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Abstract- Safety in motorway tunnels has become a critical issue in the last years, especially after the accident happened in 1999 inside the Mont Blanc tunnel, causing 39 deaths and several dozens of intoxications and wounded people. After this tragic event, the European Union imposed stricter regulations and procedures for emergency situations inside road tunnels longer than 1000 m. According to this situation, the authors propose the use of M&S (Modeling and Simulation) in order to manage a tunnel evacuation after a fire exploding in consequence to an accident, taking into account a series of significant factors like the road signs position (new criteria have been introduced with new regulation), but also human factors which significantly affect the procedure outcome. First a 2-D simulation model has been developed using Java™ Software, in which the user can analyze the behavior of the people escaping and the dynamics of the fire exploded and, consequently, assess the effectiveness of all the emergency procedures and infrastructures. In particular, regarding the state variables related to the human behavior, the model takes into account the main aspects of PECS (Physical Emotional Cognitive Social) reference models, in which physical, emotional, cognitive and social factors have to be studied. The model presented in this work is in fact quite similar to the one described by (Schmidt, 2000), called *"Adam's World"* [1] where Adam, a primitive man, lives in an environment having food sources where he can replenish his energy level, but also traps and danger points to be avoided in order not to consume his energy faster. The aim of the two models is the same: first of all preserve life and health, but the great difference between Schmidt's model and the authors' one is that in Adam's World the social aspect is missing (Adam live alone in his world), while in the evacuation model social aspects can significantly affect the individual's decisions. Upstream of the evacuation model, a weighted analysis needs to be considered, in fact the individual has to operate different choices considering several aspects, like health or goods preservation, familiar aspects, panic and so on. For this reason a suitable methodology has been detected: the Analytic Hierarchic Process (AHP), implemented by the American mathematician Thomas Saaty, which introduced this technique for Multi-Criteria Analysis. After the considerations on the individuals behavior based on the results of the analysis, the evacuation model and its results are described and analyzed in the following sections and, in the final part of the paper, a description of a 3-D tunnel model devoted to study in particular smoke dynamics is provided, thus it is possible to evaluate the impact of the smoke on the flow of the people escaping from the tunnel.

Key-words: Emergency Procedures, Simulation, PECS Models, AHP, Human Behavior

1. Introduction

In the last decade safety in motorway tunnels, especially for those longer than 1000 m, has significantly increased its importance inside the European Union; this decision has been unfortunately driven by a tragic event like the Mont Blanc tunnel disaster of 24TH March, 1999. The Alpine District countries (Italy, France, Switzerland, Austria, Germany…) have a very huge number of long tunnels, and so they take particular care in safety taking in the more restrictive criteria imposed by the Union (traffic lights, SOS columns, regular by-passes, etc…)

One of the most significant topics of this regulation is about road signs, which must be clearly visible even in smoke or fire conditions and, in some cases, providing an appropriate level of brightness by back illumination. For motorway concessionaires this represents a very significant managing cost.

For every two road tunnels in Europe, one is in Italy and, after a research led by German Automobile Club (ADAC) in cooperation with other Automobile Clubs, including Italian ACI, the situation of Italian tunnels is not so good: in the years 2005-2008 22 Italian tunnels have been examined, 14 of them did not respect the minimum safety criteria with serious lacks (emergency exits missing, fire fighting system inappropriate, etc…) and only 8 passed the exam with just the sufficiency [2].

Taking into account the current situation in Italy, the authors provided a research focused on the development of simulation models able to provide more effective measures for managing emergency situations. The case study is focused on a 4,5 km tunnel, considering important aspects of human behaviour like physical, emotional, cognitive and social factors, which can have a serious impact on the management of road signs positions and illumination.

The paper will be divided in different sections: section 2 will provide a brief description of PECS reference models with a particular focus on Schmidt's *"Adam's world"*, while section 3 is focused on the Multi-criteria analysis of the AHP (Analytic Hierarchic Process) methodology. Section 4 describes the evacuation model, while section 5 will provide a description of the 3-D model, developed for studying the smoke behaviour inside the tunnel, and section 6 describes the results obtained and presents some conclusions.

2. PECS Reference Models: Adam's World

PECS is a multi–purpose reference model devoted to simulate human behavior embedded in a social environment [3]; according to this definition, human behavior presents a complex structure because considers four different classes of factors, or state variables: physical, emotional, cognitive and social. The human being is consequently - according to Schmidt - perceived as a psychosomatic unit with cognitive capacities embedded in a social environment (in fact PECS means Physical conditions, Emotional state, Cognitive capabilities and Social status).

PECS model is the natural evolution of the BDI (Belief Desire Intention) architecture [4], by now no more appropriated for modeling real social systems because too restrictive.

The four classes of factors of PECS reference models play a significant role in the behavior control: the model of the human behavior has to take into account the following state variables, in order to be comprehensible and predictable:

Physical State Variables;
Emotional State Variables;
Cognitive State Variables;
Social State Variables.

The modeling type of human behavior depends on the nature of the problem; it is not mandatory to model all the four classes of state variables and/or all the interactions among them; in fact, considering for instance Adam's Model, the social aspect is missing, because Adam lives alone in his environment.

PECS model, however, allows modeling the greatest part of the complex systems considering the four main classes of human factors with their interactions.

The evacuation model presented in section 4 considers all the four classes, adding the social aspect to Adam's model; any case, the model presented is quite similar to the one developed by Schmidt: there are danger points to be avoided, lives and health to be preserved, the use of cognitive capacity in order to find the better solution in terms of signs interpreting and so on, but the main difference with Adam's World consists in the presence of a strong social component, which was missing in Schmidt's model. Other people could significantly affect the individual behavior, in terms of cognitive capacity and fear, in fact, without an appropriate cultural basis; the individual stretches to behave "as the others do".

Adam lives in a world composed by a 12x12 cells grid; among them there are:

○ neutral fields in which nothing happens;
○ food sources where Adam can eat and replenish his energy level;
○ high energy consuming danger points from which Adam needs to escape.

Figure 1 represents a possible configuration of Adam's environment.

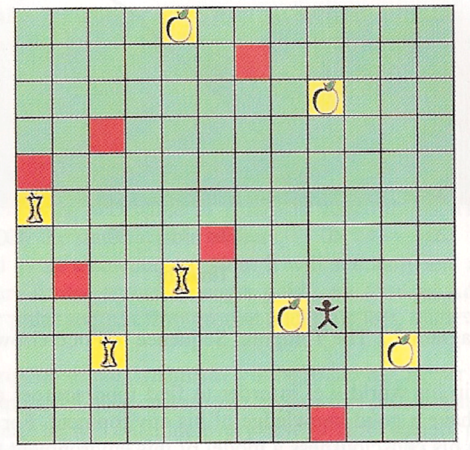


Fig. 1 – Adam's World

Schmidt's Adam model considers different aspects:

- *Adam's Environment:* Adam lives in a world that is dynamic and constantly changing. It contains food sources where he can replenish his health and danger points highly health-consuming. Adam has continually to deal with this environment.
- *PECS State Variables:* Adam's physical state is represented by the energy level, while the emotional aspect is described by fear. Adam has also cognition of himself and his environment but lacks of social aspects because he lives alone in his world.
- *Changes of the internal variables:* The state variables are subjected to continuous changes during the simulation time. Changes occur in two ways: autonomously and/or triggered by an input; for instance health or energy level is subjected to both changes, in fact it decreases slowly with time and, when Adam falls in a trap or in a danger points, the decrease is slighter. Vice versa, when Adam reaches a food source, his energy level increases, depending on the amount of food consumed, until it reaches a maximum value. Fear variable behaves in the same way: it decreases when Adam becomes more confident of himself and his world but slightly increases when Adam falls in trap.
- *Deliberative and Reactive behavior:* The first behavior type follows simple rules, driven for instance by leading motives like hunger drive or the need of thinking, while deliberative behavior needs a predetermined planning action to reach a determined goal.
- *Internal and external actions:* Adam's actions repertoire contains external actions, which have impact on the surrounding environment like gathering a food source, but also internal ones, which only affect Adam himself, like the planning or the thinking action.
- *Learning:* Adam is characterized by cognition of himself and his world and, thanks to his experience, recognizes some processes of the world where he lives in, like the food regeneration process, knowing even better the time it takes for the food to grow again. However this cognitive process is not sudden, but it is a process in a continuous evolution, because Adam initially does not know the food growth speed, but he learns that gradually in order not to mistake.
- *Forgetting:* Adam is capable to learn but is also subjected to forgetfulness because he is human and his memory capacity is finite. For instance, when he visits a field after a long time of absence, he could not remember perfectly if this field is neutral or it contains a food source or a trap. In order to refresh his memory, Adam has to revisit that field.

The model described in the following section has several points in common with Adam's model and PECS reference models, because, like Adam, the individual in the tunnel has to preserve his life avoiding danger points (fire, smoke), reaching the by passes (instead of the food sources) using the cognition to recognize the right road signs. In addition however he has to deal with other people that can affect his choices with their fear and their own behavior.

3. The Multicriteria Analysis

A critical situation like a tunnel evacuation is, involves several parameters that affect the individual choice; for this reason this situation can be addressed to a multi-criteria decisional problem. For these typologies of problem one of the most suitable analysis techniques is no doubt Thomas Saaty's AHP (Analitic Hierarchic Process) methodology.

The individual, acting as a decision maker, detects a set of alternatives to be assessed on the basis of high-level criteria and relative subcriteria determined by social studies; each criterion has a percentage of importance and reports a score, which determines the impact of the criterion on the decision.

The score of each decisional alternative is the weighted average of each criterion scores on the decision multiplied by the weight assigned to each criterion. In the case analysed the weights of the sign typologies have been considered:

The IsFireFight type: referring to the possibility to carry out active actions so as to limit the damage to the property and the life.

The IsExit type: pointing out the possibility to reach safety.

The IsPhone type: allowing communications with the road rescue service.

The IsSOS type: allowing putting in a state of alarm. There is another factor that significantly affects the weight of sign typologies, and this is the training and the natural attitudes of the individuals involved in the evacuation; in particular, three categories of people have been considered:

- **"Informed" User (or trained).** It is the user with the high culture in safety matter. This user will tend to choice the alternative able to save his life
- **"Uninformed" User (or not trained).** It is the user without specific technical knowledge. He will tend to preserve the property and life.
- **"Hero" User.** It is the user aiming to help and make himself useful for the others. Doctors, Fire Fighters and other people involved in rescuing belong to this category.

For each one of these typologies the importance of each sign type has been calculated with the AHP methodology. As an example, the procedure for "Informed" users is explained in detail; as a first step the behaviour local importance matrix (Table 1) is built considering the importance of the i_{th} line respect to the j_{th}, column, for instance, considering the line 1 (altruism) and the column 2 (property) the following question for an "informed" individual arise: how is the altruism important respect to the property? If the behaviour importance displayed in the line (altruism) is greater than that in the column (property), the a_{ij} element of the matrix is a number greater than 1 (on the contrary we would have put a number lower than 1). Table 1 represents the criteria priority for the informed individuals.

Comportamenti	Altruismo	Proprietà	Vita	W	W Normalizzata
Altruismo	1	2	0,2	0,22	14,58%
Proprietà	0,5	1	0,2	0,21	13,80%
Vita	5	5	1	1,08	71,61%
				1,51	100,00%

Table 1 – Behaviour matrix ("informed" individual)

Table 2 shows the impact of the behavioural typology on the sign types.

Comportamenti	Altruismo	Proprietà	Vita	W	W Normalizzata
Altruismo	1	2	0,2	0,22	14,58%
Proprietà	0,5	1	0,2	0,21	13,80%
Vita	5	5	1	1,08	71,61%
				1,51	100,00%

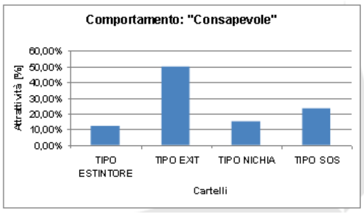
Altruismo	TIPO ESTINTORE	TIPO EXIT	TIPO NICHIA	TIPO SOS	W	W Normalizzata
TIPO ESTINTORE	1	0,33333333	0,5	0,33333333	0,35	10,61%
TIPO EXIT	3	1	2	0,5	0,81	24,38%
TIPO NICHIA	2	0,5	1	1	0,86	25,70%
TIPO SOS	3	2	1	1	1,31	39,30%
					3,33	100,00%

Proprietà	TIPO ESTINTORE	TIPO EXIT	TIPO NICHIA	TIPO SOS	W	W Normalizzata
TIPO ESTINTORE	1	0,2	0,5	0,5	0,48	16,65%
TIPO EXIT	5	1	0,333333333	0,5	0,52	17,88%
TIPO NICHIA	2	3	1	0,33333333	0,58	19,85%
TIPO SOS	2	2	3	1	1,33	45,62%
					2,91	100,00%

Vita	TIPO ESTINTORE	TIPO EXIT	TIPO NICHIA	TIPO SOS	W	W Normalizzata
TIPO ESTINTORE	1	0,2	0,5	0,33333333	0,20	11,74%
TIPO EXIT	5	1	5	4	1,05	60,95%
TIPO NICHIA	2	0,2	1	0,5	0,21	11,95%
TIPO SOS	3	0,25	2	1	0,27	15,36%
					1,73	100,00%

Table 2 – Matrix of the road sign importance as a function of the behaviours ("informed" individual)

Multiplying the local matrix importance (normalized W) the global importance or sign attractive character is obtained. Fig. 2 shows that the Exit panel is the most attractive for the "informed" user.



Tipologe Cartelli	Attrazione
TIPO ESTINTORE	12,25%
TIPO EXIT	49,68%
TIPO NICHIA	15,05%
TIPO SOS	23,03%

Fig. 2 - Global importance of the signs for the "informed" individual

In the same way the other two behavioral typologies have been analyzed, in particular for the "Uninformed" user, which represents the most common type of car driver, there is no sign more attractive than others, especially if the signs have the same brightness. For the "Hero" user the Fire Extinguisher sign is the most attractive because saves human lives, as shows Fig.3.

Tipologe Cartelli	Attrazione
TIPO ESTINTORE	14,64%
TIPO EXIT	22,74%
TIPO NICHIA	23,01%
TIPO SOS	39,61%

Tipologe Cartelli	Attrazione
TIPO ESTINTORE	50,19%
TIPO EXIT	8,58%
TIPO NICHIA	15,62%
TIPO SOS	25,62%

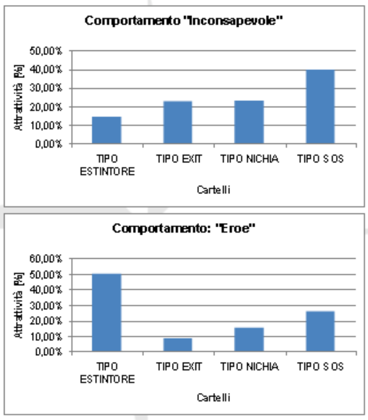


Fig. 3 – Sign global important for the "uninformed" and "hero" users

After determining the sign attractive character for every type of individual involved in the accident, it is necessary to analyze the behaviour evolution in the time during the simulation. We can identify a sequence of logical processes divided into steps, schematically we have:

Step 1. The individual is "activated" (simulation beginning) in the post-event condition with a "normal" respiratory frequency and intoxication level and a particular behaviour attitude (informed, uninformed and hero).

Step 2. The individual is conscious of the situation in which find himself (he is still inside the car).

Step 3. After that, he exits from the car (the exit from the car is modelled as a queue, not all the people inside the car shall exit simultaneously but one after the other).

Step 4. Once exited from the car, the individual is in front of a series of behaviour choices, which determinate the path and then the safety:

4.1. According to the physical conditions of the place where find himself (i.e. heat, smoke) the individual identifies a sign and possible target subset; he determines an eventual path towards the chosen target by excluding from the alternative those that cannot be followed or dangerous. The choice is rational and it depends on the instinct and the importance assessment based on the AHP multi-criteria analysis.

4.2. The individual, after having done his rational choice in the previous step, he has to evaluate the distance to cover and, according to the physical and environmental conditions, begins to run towards his target. Along the way he evaluates other eventual alternatives, considering the shortest distance among the practicable path (obstacles, heat). When he is near to the target, and so to safety, he slows down and turns his run in walking.

4.3. This phase depends on the fact that the individual would have reached or not his final target. In the first case, we suppose that the met sub target (sign/panel) can condition him to pursue towards a following target. In the second case the individual can re-think about his choice and change his destination.

4.4. While the time passes the individual ingests smoke and carbon monoxide present in the tunnel and intoxicates. Also the heat produces damage, causing hyperthermia and skin burns.

Phases 4.3 and 4.4 are iterated until the individual achieves his goal or dies.

Here we have a behavioural model driven by the so-called "Reactive Behaviour", or guided by the individual instinct, which is affected by the signs properly placed and illuminated. Individuals have also sometimes "complicated" behaviours, because instinct, fear and panic could significantly affect the rationality of the choice. For instance an individual, at the beginning of the accident, is strongly torn because he/she can not decide between leaving the car reaching safety or stay in because he does not want to leave an expensive good, as a car is, burning and so he tries until the end to preserve everything. This indecision can cause anxiety increasing fear and panic level, inhibiting the rational choice among the alternatives, especially for "uninformed" people. All these aspects and interactions have been taken into account in the pair comparison of the AHP analysis.

4. The evacuation model

The evacuation model presents two complementary and synergic modules with a graphic user interface (GUI):

- *Data input and scenario creation module*: it is implemented using bCAD software and it is capable to map the tunnel case study, to position the signs and the safety devices (fire fighting systems, SOS columns, etc…) along the carriageways, defining the brightness of the signs themselves with their height and other attributes. This module allows also positioning the means (cars, trucks and buses) involved in the accident in order to create a simulation scenario.
- *Evacuation detail module*: This module is able to determine the flow conditions of the people at the by passes according to the input conditions predetermined.

The bCAD interface is similar to most of the commercial 2-D drawing tool like Autocad or similar, in fact the toolbar allows drawing different objects like lines, poly-lines etc… and, thanks to an "ad hoc" tool developed by the authors, it is possible to position objects inserting their coordinates in a database. Thanks to this application it is possible to dispose the cars involved in the accident, the signs, the safety systems and locate the fire starting point. The GUI allows also establishing the fire power.

The evacuation module allows the users to observe the fire evolution at different time steps. In particular it is traced:

- the evacuation paths of the users involved in the accident (yellow);
- the volume occupied by the smoke and the heat (red).

Figures from 4 to 7 represent some different screenshots of the model output.

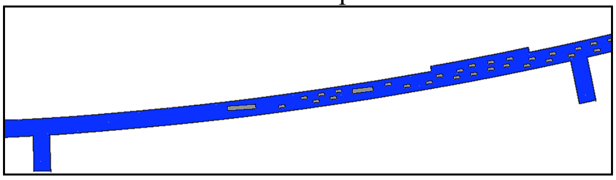


Fig. 4 – Tunnel at the simulation beginning (t=0)

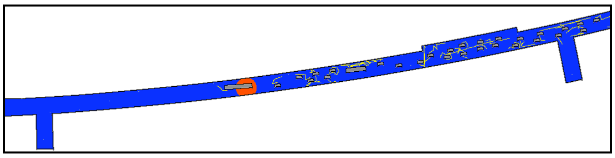


Fig. 5 – Tunnel after 30 seconds from the fire beginning

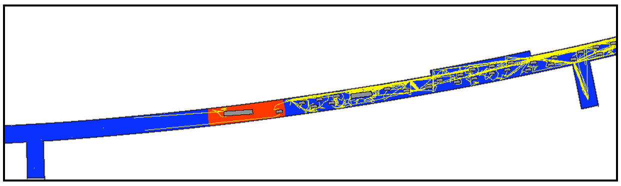


Fig. 6 – Tunnel after 60 seconds from the fire beginning

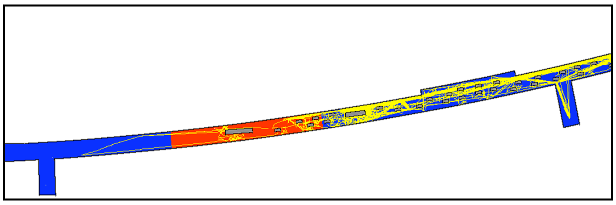


Fig. 7 – Tunnel after 120 seconds from the fire beginning

The case study reproduces an accident in a 4.5 km long tunnel triggering a fire of 30 MW power starting from a truck, the accident involvers several cars and also buses.
The simulator outputs analyzed as KPIs (Key Performance Indicators) are:

- the number of people not escaped from the tunnel at the end of the simulation time;
- the number of people escaped after the simulation time;
- the number of people injured or intoxicated by carbon monoxide (CO) at the end of the simulation time;
- the minimum, maximum and average exiting time from the vehicles; it represents a sort of "reaction time" after the fire explosion;
- the minimum, maximum and average escaping time from the tunnel bypass, which is calculated starting from the fire exploding until the escaping from the bypass.

These outputs have been set as objective functions for a monovalent Analysis of Variance (ANOVA) devoted to evaluate the improvement provided by the new sign configuration respect to the original one. The results of the analysis on the main objective functions are shown in the tables from 3 to 5.

Table 3 – Monovalent ANOVA analysis (Involved people)

Variation origin	F_{calc}	F_{tab}
Remained People	13,14	7,71
Safe Exit People	7,76	7,71
Injured People	2,18	7,71

Table 4 – Monovalent ANOVA analysis (Time of the people exit from the motor-vehicles)

Variation origin	F_{calc}	F_{tab}
Remained People	13,14	7,71
Safe Exit People	7,76	7,71
Injured People	2,18	7,71

Table 5 – Monovalent ANOVA analysis (People exit time from the motor-vehicles)

Variation origin	F_{calc}	F_{tab}
Remained People	13,14	7,71
Safe Exit People	7,76	7,71
Injured People	2,18	7,71

The results obtained clearly show how the new sign disposition significantly affects some objective functions like the maximum permanence time in the tunnel, but also the number of people remained in the tunnel after the simulation time and, even in a shorter measure, the number of the escaped people. On the contrary the alternative signs position does not affect the minimum and the average times and the number of the injured people.
In conclusion to this analysis, the alternative sign disposition improves significantly the intrinsic tunnel safety, increasing the number of the people reaching the safety.

5. The 3-D Tunnel Model

The authors also developed a 3-D model devoted to analyze the flows of the people escaping and, in particular, the smoke evolution dynamics inside the tunnel. The model is developed using specific 3-D modeling software: Blender™, by Blender Foundation. This software is open source and allows modeling non-linear systems and fluid dynamics,

and it was developed for the videogames sector of application. Blender, in fact, "was born" as a 3D application for Neo Geo Videogames Company, world famous for games like "Metal Slug" or "Double Dragon". Anyway Blender is not a simulation tool, but just a modeling one, so the tunnel 3D model needs to be exactly reproduced, concerning measures, sections, radius of curvature and slopes; for this reason the 3-D reproduction of the tunnel is imported in another software, Wolverine Proof Animation 3-D™, that allows animated simulation. The aim of this 3-D model is to provide a feedback about the evolution of the smoke propagation that the evacuation model is not able to give; in fact smoke propagates mainly on the vertical axis, so a 3-D model is required to study the phenomenon; the choice to implement the tunnel model in Blender and then in Proof Animation is devoted to implement different scenarios with different conditions of sign positions and brightness, parameters highly affected by the smoke speed, as shown in the results in the following section.
Figure 8 represents a snapshot of the section of the 3-D model created.

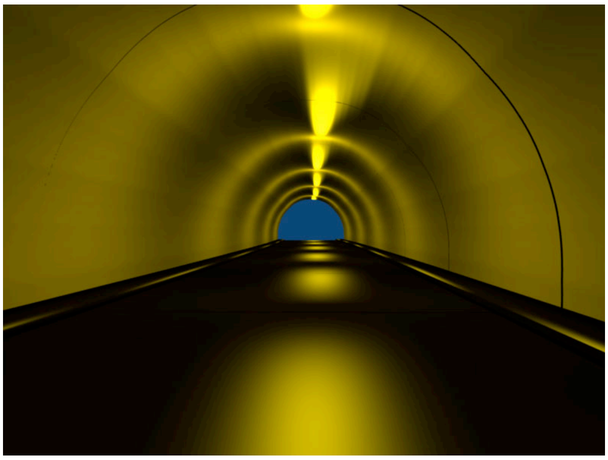


Fig.8 – Blender Rendering of the tunnel section

Analyzing in detail how the model has been implemented, the tunnel profile has been firstly developed in Blender considering the radius of curvature in the plane starting from the 2D model developed in bCAD. The tunnel reproduction considers having three bypasses at regular distance devoted to evacuate the flow of the people and to let enter in the rescue squads with their vehicles (ambulances, fire dept. vehicles, etc…). The 2D model, once designed the tunnel carriageway section, has been then "extruded" in Blender for the whole length including bypasses. In the tunnel there are also pull-ins for whom the carriageway section has been enlarged. Figure 9 represents the construction phase in Blender, while Figure 10 shows a tunnel detail nearby one of the by-pass, Figure 11 shows the extruded section of the tunnel and, finally, Figure 12 shows one of the emergency pull-ins.

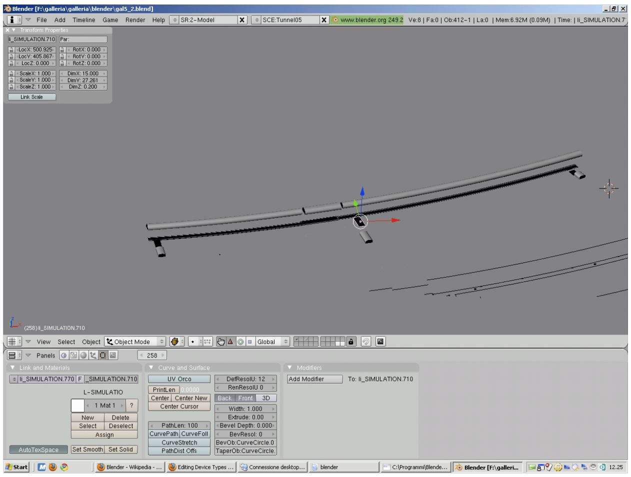


Fig.9 – Blender Tunnel Profile on plane

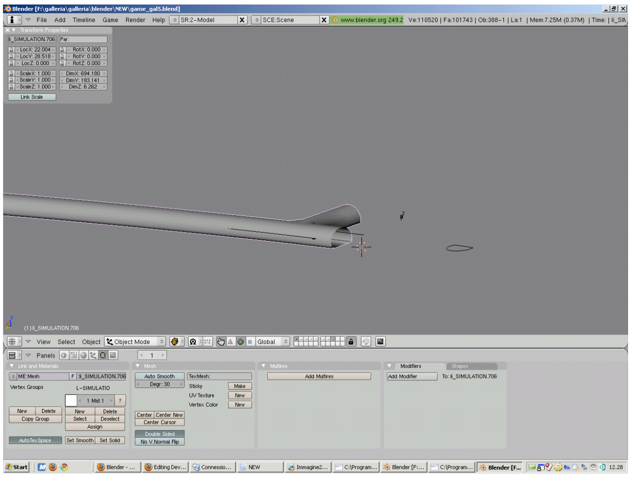


Fig.10 – Blender Tunnel Bypass Detail

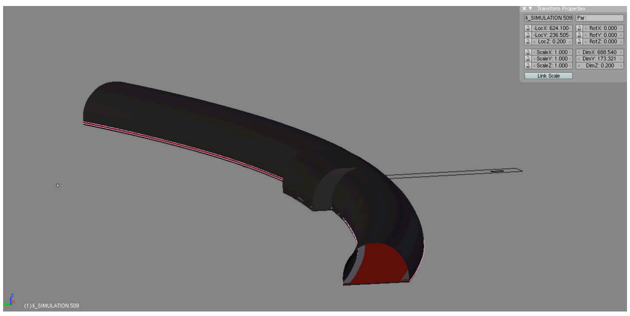


Fig.11 – Blender Tunnel Extruded Section

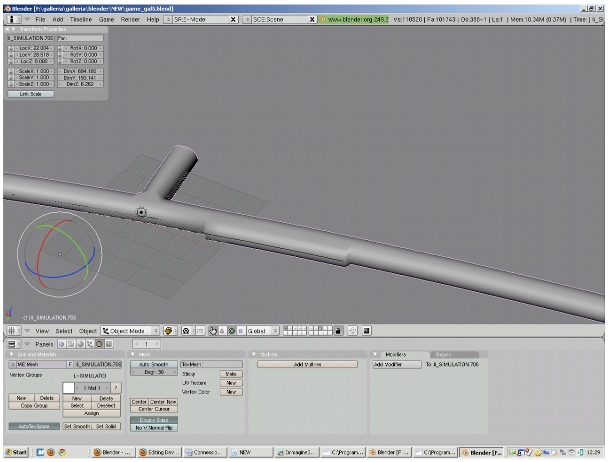


Fig.12 – Blender Emergency Pull-in

The 3D model has been rendered and inserted in a virtual scenario in which a car can be driven by the user in order to inspect the situation. By now there is only one type of vehicle but it is possible, thanks to the software flexibility, to model more suitable and sophisticated models like ambulances or fire department trucks. Figure 13 shows the tunnel inserted in the reference scenario.

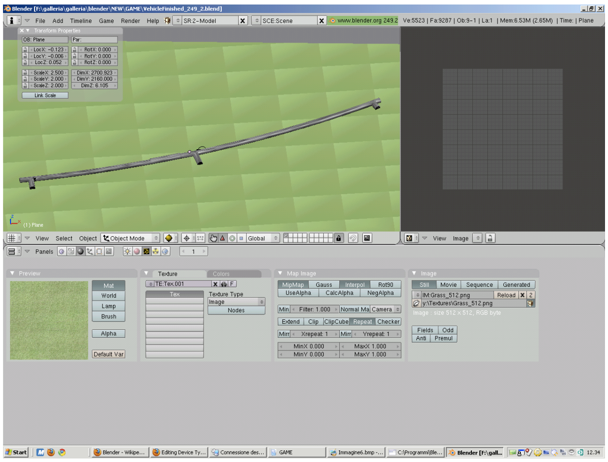


Fig 13 – The Tunnel in the Reference Scenario

The model has been then imported in Wolverine Proof Animation 3D™ in order to simulate the flow of the people escaping from the tunnel in smoky condition. The importing process was not very simple because the polygons need to be converted in triangle meshes, function possible inside Blender. The object is exported from Blender in Direct X format, and than imported in Proof Animation as a new object. It is important to define a material for the Direct X format exported. In Proof Animation, which allows animated simulation, signs, vehicles and all the data inserted in the database are placed in order to reproduce the accident scenario and then study the human behavior of the people involved also in a 3D environment.

6. Results and Conclusions

For the evacuation model other significant factors for improving safety have been identified:

- *Smoke speed*: expressed in meters per second, it is the smoke speed in the tunnel failing the forced draught;
- *Exit sign brightness intensity*: it is the brightness intensity of the exit signs by the By-pass;
- *Safe sign brightness intensity:* it is the brightness intensity of the other signs in the tunnel.

The objective functions assessed are the same discussed in the section 4 and, considering initially the first three (remained, escaped and injured people), the most significant impact is provided by the smoke speed: the faster is the smoke, the greater is the number of people remained in the tunnel, the Response Surface of Figure 14 shows these results:

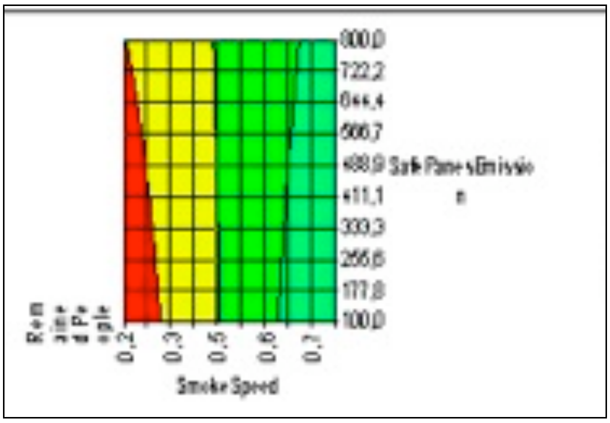


Fig. 14– Output regressive analysis: Remained People

Figure 14 demonstrates also that the sign brightness does not affect the number of people “trapped” after the simulation time, while the brightness of the exit signs has a significant impact on the second objective function: the number of the people safe at the end of the simulation time; in fact, respect to other signs which worsen the performance because “deviate” the people, bright exit signs guarantee an increasing of people who reach safety. The results of this analysis are shown in Figure 15.

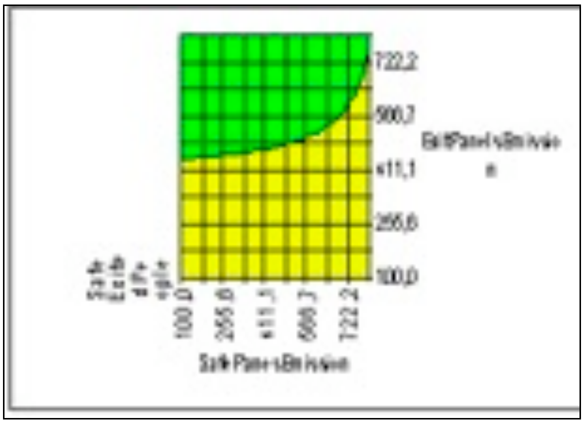


Fig. 15 – Output regressive analysis: Safe Exit People

Even the number of injured and intoxicated people is affected strongly by the smoke speed, but in a less marked way respect to the number of people remained in the tunnel. RSM (Response Surface Methodology) results are shown in Figure 16.

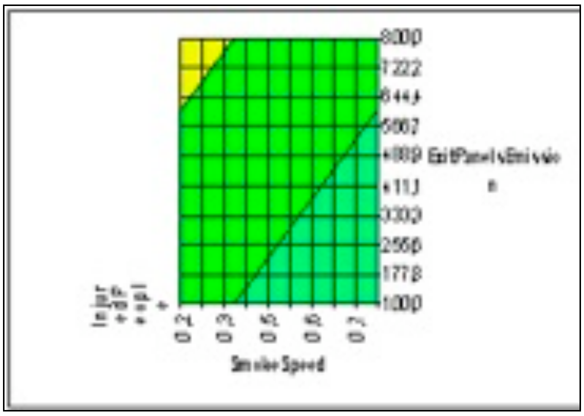


Fig. 16 – Output regressive analysis: Injured People

Smoke speed affects also the average escaping time: the time decreases when the smoke is faster; because the people are afraid and so they abandon their cars faster.
Regarding the average permanence time in the tunnel, both the smoke speed and the exit sign brightness heavily affect this objective function: when smoke is faster people escape faster, but if the signs are brighter escaping time is longer, because they are visible for more time. The results of the analysis are shown in figure 17.

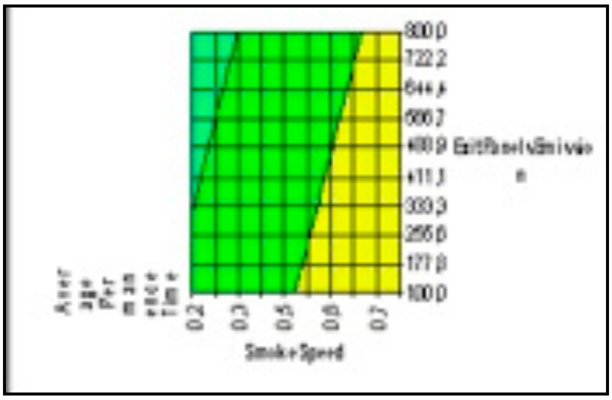


Fig. 17 – Output regressive analysis: Average Permanence Time

Concluding, this work proposed an innovative approach for managing a critical emergency situation such as a tunnel evacuation considering different sign positions and human behavior. For the evacuation the authors proposed a PECS model to study this phenomenon building a 2-D model. This model allowed "What if analysis" considering sign position and brightness in order to evaluate their impact on the model objective functions.
There is also a 3-D model that proposes to better study the dynamics of the smoke propagation inside the tunnel and the relationship with the crowd flow.

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