot d\omega_i} \leq 1\ [sr^{-1}], \tag{35}$$

$$\varrho_a(\omega_i \longrightarrow \omega_a) = \frac{I_a(\omega_a)}{I_i(\omega_i)\cdot\cos\theta_i\cdot d\omega_i} \leq 1\ [sr^{-1}], \tag{36}$$

$$\varrho_t(\omega_i \longrightarrow \omega_t) = \frac{I_t(\omega_t)}{I_i(\omega_i)\cdot\cos\theta_i\cdot d\omega_i} \leq 1\ [sr^{-1}]. \tag{37}$$

Completely is possible to describe the energy conservation law:

$$\varrho_r + \varrho_{e+} + \varrho_{e-} + \varrho_a + \varrho_t = 1. \tag{38}$$

Formulas above are the general expression of energy behaviour on the boundary area, equivalent of the vehicle design. For each traced factor is possible to define ***V*** subsystem parameters that are for each factors specific, but in the consequence they have same effect in energy behaviour.

For sound propagation, there are sound reduction indexes, sound absorbtion indexes, sound reflection indexes, densities of material, spectral filtering indexes etc.

For vibration, there are damping indexes, elasticity indexes, plasticity indexes etc.

For illumination, there are transparency indexes, reflextion indexes, color indexes etc.

For heat, there are conductivity indexes, emission indexes, tansfer indexes etc.

3.4 Energetic path tracing of factors

Main problem is that at this moment current methods used for passenger comfort evaluation are very different. These methods use different units; different evaluation and they are focused on mean value for the whole vehicle. This mean value is usually defined by standard or specification.

The design of the simulation model comes in with complex evaluation. It simulates the vehicle in environment conditions and calculates final intensity of each factor in critical point. The final intensity is not only the direct intensity from source to the critical point. The model also includes reflected, absorbed and transmissed energy of factors from in interaction with the vehicle.

In this case is selected a method of energy path tracing that is inspired by rendering equation used in rendering of 3D scenes [3]. Generally is possible to describe the sources, boundary areas and observeres at mathematical way

$$f_{sources} = f_f(\boldsymbol{X}, t),\ \ \boldsymbol{X} \in \Omega, \qquad t \in \langle 0, T) \subset \langle 0, +\infty), \qquad f \in \mathbb{N}, \tag{39}$$

$$u_e = u(\boldsymbol{X_e}, t),\ \ \boldsymbol{X_e} \in \Omega_{\mathrm{e}}, \qquad t \in \langle 0, T) \subset \langle 0, +\infty), \tag{40}$$

$$u_i = u(\boldsymbol{X_i}, t),\ \ \boldsymbol{X_i} \in \Omega_{\mathrm{i}},\ \ t \in \langle 0, T) \subset \langle 0, +\infty), \tag{41}$$

$$\partial\Omega_{vehicle} = \sum_{v=1}^{n} \partial\Omega_v\,, \qquad v \in \mathbb{N}, \tag{42}$$

$$\mathrm{O}_{passengers} = \sum_{p=1}^{n} \mathrm{O}_p\,, \qquad p \in \mathbb{N}. \tag{43}$$

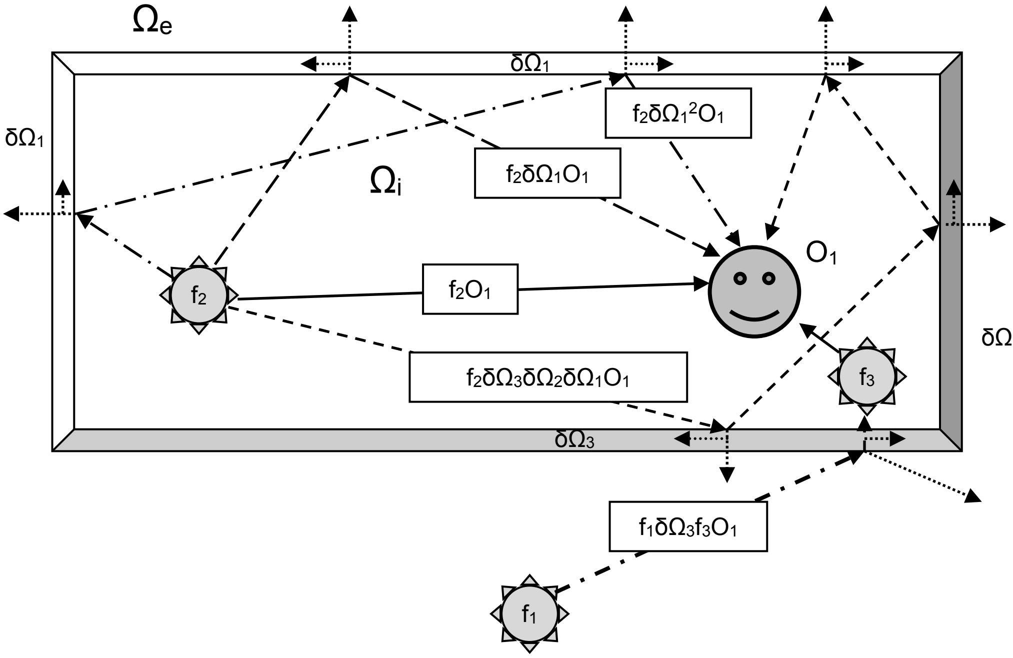

Fig. 8 Path tracing of energy from sources to observer

As is shown in the example in the figure above, there is the whole traced space $\boldsymbol{\Omega}$. By the boundary area $\boldsymbol{\delta\Omega_{vehicle}}$ is the space splitted into the exterior $\boldsymbol{\Omega_e}$ and interior $\boldsymbol{\Omega_i}$ space of the vehicle. In the space $\boldsymbol{\Omega_e}$ there is the source $\boldsymbol{f_1}$ and in the space $\boldsymbol{\Omega_i}$ there are sources $\boldsymbol{f_2}$ and $\boldsymbol{f_3}$ and the observer $\boldsymbol{O_1}$. The boundary area is possible to split into particular boundary areas with different parameter $\boldsymbol{\delta\Omega_1}$, $\boldsymbol{\delta\Omega_2}$ and $\boldsymbol{\delta\Omega_3}$.

The design of the mathematical model is calculating all possible ways of interactions between the sources and observer. That means that effective traced factor is interacting with all relevant

E subsystem parameters together with all relevant ***V*** subsystem parameters. This fact has an effect on the final energy that comes to the observer and describes the relationship ***E-V*** of subsystems.

3.5 Simplification of design of mathematical model

Because of huge count of possible paths is the design of the mathematical model very complex for analytic solution. In this case is necessary to consider some simplifications and select stochastic methods and approaches as followings:

- reverse path tracing from the observer in direction to defined source, as is shown in the figure below – it leads to a filtering of not required paths,

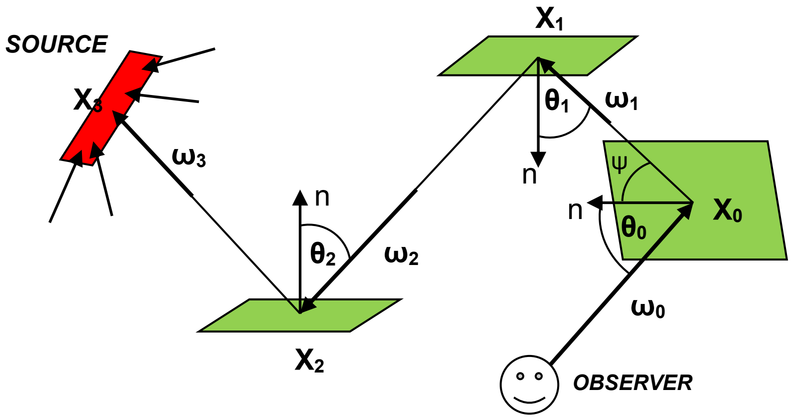

Fig. 9 Reverse path tracing

- simplification of vehicle body structure - setting of functional assemblies,
- selection of a calculation method - statistic evaluation of pseudo-random processes, as is ilustrated in the figure below.

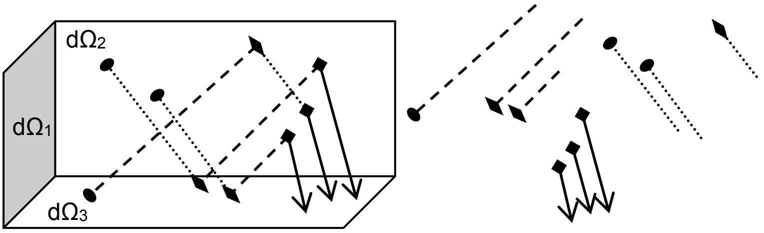

Fig. 4 Statistical evaluation of parallel energetic paths

Using by Monte Carlo method is possible to process in statistical way the intensity data of the parallel paths and their estimation is possible to describe in probability steps expressed by formula (X):

$$\langle I \rangle_{OBSERVER} = \frac{I_i(X_0, \omega_0) \cdot \cos\psi}{p_0(X_0, \omega_0)} \cdot \sum_{l=0}^{k} \left[\prod_{m=1}^{l} \frac{\varrho_r(X_{m-1}, \omega_m \longrightarrow \omega_{m-1}) \cdot \cos\theta_{m-1}}{P_m \cdot p_m(\omega_m)} \right] \cdot I_{e+}(X_l, \omega_l). \tag{44}$$

P**m*................. probability of next step ***m
p**m**(ω**m**).......... probability density for incoming direction ***ω**m*

Mathematical description of the integral of the energetic path from the observer to the source is completed by geometric factor that is connected with the vehicle geometry and by visible factor that defines direct path between the observer and the source:

$$\begin{aligned} I(\boldsymbol{X_0},\boldsymbol{\omega_0}) = I_{e+}(\boldsymbol{X_0},\boldsymbol{\omega_0}) + \int_{\partial\Omega} & I_{e+}(\boldsymbol{X_1} \rightarrow \boldsymbol{X_0}) \cdot \varrho_r(\boldsymbol{X_1} \rightarrow \boldsymbol{X_0} \rightarrow \boldsymbol{\omega_0}) \\ & \cdot Gf(\boldsymbol{X_0} \rightarrow \boldsymbol{X_1}) \cdot Vf(\boldsymbol{X_0} \rightarrow \boldsymbol{X_1}) dS_{X_1} \\ & + \iint_{\partial\Omega} I_{e+}(\boldsymbol{X_2} \rightarrow \boldsymbol{X_1}) \\ & \cdot [\varrho_r(\boldsymbol{X_2} \rightarrow \boldsymbol{X_1} \rightarrow \boldsymbol{X_0}) \cdot Gf(\boldsymbol{X_1} \rightarrow \boldsymbol{X_2}) \\ & \cdot Vf(\boldsymbol{X_1} \rightarrow \boldsymbol{X_2})] \\ & \cdot [\varrho_r(\boldsymbol{X_1} \rightarrow \boldsymbol{X_0} \rightarrow \boldsymbol{\omega_0}) \cdot Gf(\boldsymbol{X_0} \rightarrow \boldsymbol{X_1}) \\ & \cdot Vf(\boldsymbol{X_0} \rightarrow \boldsymbol{X_1})] dS_{X_1} dS_{X_2} \\ & + \iiint_{\partial\Omega} I_{e+}(\boldsymbol{X_3} \rightarrow \boldsymbol{X_2}) \ldots dS_{X_1} dS_{X_2} dS_{X_3} \,. \end{aligned} \tag{45}$$

Gf.... geometric factor

Vf.... visible factor

3.6 Implementation of vehicle parameters to simulation

The formula (45) is a mathematical expression and is too complicated. The formula of the energetic path is possible to express in operators form as is shown in formula (46). Generally is possible to describe the energetic path as follows:

$$I = \sum_{s=0}^{n} T^s \cdot I_{e+} + T^{n+1} \cdot I. \tag{46}$$

I......final intensity of the traced factor in the critical point,

I

I_{e+}...source behaviour,

T.... integral, alias transport, operator determines the direction and character of the propagated intensity.

The path is possible to express like a Neumann progression:

$$I = I_{e+} + T \cdot I_{e+} + T^2 \cdot I_{e+} + T^3 \cdot I_{e+} + \cdots, \tag{47}$$

By recursive application of the transport operators ***T*** is achieved the recursive energetic path tracing from the observer to the source:

$$I = I_{e+} + T(I_{e+} + T(I_{e+} + T(I_{e+} + \cdots. \tag{48}$$

Integral, alias transport, operator ***T*** is splitted into an ambient (***A***), diffuse (***D***) and sharp (***S***) component in the proportion to perform the realistic simulation in the best way.

$$T = (A) + (D) + (S) \tag{49}$$

The components is possible to write out according to Phong model [4] in following way:

$$(A) = I \cdot C_a, \qquad C_a \in (0,1), \tag{50}$$

where C_a is the material index, zero value of which means, that the ambient component is not valid.

$$(D) = I \cdot C_d, \qquad C_d \in (0,1), \tag{51}$$

where C_d is the material index, zero value of which means, that the diffuse component is not valid.

$$(S) = I \cdot C_s, \qquad C_s \in (0,1), \tag{52}$$

where C_s is the material index, zero value of which means, that the sharp component is not valid.

Graphically is possible to present each component in the plane element ***dS*** according to figure below.

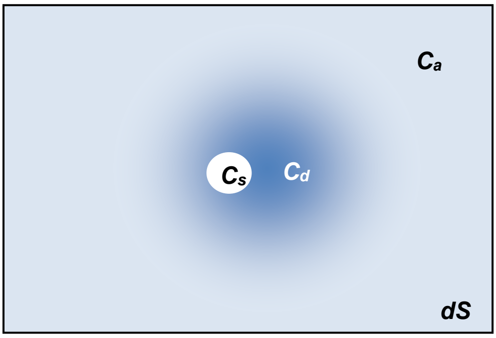

Fig. 5 Presentation of material components in plane element dS

3.7 Results of simulation of design of vehicle interior

The result of the simulation is the final intensity calculation in the critical point. The final intensity is created by direct paths from the source and by indirect paths.

The intensity propagation is affected by ***E*** subsystem parameters (space ***Ω***) and ***V*** subsystem parameters (boundary area $\delta\Omega_{vehicle}$).

The final intensity is important input for human factors implementation (***H*** subsystem parameters) and for system validation, because by ***H*** subsystem parameters implementation there is a way to evaluate the comfort and get the appropriate feedback of the vehicle design and its environment.

4 CONCLUSION

In fine is required to remind, that the travel comfort is not included in TSI targets and is not controlled by governments, European Union. The travel comfort is a subject of competitive market behaviour and of relationship between a customer and seller.

Energetic and environmental profitability of a public transport, especially the rolling stocks, against the automotive industry is indisputable. But this is not sufficient to passenger conversion to the public transport. Is required to motive the passengers. Significant motivation factor of population orientation to the publich transport is the travel comfort. That is the reason to understand this topic, get the know-how to mathematically describe it, evaluate it and targeted solve it.

The design of the mathematical model is splitted into four base parts. The figure below illustrates geometrically current and future development phases:

a) **System creation** – 1st part of the model design: Information inputs and critical components and parameters definition, causes and consequences of travel comfort - publicated in [5]
b) **Simulation of interior vehicle design** – 2nd part of the model design: Mathematical description of relationship between the vehicle and the environment from the point of view of the propagation of traced factors in 3D - subject of this paper
c) **Comfort evaluation** – 3rd part of the model design: Implementation of ***H*** subsystem parameters (human factors) and comfort validation - not publicated yet
d) **Setting of system reliability and stability** – 4th part of the model design: Macroscopic system evaluation - not publicated yet

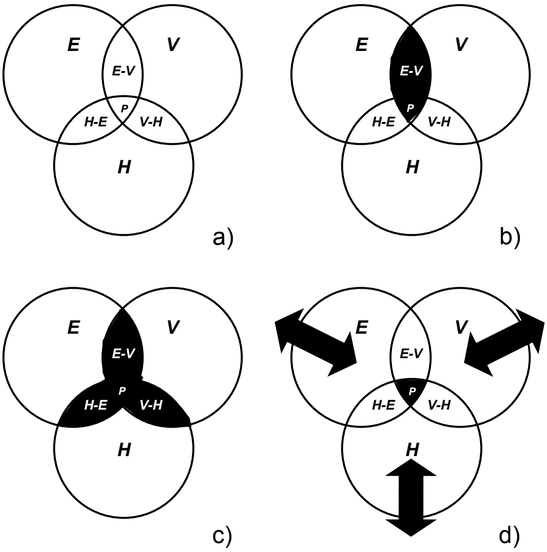

Fig. 6 Method progress and perspective

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