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Deliverable report D 5.6

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Section I - Executive summary

A decision tool for train design is developed to produce an easy-to-use decisional tool for assessing safety of life for the train conception (based on the other tasks) which takes into account the design and product performance effects on the fire.

In order to avoid a systematic heavy calculation approach, it relies on a wide range of pre-calculations made on different designs, according to different fire scenarios. Those pre-made calculations produce tendencies, assorted with statistical margins, on the output quantities ASET and RSET.

The input data for this tool will roughly be the same as the one needed for the RSET calculation tool: design of the vehicle, strategy of evacuation, availability of absolute or relative safe places, information on passengers and staff in terms of number, composition, with an additional database of tendencies and statistical uncertainties related to any relevant parameter of the design of the vehicle.

The output of this tool is ASET and RSET, evaluated according to the decisions taken in the conception of the vehicle.

This tool will typically produce three types of answers:
- ASET >> RSET: the evacuation is obviously safe (white zone);
- ASET << RSET: the evacuation is obviously compromised (black zone);
- ASET and RSET are in the same order of magnitude: the evacuation is questionable and deeper analysis is needed (grey zone).

According to this information and to the results obtained in modelling, D5.3, a simple software taking into account these inputs and outputs is developed for simple assessments.

This tool could be used in order to demonstrate that a new design of train like the train tubes satisfy the fire safety requirement or to optimise their design (e.g. number and the position of the doors) or to prove that the use of new product which don’t respect the requirement (e.g. HL2) don’t decrease fire safety level.
Section II - Framework of simplified assessment tool for the train design

The simplified assessment tool is divided in two parts:
- Part 1: guidance about the way to use the simplified decision tools for the train design to estimate safety of evacuation
- Part 2: Software for the optimisation of the train fire safety base of design (with a description of logigram)

The output of this simplified assessment tool is an answer to the question: is the conception of the train satisfies the requirement fire safety when the requirement is express as “Available Safe Evacuation Time (ASET) > Requirement of Safe Evacuation time (RSET)”?

This tool takes into account the information, which have been obtained from the TRANSFEU study in the WP5.3 concerning the appliance and the limits of the simulation tools.

The results obtained by the different studied scenarios for ASET and RSET are summarized in the following two tables as an example of the appliance of these simulation tools. These values are generic values and don’t constitute guidance values to be directly used in other train designs.

### Results ASET obtained in task 5.3 (by simulation)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>ASET for FED/FEC over 0.3</th>
<th>Parameter driving ASET</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Commuter Train, Operation category 1</td>
<td>&gt;1200 s</td>
<td>-</td>
</tr>
<tr>
<td>1B</td>
<td>Single deck, Operation Category 2 (Cat A TSI SRT)</td>
<td>236 s</td>
<td>FEC</td>
</tr>
<tr>
<td>2A</td>
<td>Double deck car, Operation category 2 (Cat A TSI SRT)</td>
<td>&gt;1200 s</td>
<td>-</td>
</tr>
<tr>
<td>2B</td>
<td>Double deck car, Operation category 3 (Cat B TSI RST)</td>
<td>200s</td>
<td>FEC</td>
</tr>
</tbody>
</table>

### Results RSET obtained in task 5.4 (by simulation)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>RSET (s)</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Aa</td>
<td>Evacuation of a commuter train to the platform</td>
<td>82 to 101</td>
<td>101 s when very crowded</td>
</tr>
<tr>
<td>1Ab</td>
<td>Evacuation of a commuter train between stations</td>
<td>89 to 106</td>
<td>106 s for very high exit step (1.24 m)</td>
</tr>
<tr>
<td>2Ba</td>
<td>Evacuation of a double-decker to the platform</td>
<td>168 to 248</td>
<td>248 s when very crowded</td>
</tr>
<tr>
<td>2Bb</td>
<td>Evacuation of a double-decker between stations</td>
<td>236 to 444</td>
<td>444 s when very crowded</td>
</tr>
</tbody>
</table>
Preliminary comparison between ASET and RSET

According to these differences, for all studied scenarios, the safety margin available for commuter trains is sufficient for single deck trains. For double deck trains (scenarios 2Ba and 2Bb for RSET), situation is less contrasted and the safety margin could be a priori insufficient. Further analyses are needed for such kind of design.

Section III - Guidance about the way to use the simplified decision tools for the train design to estimate safety of evacuation

This guidance presents a decision tool and explain how to use it in function of the type of risk (fire starting, fire development, toxic effect, smoke effect on the passengers and staff) in order to reach the fire safety objective for conventional EN 45545-1 scenarios.

The decision tool consist to determine which practical disposal have to be used for the conception of train in order to reach the fire safety objective in function of the category of train.

These practical disposals could be

- Design parameter of coach (position of the products, ventilation, position of the doors, exit etc..)
- The type of fire safety disposal (passive, active)

The output of this tool will be in function of the practical disposals

- ASET >> RSET: the evacuation is obviously safe (white zone);
- ASET << RSET: the evacuation is obviously compromised (black zone);
- ASET and RSET are in the same order of magnitude: the evacuation is questionable and deeper analysis is needed (grey zone).

RSET give the estimated time, which is necessary for the passenger to evacuate the train. It could be determined according to a conventional approach (like EN 45545-1) or refined and calculated in function of train category according to an advanced method as described in Task 5.4 report.

Deliverable 5.4 explains which simplified tools (pre-calculation) which could be used in order to have a first estimation of RSET as a screening approach

ASET is determined by simplified and refined simulation tools
A guidance explains which simplified simulation tools and how they have to be used in function of the different types of risk as a screening approach

The process for the decision tool is summarized in the following flowshart
Selection of the type of train and its parameters to be studied

Which fire safety objective?

According to Objective of EN 45545?

no

Fire objective according to objective of EN 45545

Selection of RSET according to the category of train

Determination of Design fire scenarios

Design fire

Ventilation: HVAC, open doors, window break

Train parameters

Passive fire protection

Estimation of ASET by Numerical simulation (chapter 3.2)

ASET << RSET

ASET and RSET in the same order of

ASET >> RSET?

ASET and RSET in the same order of

ASET >> RSET?

ASET and RSET in the same order of

ASET >> RSET?

the evacuation is obviously compromised (black zone)

the evacuation is obviously compromised (black zone)

Which parameters have impact of ASET?

Modifications of the parameter which have an impact on ASET

The train is OK

The train is OK

the evacuation is obviously safe (white zone)

the evacuation is obviously safe (white zone)
III.1. **Guidance for the determination of RSET**

RSET could be determined according to a conventional approach (like EN 45545-1) or refined and calculated in function of train category according to an advanced method as described in Task 5.4 report. Deliverable D5.4 explains which simplified tools (pre-calculation), which could be used in order to have a first estimation of RSET as a screening approach.

The train parameters to be considered are its geometry and the positions of the products.

III.2. **Guidance for the determination of ASET**

The aim of this guidance is to provide design guideline for estimating the fire impact on passenger in function of the train parameters.

The train parameters to be considered for ASET are

- Design vehicles (Geometry of train, ventilation etc.;)
- Fire design
- Reaction to fire of products

The fire impact on the passengers in function of the train parameters is estimated step by step as following by using simplified tools and more sophisticated tools which use field models.

In the first step a simplified tool, such as two zone model (see in annex 1 the description of zone model), is used. In this case, a large number of trials could be performed to determine the effect of a given fire in geometry, considering few variables. From this process acceptable train parameters are selected. The process is described in the section IV.

In the second step the influence of the train parameters selected from the first step is studied with detailed simulation tools (field model) according to the following design guide for the safety assessment applied based on Fire Dynamics Simulator (FDS) software.

**III.2.1 Design guide for the safety assessment applied with simulation tools based on FDS**

In this guide the simulation tools are based on more sophisticated simulation tools (field models) than zone models, which are presented in the deliverable D5.1 and 5.2.

Several methods for this simulation are described in these deliverable.

The principle of this guide is to explain how to apply the simpler method of simulation 1 (for the product fire behaviour) and the approach B (kinetic yield) concerning the toxic gases generation, developed respectively in the deliverable D 5.1 and D 5.2 in TRANSFEU project.

It is performed in 3 step

- Step 1: definition of the design fire scenario (ignition source, geometry of coach etc..)
- Step 2: introduction of the input data for simulation of the fire growth, fume and toxic gas production
Step 3: determination of the impact on the passengers from the simulation

The process to follow is described in the following figure 2.

**Figure 2**
III.2.1.1 Definition of the design fire scenario

III.2.1.1.1 Design fire
To begin, it is important to define the fire source, i.e.:
- its type of fire source: chemical composition
- its effective heat of combustion
- its intensity of heat release and the combustion time period
- its geometrical dimension
- its position in the vehicle.

III.2.1.1.2 Design fire scenario
The FDS user has to know:
- the dimension of all products present inside the vehicle
- the vehicle dimensions
- the positions of all products inside the vehicle
- the ventilation conditions (flow and position of the ventilation system)
- the opening time or not of the door(s) during the fire and the number of doors

III.2.1.1.3 Numerical calibration of the fire scenario
The numerical calibration consists to reproduce a numerical representation of the coach, the materials which are inside it and the impacted burn area of each combustible product, as following:

III.2.1.1.3.1 Numerical meshing of the fire scenario in FDS
The mesh size has an important influence on the fire behaviour and the fire spread according to literature and TRANSFEU results at any scale. Considering that, in this guide, the method, used in FDS to simulate the fire, is based on the prescribed heat release rate per unit of surface, and thus the mesh size has not a lot of influence on the product fire behaviour. This mesh size in fact (for the method 1) is a compromise between the vehicle and products geometry and the calculation time. A mesh size from 5cm to 10 cm can be chosen.

III.2.1.1.3.2 Numerical calibration of impacted burnt area
The aim of this numerical calibration is to estimate the impacted burnt area of each combustible product. The principle is to represent exactly the same numerical geometry of the design scenario with only the fire source. The code user affects all thermal properties (conductivity, heat capacity, emissivity and density), if they are known, or adiabatic properties to each product. The characteristics of the chemical reaction in line gas phase corresponds to the chemical composition and the effective heat of combustion of the fire source. Only, a ramp of heat release of the fire source (burner) is affected to the surface burner. The only required output data is the product heat flux boundaries (incident of the cold object). It is important to note that each range of heat release from the burner have to be studied. In TRANSFEU scenarios, the burner starts to release 75 kW then 150 kW. Thus, a first set of products impacted areas have to be taken into account during the first level of the burner (75 kW) and then increased by the second burner range (150 kW). The important question is which threshold to consider for the product impacted area to be considered. The following proposal is a guidance to determine the impacted surface:
- For lining products:
  o If the CFE (critical flux at extinguishment) is known, thus the selected impacted area are those which receive an incident heat flux higher than the CFE.
  o If the CFE is not known, the chosen impacted area are those which receives an incident heat flux higher than the 20 kW/m² (according to the requirements of the EN 45545-2).
- For the seat products: the chosen impacted area is driven by the surface, which receives an incident heat flux higher than the 10 kW/m² (according to Transfeu tests on seats).
Note that the technique used is only valid for materials compliant with EN45545 Reaction-to-Fire criteria. It means that these products have a so good fire behaviour that, in conventional design fire scenarios, they don’t propagate outside the surface impacted by the primary source.

### III.2.1.2 Input data for fire code

The objective of this process is to explain how to use the input data in the simulation tool in order to simulate the fire growth (chapter III.2.2.2.1), the toxic gas production (chapter III.2.2.2.2) and the soots production (chapter III.2.2.2.3) in the coach as following:

#### III.2.1.2.1 Prescription of the fire growth for the materials

This is performed by combining the thermal and energy model (chapter III.2.2.2.1.1) with the combustion model (chapter III.2.2.2.1.2). An iterative approach could be used for the simulation on possible other impacted surface(s) (than preliminary selected) if the heat contribution from products is not negligible compared to the primary incident heat flow (chapter III.2.2.2.1.3).

**III.2.1.2.1.1 Determination of the quantity of fuel by Thermal and energy models**

The two input data concerning these models are:

- The heat release rate per unit of surface: This data can come from either the cone calorimeter test at a given irradiance level, selected during the numerical calibration step. If it is needed, additional cone calorimeter tests can be performed at a specific irradiance level. The heat release per unit area could also be issued from a full scale test if it is the same configuration as the real simulation and if the impacted surface are equivalent. This last solution has to be selected for complex products and assemblies, as cone calorimeter could not catch all phenomenon that take place during fire exposure of such items in end-used configurations.

- The ignition delay time: This delay time period corresponds to the time period before the ignition of the product only if the product is supposed to burn based on the heat impact analysis. In fact, the user decides when the product starts to burn according different possible assumptions:
  - This time period is the same as those obtained in a corresponding full scale test.
  - The time period is the same as the cone calorimeter test at the given irradiance level.
  - Concerning the seat product: a conservative delay time can be used as 30 s according to the TRANSFEU full scale tests results on seats.

**III.2.1.2.1.2 Combustion model**

For “Mixture Fraction” combustion models, only one gaseous fuel and chemical reaction could be used. The chemical composition and the effective heat of selected in such case correspond to the material which is supposed to release the dominating quantity of heat and mass. In many cases during our studies, propane from the initial burner has been selected as main reaction.

**III.2.1.2.1.3 Simulation on possible other impacted surfaces than initially**

With this method, all the impacted burnt areas at the early stage of a fire are taken into account according to the numerical calibration of the burner. Indeed, the impact of the combustion products in the simulation is not considered because the fire spread is totally prescribed by the user. Of course further potential products impacted surfaces can be
identified after simulation and the user can go back to the ‘thermal and energy input data’ paragraph to consider these additional surfaces.

Note that it is an iterative process, and it has to be used carefully, especially when no full-scale test is available to confirm these additional impacted surfaces. In case of materials, which propagate the flame widely, this technique is not suitable and will lead to incoherent results.

### III.2.1.2.2 Prescribed gases mass flux to evaluate the toxic gas production

In order to estimate the toxicity, it is necessary to obtain the correct mass loss of the burnt product, to link this mass loss to the release of toxic products. The total mass which comes from several different fuels is skewed in Mixture Fraction combustion models because of the unique effective heat of combustion and the unique global combustion reaction. Thus, in order to calculate toxic gases mass flux, follow these steps:

1. **Design fire scenario**
   - Numerical calibration with only burner simulation
   - Definition of impacted material area at a given heat flux
   - Prescribed HRRPUA of a material for a given selected impacted area
   - Gases model (Approach A): CO₂ passive ramp inserted for each fuel
   - CO₂ concentration estimation from the simulation for the material and the scenario at three different points in the design vehicle volume
   - Toxic gases concentration estimation from CO₂ concentration and Smoke Box tests
   - Volumetric gases ratio from smoke box tests

   - The approach B (kinetic yield) of the report Task 5.2 is used as following

The “mixture fraction” model is not used to calculate the toxic gases quantity in FDS but the added track species according to the following principle.
Insert a no-reactive ramp quantity of CO$_2$ associated to each possible fuel in simulation (see “added Track” species in annex 2).

Place a sensor of CO$_2$ volumic measurement where impact has to be calculated.

Calculate the quantity of all toxic gases generated by each fuel from the quantity of CO$_2$ released and the [toxic gases/ CO$_2$] volumic/molar ratio matrix obtained from ISO 5659-2+FTIR or other bench-scale tests.

The detailed process is described in annex 3.

Some example of this approach is presented in the figures 4 and 5.
Figure 5

III.2.1.2.3 Soot yields
In many codes it is necessary to specify the soot yield in order to estimate the smoke quantity dispersed. Considering the combustion reaction mechanism in FDS, it is possible to add only one soot yield corresponding to one type of fuel. The product which has the most total quantity of mass and heat release is selected as the soot yield reference. The soot yield of the selected product is estimated according to the following equations and cone calorimeter tests data.

The total smoke production rate, $SPR_{\text{total}}$ (m$^2$/s), can be expressed in extractive methods as follows (as explained in standard EN 13823):

$$SPR_{\text{total}}(t) = \frac{V(t)}{L} \ln \left( \frac{I_0}{I(t)} \right)$$

with

- $V(t)$: Extraction flow in the duct (in m$^3$/s)
- $L$: Duct diameter (optical path, in m)
- $I_0$: initial intensity signal of the light (UA)
- $I$: actual intensity Signal from the light receiver (UA)

Moreover, it is known that:
\[ \frac{I}{I_0} = e^{-k_s \cdot L} \]

and \( k_s = \sigma_s \cdot C_s \)

with

\( k_s \) Extinction coefficient (m\(^{-1}\))

\( \sigma_s \) Specific extinction area, (9600 ± 300) m\(^2\)/kg

\( C_s \) Soot mass concentration mass (kg.m\(^{-3}\))

Then, the following equation is obtained from the previous ones:

\[ C_s(t) = \frac{SPR(t)}{V(t) \cdot \sigma_s} \]

and \( C_s(t) \cdot V(t) = \frac{SPR(t)}{\sigma_s} \)

where \( Cs(t) \cdot V(t) \) (in kg/s) is the soot mass going from the duct by unit of time. This quantity can be related to the product mass loss rate, obtained by dividing the heat release rate by the effective heat of combustion. The soot yield is expressed as:

\[ Y_{soot}(t) = \frac{C_s(t) \cdot V(t)}{\dot{m}(t)} = \frac{SPR(t) \cdot \Delta H_{c,mean}}{\sigma_s \cdot HRR(t)} \]

or \( Y_{soot}(t) = \frac{SPRUA(t) \cdot \Delta H_{c,mean}}{\sigma_s \cdot HRRPUA(t)} \)

then

\[ Y_{soot} = \frac{TSP}{\sigma_s \cdot TML} \]

where TSP is the total smoke production and TML is the fuel total mass loss during the combustion, assuming that the soot production per kg of fuel is a constant for a specific fuel.

As an example in the case of propane for full-scale tests with burner alone

\[ \chi_{s_a} = \frac{148.3}{9700 \times 1.76} = 0.009 \]

In some cases when the fire spreads to the nearby seats or other objects the dominating fuel changes and so does the smoke yield. Generally the smoke yield of solid fuels is greater than this value.

### III.2.1.3 Determination of the fire effects on the persons

#### III.2.1.3.1 Toxicity

The toxicity is estimated with the FED/FEC models of the ISO 13571:

\[ FED = \sum_n \left( \frac{[CO] \cdot v_{CO_2}}{(Ct)_{CO}} \right) \Delta t + \sum_n \left( \frac{[HCN] \cdot v_{CO_2}}{(Ct)_{HCN}} \right)^{2.36} \Delta t \]

with

\( (Ct)_{CO} = 35 \, 000 \, \mu l.l^{-1}.min \)

\( (Ct)_{HCN} = 10^6 \, \mu l.l^{-1}.min \)

[CO] is the average concentration, expressed in \( \mu l.l^{-1} \), of CO over the time increment, \( \Delta t \); [HCN] is the average concentration, expressed in \( \mu l.l^{-1} \), of HCN over the time increment, \( \Delta t \); \( \Delta t \) is the time increment, expressed in minutes.

\[ v_{CO_2} = \exp \left( \frac{[CO_2]}{5} \right) \]

with

\( v_{CO_2} \) : Frequency factor;
$[\text{CO}_2]$ : CO$_2$ concentration (%).

$$FEC = \sum_{i=1}^{n} \frac{\Phi_i}{F_i}$$

with

$\Phi_i$: Irritant gas concentration of species $i$ (µl.l$^{-1}$);

$F_i$: is the concentration, expressed in µl.l$^{-1}$, of each irritant gas that is expected to seriously compromise occupants tenability.

$F_{\text{HCl}} = F_{\text{HBr}} = 1000$ µl.l$^{-1}$

$F_{\text{HF}} = 500$ µl.l$^{-1}$

$F_{\text{acrolein}} = 30$ µl.l$^{-1}$

$F_{\text{NO}_2} = 250$ µl.l$^{-1}$

$F_{\text{SO}_2} = 150$ µl.l$^{-1}$

$F_{\text{formaldehyde}} = 250$ µl.l$^{-1}$

Experimental and numerical FED/FEC are compared at each analysis point.

**III.2.1.3.2 Heat**

Concerning the heat model, the FED is compared at each DEVC point, according to the following equations:

$$FED = \sum_{i=1}^{n} \left( \frac{1}{t_{\text{rad}}} + \frac{1}{t_{\text{conv}}} \right) \cdot \Delta t$$

$\Delta t$ is the time increment, expressed in minutes.

with

$$t_{\text{rad}} = 4.2 \cdot q^{-1.9}$$

where $q$ is the radiant heat flux, expressed in kilowatts per square metre and $t_{\text{rad}}$, expressed in minutes, to experiencing pain due to radiant heat

And

$$t_{\text{conv}} = \left(4.1 \cdot 10^8 \right) \cdot T^{-3.61}$$

$t_{\text{conv}}$ is expressed in minutes, to experiencing pain due to convected heat accumulated per minute

$T$ represents the temperature (°C)

When the radiant heat flux to the skin is under 2.5 kW/m$^2$, the term $\frac{1}{t_{\text{rad}}}$ is set at zero.

**III.2.1.3.3 Smoke obscuration model**

The smoke obscuration is based on the comparison of the experimental and numerical extinction coefficient ($k_\lambda$).

The numerical extinction coefficient is obtained directly by the simulation code as a consequence of “Mixture Fraction” model and soot yield parameter.

**III.2.2 Influence of the train parameters**

According to the first simulation results (III.2.1) the impact of the fire on the passengers (ASET) could be estimated.

It is compared with the RSET as following

If ASET > RSET (white zone) the conception of train will consider to be safe because the method 1 is a conservative simulation.
If $A_{\text{SET}} = \text{or} < R_{\text{SET}}$ (grey zone) the method 3 of simulation (see D5.1 and 5.2) will be used in order to precise the simulation. A validation of the simulation by full or real scale test will probably necessary.

If $A_{\text{SET}} < R_{\text{SET}}$ (black zone) the conception of train is not accepted and other parameters have to be selected and a new simulation according to the method 1 is needed with this new variation of design. Another possibility is to start a new refined simulation according to the method 3 (See D5.1 and D5.2).

Preliminary analysis of simulation results obtained within TRANSFEU Project highlighted that situation in single deck was not problematic in the studied situations. Simulations highlighted too that for double-decks, situation was sometimes in the black zone. For such designs who fail to demonstrate the conformity, there are few solutions for the conception, such as the proposed ones hereunder (not exhaustive):

- Improve $R_{\text{SET}}$ by additional doors or reduction of number of passengers;
- Reduce exposure scenarios by compartmentation with various fire doors to separate upper- and lower-rooms ($A_{\text{SET}}$ improvement by design);
- Reduce impact by selection of materials ($A_{\text{SET}}$ improvement by materials).

**Section IV - Software for the optimisation of the train fire safety base of design (with a description of logigram)**

This software will consist to estimate automatically the $A_{\text{SET}}$ according to the practical disposal for the conception of train with this following flowchart approach.

This software is built according to the general flowchart presented in the figure 1 combined with the flowchart presented in the figure 2 which is used for the determination of $A_{\text{SET}}$. The input will be Train parameters. The outputs will be

- the estimated $A_{\text{SET}}$ and $R_{\text{SET}}$ and there comparison.
- Which train parameters have an influence
- The train design which is the most safe.

During the process the list of input data for products to be considered, the type of simulation tools to be used and the different step to respect according to the flowchart presented in the figure 2 will be indicated.

This software is completed by the following software which describe the process for the pre-design phase.

**Process for the pre-design phase**

Results obtained in task 5.3 used refined models to determine $A_{\text{SET}}$. Results obtained in task 5.4 used refined models to determine $R_{\text{SET}}$. In pre-design phases, a simplified approach could be to use only one of both tools (fire/smoke development or evacuation), or more simplified tools, to overestimate $A_{\text{SET}}$ or $R_{\text{SET}}$.

**Case of ASET:**


ASET is determined using advanced field modelling. TRANSFEU proposed a method (method 1) applicable when train design is already defined (volumes of train, fire source, doors widths). A complementary approach could be based on Probabilistic Fire Risk Assessment. The following paragraph describes the definition of possible tool for such purpose:

A simplified tool, such as zone model, is used and validated such as \( ASET_{\text{simplified tool}} < ASET_{\text{detailed tool}} \) for all studied scenarios (1A-1B-2A-2B). In this case, a large number of trials could be performed to determine the effect of a given fire in geometry, considering few variables. ASET is not directly measured with simplified tools such as Zone models. However, it could be estimated through characteristics such as:

- lower layer temperature >60°C (fail by overheat),
- upper layer temperature >200°C (fail by radiation),
- layer interface < 1,8 m (people directly exposed to the smoke).

The contributions of materials, as well as the flow characteristics, are not fully represented with zone models. However, these simplified tools allow managing a large number of simulations. These simulations could be used to select the most suitable family of characteristics, and in the end, after full validation, the limit heat release contribution of materials or the effect of design variations. The use of such simplified tools is described in the logigram of Figure 6

**Case of RSET**

Similar to ASET, simplified calculations could be performed on RSET using analytical tools. A large number of trials could be performed to check at different parameters of the scenario, such as door opening time, doors width, travel path length. They could be helpful to select the most suitable scenario for a detailed study, or effects such as break-down effects on RSET (e.g. small variation of design producing a large variation of RSET). When scenario is selected, tools such as described in D5.4 are applied.
Figure 6. Logigram for parametric analysis
Figure 1. Example of zone model application to scenario 1A.

Figure 2. Example of zone model application to scenario 2A.
two zone model

In a two zones model, the main assumption is that the hot gases goes up to form a stratified hot layer zone. The layer starting at floor level up to that hot layer is called the cold layer. The figure below shows a two zone model.

![Diagram of a two zone model](image)

**Figure 7: Example of ventilation in a coach – two zones model**

This assumption may not be completely correct in a railway environment, where ventilation is made to ensure an optimal thermal comfort for all passengers, thus leading to a mixing of the air in the coach volume.

In this kind of model, the volume is then divided in two zones, with (by hypothesis) a perfect plane infinitely thin that separate them. The height at which this plane is situated depends on (among others) the respective temperatures of the cold and hot layers, i.e. the heat release rate of the fire source, and of the openings (areas and heights).

The usual output data for this kind of model are the hot layer temperature, the cold layer temperature, and the plane height.

The gas from the fire source are supposed to feed the upper layer by buoyancy. However, the cold layer may not be completely free of toxic gases, as in some models, a diffusion term is taken into account that transfers a part of the gases from the hot layer into the cold layer and vice versa.

Consequently, two CITg have to be calculated: one for the hot layer, and one for the cold layer. Then, the CITg that has to be taken into account for depends on the height of the plane, and the mean height of the respiratory tracts for a mean human being (e.g. 1.60 m as a first approach).

Then, while the plane height is over that critical height, the CITg from the cold layer is taken into account. When the plane height goes under that critical height, the CITg from the hot layer is then considered.

In this kind of model, the solution is given through a system of Ordinary Differential Equations, and requires a computer model to be solved. Among the solved equations are consideration about energetical balance and mass conservation.
To correctly calculate all required quantities, this model would at least require:

- a toxic gas production term (gas brought in the system);
- a source term for Heat Release Rate (energy brought in the system, that allows the correct calculation of plane height and layers temperatures)

The toxic source comes from the ISO 5659-2 toxic gas measurements, that need to be derived to get a mass production rate as a function of time.

The Heat Release Rate source term may come from the cone calorimeter test (ISO 5660-1) under a 25 kW/m² or 50 kW/m² exposure (same as for ISO 5659-2).

An obvious bias in this approach is that the ventilation conditions with cone calorimeter (well ventilated) are different from the one in the smoke chamber (with oxygen in excess at the beginning to a vitiated atmosphere at the end of the test).

Moreover, the mass production rate and the heat release rate are linked together through the enthalpy of combustion (function of time). As the heat release rate comes from one test bench and the mass production rate from another, with different exposed areas, a correction factor is needed to account for this, and decrease the inherent bias between Cone Calorimeter and Smoke Box. However, the bias due to the difference of ventilation conditions will remain.

Nevertheless, for a conventional way to determine a pragmatic ASET, this solution may give good results in a comparative approach (all materials will suffer from approximately the same bias).
Annexe 2

Added track species

A track species mass flux has to be added by the FDS user for each burnt product (the burner and each potential material to burn). These track species are considered as passive vector, which have not influence on the gases released during the combustion reaction in FDS.

Affected for each product burnt for each impacted surface, a mass flux per unit of area (MFPUA) from the full-scale test or the cone calorimeter test at a given irradiance level (the same chosen as the HRRPUA) according to the equation 1.

$$MFPUA(t) = \frac{HRRPUA(t)}{\Delta H_{c,mean}}$$

In fact this MFPUA calculated for each burnt product corresponds to the mass flow of the product added the FDS gas phase. This mass flow does not react with the FDS gas phase. However, this added MFPUA (a passive vector) must be corresponds to the carbon dioxide mass flow. Thus this MFPUA is adjusted according to the complete combustion reaction and the molar mass ratio between the product and the carbon dioxide:

$$MFPUA(t)_{adjusted} = MFPUA(t) \times R$$

$$R = \frac{v_{CO_2} \times M_{CO_2}}{v_{product} \times M_{product}}$$

For example, for the propane product:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

$$R = \frac{3 \times 44}{1 \times 44} = 3$$

Of course, if the CO$_2$ measurement is directly available, these calculations are not required. The CO$_2$ mass flow required in FDS is in kg.s$^{-1}$.m$^{-2}$. This mass flow adjusted (MFPUA) is calculated for each product susceptible to burn.

Moreover, the ignition delay of the MFPUA$_{adjusted}$ ramp is the same as the HRRPUA ramp. For instance, in FDS file:

```
&SPEC ID = 'PHASE1'
  MW = 44 / same density as CO2
&SPEC ID = 'PHASE2'
  MW = 44 / same density as CO2
&SURF ID = 'SpeciesProduction'
  MASS_FLUX(1) = 0.00957,
  RAMP_MF(1) = 'Phase1'
  COLOR = 'GREEN'/
&RAMP ID = 'Phase1', T = 0, F = 0 /
&RAMP ID = 'Phase1', T = 13.8, F = 0.146 /
&RAMP ID = 'Phase1', T = 53.8, F = 0.146 /
&RAMP ID = 'Phase1', T = 60, F = 0 /
&SURF ID = 'SpeciesProduction2'
```

Date – Version 9
Security: Confidential
MASS\_FLUX(2) = 0.03, RAMP\_MF(2) = 'Phase2' 
COLOR = 'GREEN' / 
\&RAMP ID = 'Phase2', T = 0, F = 0 / 
\&RAMP ID = 'Phase2', T = 20, F = 0.5 / 
\&RAMP ID = 'Phase2', T = 40, F = 0.5 / 
\&RAMP ID = 'Phase2', T = 60, F = 0 / 

Then these MFPUA\_adjusted are affected to each impacted surface by a VENT line: 
\&VENT XB = 1.3 , 1.5 , 0 , 0 , 0.3 , 1 , SURF\_ID = 'SpeciesProduction' / 
\&VENT XB = 1.3 , 1.5 , 0 , 0 , 0.3 , 1 , SURF\_ID = 'SpeciesProduction2' / 

And for example, the red areas are the HRRPUA areas, and the green and the blue areas 
are the MFPUA areas:

Moreover, passive area can be set on the burning surface. This measure is definitely better. 
It has been checked that there is no significant influence on combustion. 

After, a toxicity matrix is building according to the Smoke box results for the results post-
processing. This matrix is explained in the following section. 

Another method that could be used in these scenarios is to exactly introduce all toxic species 
as measured on the individual surfaces. This method takes the molecular weight into accounted, and provides the possibility of setting individual input for each species. The number 
of inputs could be huge. However, note that the yields of combustion products including toxic 
gases are generally proportional to the mass burning rate of the fuel. This may suggest that 
all toxic gases approximately follow the HRRPUA curve. This measure is able to significantly 
reduce the work load. 

In fact, these two methods are closely the same, except the second method takes all species 
into account including the molecular weight of each species, and provide the possibility for 
the users to directly obtain the results of the toxic gases concentrations after the simulation. 
However, the calculation time is higher than the first method.
Toxicity matrix

The first step is to compare the kinetic and the intensity of the toxic gases in the experiment scenario and in the simulation. The added track species is the CO\textsubscript{2} from different products (in this example: propane and seat). The other toxic gases (CO, HCN, HCl, NO\textsubscript{2}...) presents in the experiments are estimated in the simulation with the CO\textsubscript{2} track species, named here PHASE 1 and PHASE 2, and the ratio of [gas]/[CO\textsubscript{2}] obtained from the smoke box test. For example, the [CO]/[CO\textsubscript{2}] max volumetric ratio for the F1A-1-2 product is 0.062. Then, the CO\textsubscript{2} track vector, obtained from the DEVC in FDS, is multiplied by 0.062 in order to estimate the CO vector at this location in the scenario. This calculation implies that the toxic gases generation during the simulation are the same as well as the Smoke box test conditions (irradiance level and oxygen concentration in the box). The toxic gases in the FDS simulation are only transported as passive vector.
Annexe 3

Determination of the Numerical instrumentation

For the same location in the FDS domain, FDS output data are: the carbon dioxide yield of each species, the temperature, the radiative heat flux and the extinction coefficient.

&DEVC XYZ=22.1,1.5,2 , QUANTITY = 'VOLUME FRACTION', SPEC_ID = ' PHASE1', ID = 'pr-VF-1' /
&DEVC XYZ=22.1,1.5,2 , QUANTITY = 'VOLUME FRACTION', SPEC_ID = ' PHASE2', ID = 'pu-VF-1' /
&DEVC XYZ=22.1,1.5,2 , ID='T2-Z', IOR=-3 , QUANTITY='THERMOCOUPLE' /
&DEVC XYZ=22.1,1.5,2 , ID='G1-Z', QUANTITY='RADIATIVE HEAT FLUX GAS', ORIENTATION=0,0,-1/
&DEVC XYZ=22.1,1.5,2 , ID='VISI-1', QUANTITY='EXTINCTION COEFFICIENT' /
Annex 4

Example of application of simplified assessment tools