THE 10TH INTERNATIONAL WORKSHOP ON APPLIED MODELING & SIMULATION

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General Co-Chairs' Message

Welcome To WAMS 2017!

This International Workshop in Applied Modeling and Simulation (WAMS) was established several years ago as a series of International Conferences organized in Latin America: AMS2004 (Rio de Janeiro) and AMS2006 (Buzios); these events were focusing on Application and Theory of Modeling & Simulation for promoting joint research projects across the ocean. The success of these events was guaranteed by the establishment of the I M CS (International Mediterranean & Latin American Council of Simulation) that created effective co-operations among Simulation Communities around the world (e.g. Liophant, Simulation Team, SCS). In following years WAMS was organized in both Atlantic sides (i.e.Rio de Janeiro, Italian Riviera); WAMS 2011 was organized in St. Petersburg, Russia as joint co-operation with SPIIRA, Russian Academy of Science and co-located with the International Marine Defense Show. The 2011 edition created new strong connections with Russian simulation community and provided further opportunities for M&S. In 2012, WAMS was held in Rome in connections with the NATO CAX Forum, where several innovative Serious Games and Simulators were presented as interactive experience for the attendees demonstrating the potential of new advances for defines and logistics sectors.

The WAMS 2013 moved back to Latin America and attracted scientists, technicians and experts from world leading Universities, Institutions, Agencies and Companies; indeed the 2013 edition was held in Buenos Aires, Argentina, and it was attended by almost all Latin America Countries as well as by scientists from Europe, North America, Asia and Australia.

This year, WAMS is again co-located with the NATO CAX Forum in Florence, Italy and provides the attendees with the possibility to attend both WAMS and NATO CAX Forum sessions. Therefore, in addition to scientific sessions and papers that concentrate on Applications of Simulation and Computer Technologies in different areas (including Industry, Logistics, Cultural Heritage, etc.), the attendees will take advantage of the NATO CAX Forum sessions providing an overview on the latest news about the use of Modeling & Simulation in Defence and Military Applications.

Historically WAMS also provided opportunities for setting up new collaborations and research project; we still bring ahead this idea and that's the most important reason to keep, also this year, the ongoing cooperation with the NATO CAX Forum and with the Military and Deference Community. Furthermore, WAMS will be held the week after the I3M 2017 Multi-Conference that this year will be held in Barcelona; this is a very good opportunity for researchers and scientists to attend two of the most important simulation appointment in Europe.

We take also this opportunity to thank the WAMS 2017 International Program Committee, the track chairs, the reviewers and the local organization committee: the success of WAMS is mostly related to their hard work along the last year.

We hope you will enjoy WAMS and have a wonderful stay in Florence.

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The WAMS 2017 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The WAMS 2017 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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Index

Use of Simulation for Studying Ecosystem Tipping Points

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ABSTRACT

Simulation models have been extremely useful in ecology for determining ecosystem dynamics. When very many species may occur together, the computational costs of simulating a wide parameter space may be very high. In this paper we describe an abstract canonical model of species competition, first used for species of coral on reefs. Such lattice based models are well-suited to GPU clusters and we report performance figures for a consumer GPU board and a purpose built larger scale GPU cluster.

Keywords: ecosystem, compete model, coral, GPU cluster

1. ECOLOGICAL SIMULATION

Coral reefs are important ecosystems occurring in many parts of the world. They are rich ecologies, supporting various types of fishing industry. They are also important tourist destinations, known for their diverse coral colours and shapes and the multitude of brightly coloured fish and other sea creatures which inhabit them.

Yet coral reefs are under constant threat (Pandolfi et al., 2003). In fact in the last couple of years the Great Barrier Reef has suffered two major bleaching events, destroying a large fraction of the coral (Ainsworth et al., 2016). Large-scale simulations with extensive parametrisation from real, ocean data successfully reproduce reef dynamics (Melbourne-Thomas et al., 2011a,b; Steneck and Johnson, 2014). Such models have proved valuable in estimating effects of climate-change and overfishing (Ling et al., 2009).

Particularly important for ecological management are tipping points, or phase transition, where the ecology goes through a massive, possibly irreversible change, such as species extinction. Phase transitions frequently involve increases in correlation around the transition and simulation models have also been valuable in determining characteristic length scales of ecological systems (Johnson, 2009; Habeeb et al., 2005). However, predicting an impending phase transition is much more difficult. Features such as critical slowing down and increased variance (Scheffer et al., 2012) have proved insightful, while for the Ising spin model, used widely by physicists as a model for a second-order phase transition, the global transfer entropy is an effective predictor (Barnett et al., 2013).

A variety of simulation approaches for studying ecologies exist (Fulton et al., 2003). Full, data-driven simulations are computationally demanding and to develop insight into ecosystem phase changes requires simpler models, such as the Ising model. One such model developed by author Johnson is the *Compete* model, which captures the dynamics of competition between coral species and other benthic (seabed) warfare.

There are numerous species of coral within a reef and these compete with each other for space. Thus one coral species will grow into the territory of another one, partially, or fully, displacing it. However, *overgrowth* is non-transitive. Species A may overgrow species B and B may overgrow C. However, this does not imply that A will overgrow C. With as many as dozens of species present in any one reef, studying the complex dynamics of the emergent populations requires extensive simulation. This is the motivation for the Compete model. As an abstract model, akin to a spin model or cellular automaton, it can be used to study a wide range of dynamic scenarios with feasible computing resources.

We have applied the model to other domains, such as the stability of shopping malls, using data from Australian towns and cities (Duncan et al., 2015), hence a detailed understanding of its tipping points is called for. In this paper we create an extensive phase diagram, as a precursor to developing information theoretic models of the transitions. The model is highly suitable for implementation on GPUs and we measure the efficiency on a 10,000 element GPU cluster.

2. THE COMPETE MODEL

The Compete model uses a 2D lattice with local, stochastic update rules. An arbitrary number of species occupy sites in the lattice, with one specimen per site. Each species has a growth rate, which determines how likely it is that it will displace a species in its immediate neighbourhood. Just as in a natural ecological system, species overgrow contiguous neighbours and in this model a four neighbour (von Neumann) update is used (North, South, East, West).

Since the overgrowth is intransitive, we need to represent this as a matrix of size equal to the number of species. Each element of the matrix is the probability of overgrowth of one species by another (hence non-symmetric). Thus overgrowth is not binary, but stochastic with a probability range in [0..1]. The key parameters are:

- The number of species, M and the lattice size, $LW \times LW$
- The growth rate of each species. With a large number of species, exploring the space of growth rates requires a way of organising the ensemble of rates. To bring these into a uniform framework we use an empirically based Gaussian behaviour, where each species has an optimal growth temperature, and falls off as a Gaussian above and below, Eqn. 2.
- The dominance factors, which describe how one species will replace another. These rules may be intransitive: B may over grow (replace) A, C over grows B, but A over grows C. We bring the dominance factors into a similar temperature based framework in (Sect. 3.1.).

The lattice is initialised at random with a member of a single species at each lattice point. All sites are updated synchronously at each time step. Each cell picks a neighbour, d, at random and determines if it can dominate it. If so, it changes to the dominant neighbour with probability, p_d

$$p_d = g_d O_d \quad (1)$$

where O_d is the probability of the neighbour winning (dominating) in an encounter with the central cell and g_d is the growth rate of the dominant neighbour. The growth rates have a normal distribution dependence on temperature (Eqn. 2) and are normalised to the range [0–1].

$$g_d \propto e^{\gamma(T-T_{opt})^2} \quad (2)$$

where T_{opt} is the optimum temperature and γ determines the variance.

One important aspect of the dynamics is that the growth rates do not determine the ultimate survival of any given entity. It is the combination of growth rates and dominance factors which determine the ultimate outcome.

3. GPU IMPLEMENTATION

To get an accurate assessment of the GPU performance, we rewrote the model in C++ using the Nvidia CUDA library for accessing the GPU cluster, in this case a Xenon NITRO T6 4GPU Visual Workstation comprising 2 Intel Xeon E5 2.10GHz each with 6 physical Hyper-Threaded Cores—totalling 24 virtual Cores—with 4 Nvidia Tesla K20 GPUs.

The generalisation of the C++ code to run under CUDA is relatively straightforward, albeit somewhat complicated.

The main initialisation task is to allocate memory for the model on the GPU cluster itself as shown in Figure 1.

The central routine for the model is shown in Figure 2, where the $global$ prefix indicates work to be carried out in parallel on the cluster. Conceptually there is a copy of this routine for each site of the lattice, subdivided into thread blocks, which CUDA further divides into *Warps*. Each warp comprises 32 instruction-synchronised threads which favours avoiding any execution branches. Each thread is provided a thread identifier within a block, and each block is located within an overall grid. The block coordinates and thread identifier are used to associate a specific GPU thread with a lattice element.

Once the histograms are calculated on the GPU, the information theory quantities are easily calculated on the main processor.

Random number generation was found to be a significant computational overhead. The CUDA cuRand library was used, which has a good quality Mersenne twister generation. To try to reduce cache misses, all random numbers were calculated and stored before the first timestep. This was not effective causing about a 20% increase in execution time.

We also ran simulations on a workstation comprising an Intel i7-4790 @ 3.60 GHz with a significantly lower cost Nvidia GTX 770 GPU. We found that the GTX 770 performed better than the Tesla K20 GPU for this task, as it is memory bound rather than compute bound. The peak memory bandwidth of the GTX 770 is $1.17\times$ greater than the Tesla K20, which matches the performance increase we see for this model. This is opposed to the $8\times$ increase in double precision operations per second that the K20 has over the GTX 770, which would be utilised if our simulation was more computationally bound.

Despite some indications to the contrary, the superiority of the Tesla for double precision floating point was not apparent for the Compete model. We also ran a simple component-wise multiplication and add on two 2^{25} length vectors with the results show in Table 1, showing that the GTX is in fact faster for memory bound tasks.

A demonstration application included in the CUDA library which performs n-body simulations, a compute bound task, does indeed reveal the expected $8\times$ speed up of the Tesla K20 over the GTX 770 when using double precision calculations. These results highlight that while one might expect significantly

```
// Allocation
gpuErrchk(cudaSetDevice(0));
gpuErrchk(cudaMalloc((void**)&dev_thenn, sizeof(int) * lwsq * DIR::COUNT));
gpuErrchk(cudaMalloc((void**)&dev_world_batch,
                     sizeof(char) * lwsq * batchSize));
gpuErrchk(cudaMalloc((void**)&dev_g, sizeof(double) * ns));
gpuErrchk(cudaMalloc((void**)&dev_c, sizeof(double) * c.size()));

gpuErrchk(cudaMemcpy(dev_thenn, &(thenn[0]), sizeof(int) * lwsq * DIR::COUNT,
                     cudaMemcpyHostToDevice));
gpuErrchk(cudaMemcpy(dev_world_batch, &(world[0]), sizeof(char) * lwsq,
                     cudaMemcpyHostToDevice));
gpuErrchk(cudaMemcpy(dev_g, &(g[0]), sizeof(double) * ns,
                     cudaMemcpyHostToDevice));
gpuErrchk(cudaMemcpy(dev_c, &(c[0]), sizeof(double) * c.size(),
                     cudaMemcpyHostToDevice));
// Release
gpuErrchk(cudaFree(dev_states));
gpuErrchk(cudaFree(dev_c));
gpuErrchk(cudaFree(dev_g));
gpuErrchk(cudaFree(dev_world_batch));
gpuErrchk(cudaFree(dev_thenn));
gpuErrchk(cudaDeviceSynchronize());
```

Figure 1: Allocation and release of memory for the typical arrays — the world (model, size lwsq) and the neighbours (thenn). World states are batched on the GPU to reduce the memory overhead of transferring back to system RAM. A synchronisation step is utilised at the end of the simulation to ensure all commands are finished on the GPU. `gpuErrchk` is a helper macro for checking error codes returned by the CUDA library.

```
__global__ void competeKernel(char const ns, int const lwsq,
           double const*const c, double const*const g, char *newWorld,
           char const*const backbufferWorld,
           int const*const thenn, curandState *rngStates)
{
    // Get id of lattice element the current thread is processing
    int idx = blockIdx.x*blockDim.x + threadIdx.x;
    if(idx >= lwsq) return;

    // Pick random direction
    DIR dir = DIR(curand(&rngStates[idx]) % DIR::COUNT);

    // Get index of neighbour
    int nnIdx = thenn[idx * DIR::COUNT + dir];
    // Get index in overgrowth matrix
    char cIdx = backbufferWorld[idx] * ns + backbufferWorld[nnIdx];

    // Check if neighbour overgrows
    bool nCheck = c[cIdx] * g[backbufferWorld[nnIdx]]
                  > curand_uniform_double(&rngStates[idx]);

    // Set cell to neighbour or itself based on nCheck
    newWorld[idx] = backbufferWorld[nCheck ? nnIdx : idx];
}
```

Figure 2: Fragment of CUDA code for the model showing the discovery of the site indices (cIdx for the cell and nnIdx for the neighbours)

greater performance on the Tesla card in all cases—particularly given its cost relative to the consumer card—in practise it is highly dependent on the nature of the task, that is, if it is compute bound and requires double precision calculation.

Figure 3 shows the speedup relative to the i7 processor using all its 8 threads. Timings are collected without any time-consuming writes to file occurring within the simulation. This requires the entire simulation output to be stored in system (not GPU) memory. This thus limits the length of simulation, hence the 100,000 time steps can only be achieved for models of lattice size 100x100.

Figure 4 shows the performance increase for the Tesla GPU against its own Xeon processor, which has 24 threads, compared to the i7's 8 threads, but it runs at approximately two thirds of the clock rate (see above).

Finally Fig. 5 shows the computation time for the GTX770 as a function of lattice (model) size. When the model size does not fit an integer number of times into the GPU size, then a discontinuity in performance occurs as a single additional warp needs to be executed in isolation.

3.1. Phase Diagrams for Compete

Even a three species model has 6 parameters, the three growth rates and the overgrowth rules. To simplify this we use a Glauber dynamics-like approximation, where the overgrowth probability $p_{A \to B}$

$$p_{A \to B} = \frac{1}{1 + e^{\frac{-\Delta E}{T}}} \tag{3}$$

and

$$p_{B \to A} = \frac{1}{1 + e^{\frac{\Delta E}{T}}} \tag{4}$$

where ΔE represents an energy of overgrowth and T is temperature. The two add up to one, hence the *Compete* simulation runs in exactly the same way with the overgrowth probabilities calculated as a function of temperature.

Thus we can now produce a phase diagram for any given choices of energy differences as a function of growth rates, or functions thereof.

4. ILLUSTRATIVE SIMULATION RESULTS

A minimal 3 species system exhibits a discontinuous phase transition with hysteresis. Starting out with 3 species and equal growth rates, each at 20 units (1 = blue, 2 = yellow, 3 = red). This system shows stable fluctuations with each species having similar abundances on the landscape (each ~33% cover) (Fig. 6).

Letting the environment change so that the growth rate of one species increases relative to the other two (e.g. let growth of species 3 [red] increase to 50). In this circumstance cover of species 2 increases to ~60% while cover of species 1 and 3 decrease to ~20% each, but the system is otherwise stable in these circumstances (Fig. 7).

Allowing the growth of species 3 to increase further, the system dynamic becomes unstable and species 3 will eventually go extinct, thus in one sense representing a phase transition that ultimately results in a monoculture of species 1 [blue] (Johnson and Seinen, 2002). Here is the result when growth rates of species 3 are allowed to increase to 100 (species 1 and 2 remain at 20) (Fig. 8). Note the counter intuitive behaviour here, where the *fastest* growing species is the one which goes extinct. Species 3 rapidly devours 2, allowing 1 to flourish, which in turns devours and completely eliminates 3. Once S2 is eliminated by S3, there is no species to limit S1 overgrowth of S3, and the system moves to a monoculture of S1. If the simulation is initiated with growth of S1 and S2 fixed at 0.2 (20%) but with all possible growth rate genotypes 1-100% for S3 scattered over the landscape, selection eliminates colonies with low and high growth rates so that eventually only colonies with growth rates between 0.4 and 0.5 (40-50%) persist (Johnson and Seinen, 2002). The phenomenon is an example of community-level selection (Johnson and Boerlijst, 2002).

If Species 3 grows sufficiently fast, it will wipe out 2, which in turn would not have had much time to over grow 1. Thus eventually 1 will remove 3 leading to a monoculture. If once the dynamic leads to a monoculture of species 1, we allow open recruitment of all 3 species back to this landscape, AND return the environment back to what it was so that all growth rates are again equal (at 20), we do NOT return to a dynamic of coexistence of all 3 species in approximately equal abundance (as shown in section 1 above) because of a transition in the scale of spatial self-organising. Instead, there is a fundamentally different kind of dynamic in which there are massive fluctuations even though there are periods where all 3 species occur together on the landscape (Fig. 9). In this sense, this shift in dynamic defines a tipping point in the emergent dynamics around a discontinuous phase transition with pronounced hysteresis.

Finally, in some parts of parameter space it also seems possible to have spontaneous shifts between two fundamentally different types of dynamic associated with two fundamentally different scales of self-organised patch size (Fig. 10). These shifts will reflect as changes in length scale of the system.

5. INFORMATION THEORY MEASURES

Information theory has proved an important tool for studying phase transitions. The measure found to peak at the phase transition in second order simulations is the Mutual Information, Eqn. 5, discussed

	Tesla K20		GTX 770	
Precision	Float	Double	Float	Double
Average Time	2.986	5.388	2.513	4.554
Std Dev.	0.008	0.008	0.018	0.020

Table 1: Performance figures for Tesla and GTX770

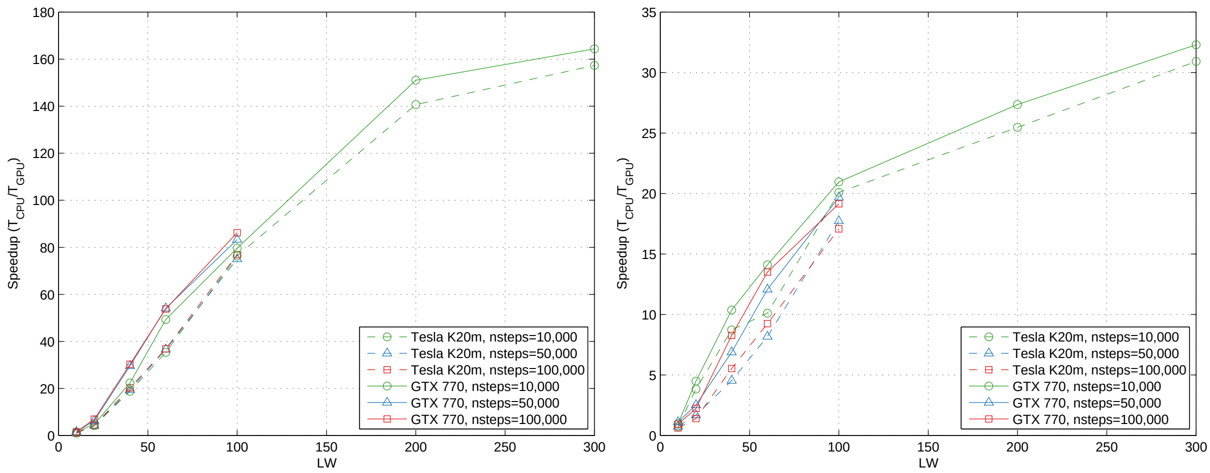

Figure 3: Speedup of the GPUs as a function of model size, compared to the i7 processor using 8 threads

in Bossomaier et al. (2016).

$$\mathbf{I}(X:Y) = \mathbf{H}(X) - \mathbf{H}(X|Y) = \mathbf{H}(Y) - \mathbf{H}(Y|X), \quad (5)$$

which is clearly symmetric in X and Y. between two probability distributions X,Y. In this paper X, Y would be species counts as a function of time, over some time window in the simulation. We calculate the mutual information between each species pair and average them for Figure 11.

If one process influences another, then one would expect there to be mutual information between them, but with a time lag, corresponding to the time to transfer effect from one to the other. This, however, runs the risk of artefacts arising from common causes. To address these concerns, Schreiber (2000), introduced the *Transfer Entropy*, $\mathbf{T}_{Y\rightarrow X}$ in Eqn. 6, in which we take the time-lagged mutual information, but *condition it on the past of* X, where X is the recipient of the information.

$$\mathbf{T}_{Y\rightarrow X} = \mathbf{H}(X_t|X_{t-1}) - \mathbf{H}(X_t|X_{t-1}, Y_{t-1}), \quad (6)$$

One important metric introduced by Barnett et al. (2013) was found to be the *Global Transfer Entropy*, G, in which we measure the flow of information to one species from all other species on average, as in Eqn. 7 over the N species.

$$\mathbf{G} = \frac{1}{N}\sum_{i}^{N} \mathbf{T}_{Y'\rightarrow X_i}, \quad (7)$$

Figure 11 shows the three information theoretic measures for a single simulation where one species (S1) becomes extinct. There is a marked drop in **T** and **G** as the S1 population drops, before converging to constant values which persist for the remainder of the simulation where both S2 and S3 exist in approximately equal measures. **I** also experiences a decline as S1 becomes extinct, but is more volatile to local neighbour interactions.

6. CONCLUSIONS AND FURTHER WORK

We have shown that the Compete model of benthic species competition leads to rich dynamics. Species may coexist, or one or more species may go extinct. We showed how information theory measures can be used for studying transitions such as species extinction. This model is part of a larger project to determine indicators of ecological phase transitions, such as this. Implementation of the model on GPU architectures achieves cost-effective speedups, yet the actual performance increase turns out to be quite algorithm sensitive. In particular, we found that the expected performance increases between different GPU architectures would only be realised when the computation was compute, rather than memory, bound.

Further work will involve calculating the three information theory measures for a wide range of species growth rates and overgrowth rules, for increasing numbers of species. These measures will then be compared with other metrics for predicting tipping points.

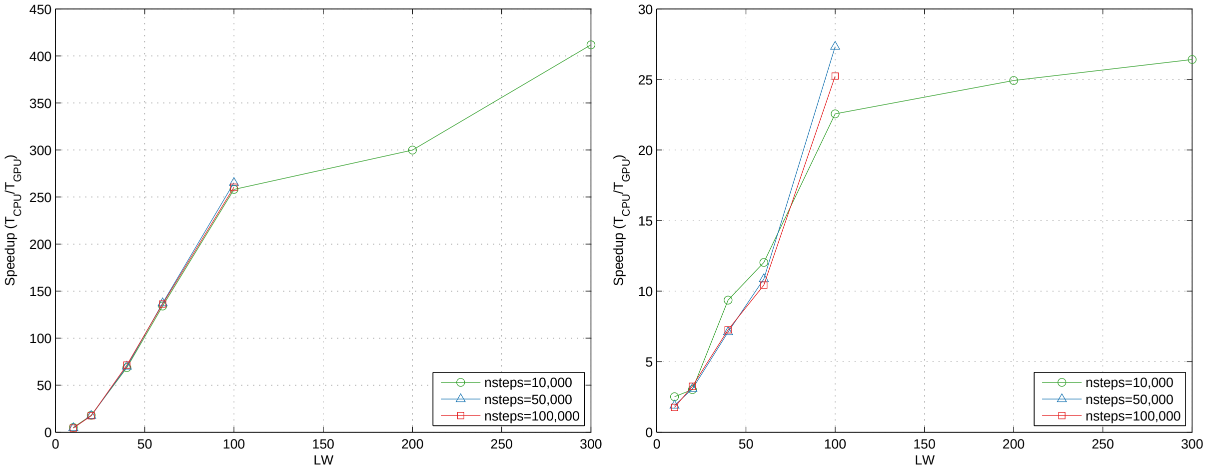

Figure 4: Speedup of the Tesla cluster relative to its own Xeon processor.

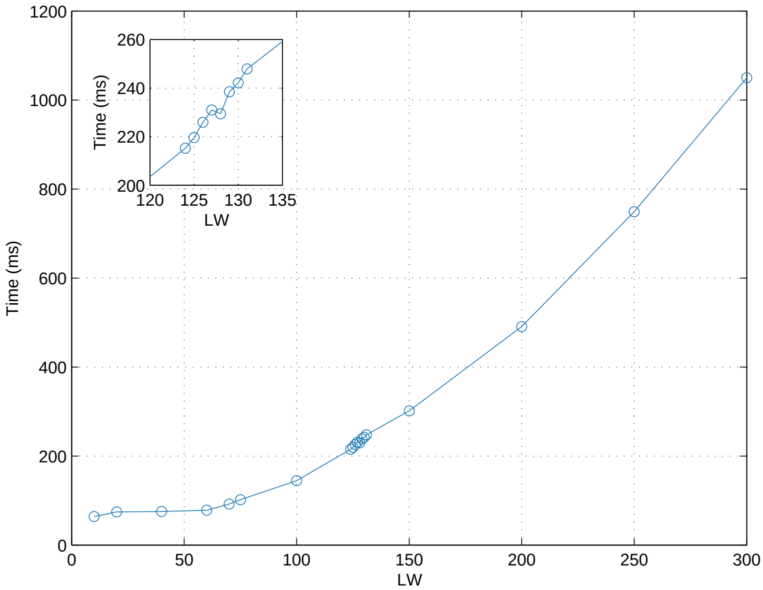

Figure 5: Time taken as a function of model size

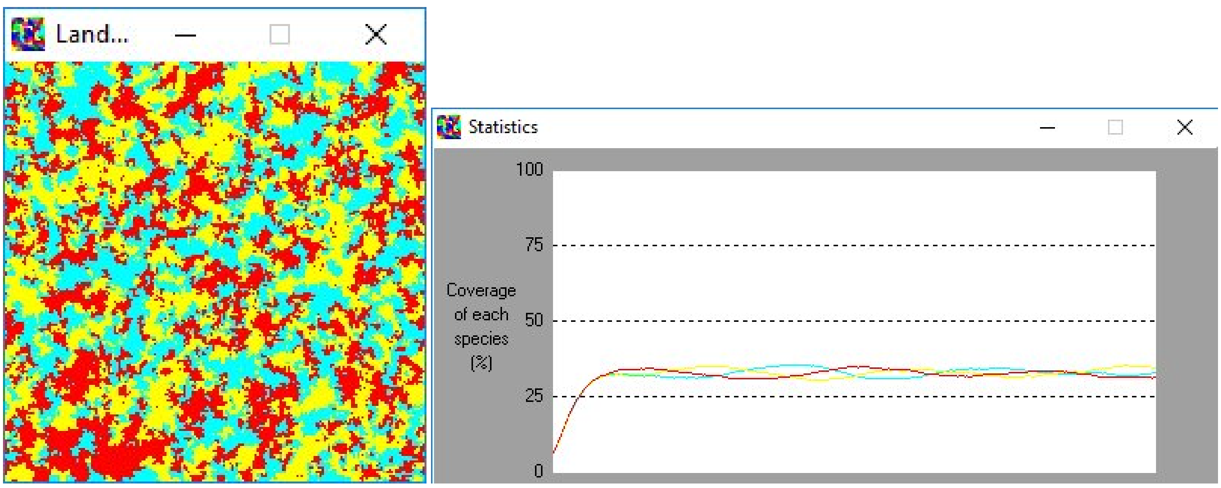

Figure 6: Three species, equal growth rates.

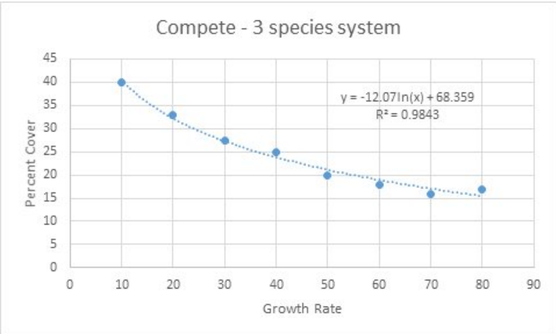

Figure 7: One species with higher growth rate

Figure 8: Elimination of the fastest growing species

Figure 9: Oscillations in species abundance

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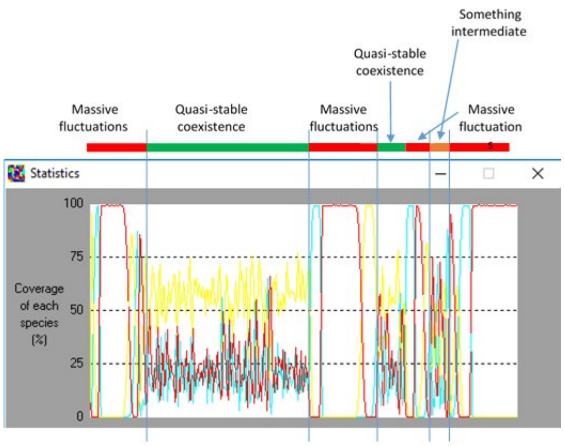

Figure 10: Massive fluctuations in species abundance

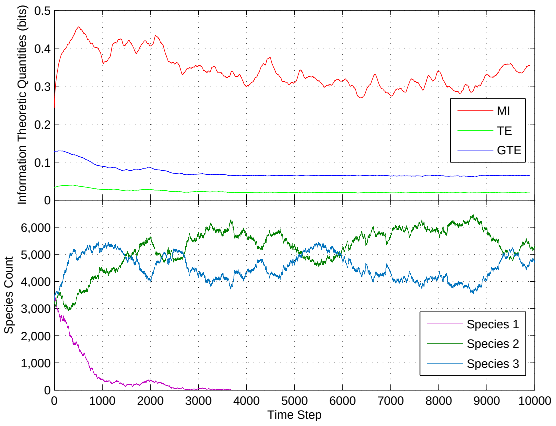

Figure 11: Information Theoretic quantities (top) and species count (bottom) for a single simulation where a single species goes extinct. O_d is 0.58 for S2 and S3 overgrowing S1, while $O_d = 0.5$ for S2 and S3 overgrowing each other. Growth rate, g_d, is $0.68, 0.5$, and 0.5 for S1, S2, and S3, respectively.

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SIMULATION OF THE CONSTRUCTION OF A LUNAR HABITAT

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ABSTRACT
This paper shows the work developed on the NASA SIMULATION EXPLORATION EXPERIENCE (SEE 2017) by FACENS Brazil team. The SEE involved fourteen teams from ten different countries with the objective of simulating a virtual space mission in the moon, using Distributed Observation Network (DON) and High-Level Architecture (HLA). FACENS Brazil team was the responsible for developing a lunar habitat, containing several astronauts in a very diverse ambient.

Keywords: simulation, lunar habitat, space mission, HLA, DON, SEE.

1. INTRODUCTION
Since 2015 FACENS Brazil team have participated in the SEE, an international modeling and simulation (M&S) project, created and sponsored by the National Aeronautics and Space Administration (NASA), in which the American agency proposes space missions that must be fulfilled through cooperation among the participating teams, being each team responsible for the creation of its own part of the simulation. When put together, the teams' simulations should meet the proposed objectives.
Being responsible for the creation of the astronauts' accommodation when in lunar missions, we developed a lunar habitat, codename LUHA, capable of housing astronauts on long-duration lunar surface missions.
The habitat was designed and developed having in mind many aspects and meeting the necessary requirements to provide survival and living conditions, as well as safety and comfort to its dwellers. Having different areas and environments, all of them have been thought of to improve the experience of those who would, even if temporarily, live there. In addition, its design allows it to be replicated and expanded, housing many astronauts.
To put their solution in the SEE the teams have to create their federate using a program capable of using the standard HLA and a 3D Model that represents the building as planned to be constructed in the Moon.
The first topic of this article has a brief introduction of the subjects that will be discussed in it. Then, in topic 2, there is an overview of this year's SEE Mission. Topic 3 addresses the lunar environmental conditions in which the simulation is based on. Meanwhile, in topic 4, there is a description of the technologies involved in the creation of the simulation. Topic 5 brings a description of the created federates (simulation parts). Additionally, it is defined in topic 6 the results and validation tests of the project. The conclusion is the last topic in this article.

2. SEE MISSION 2017
The 2017 NASA's SEE's mission was to create a lunar colony, base for future asteroid captures (for research purposes) and future exploration missions (manned or not) on Mars, further developing previous SEE simulations.
The SEE teams were to virtually construct a Moon City at the 3,9 billion years old and 2,500km wide asteroid-created crater Aiken's Basin at the so called "Dark Side" of the Moon, building and maintaining infrastructure and services for further exploration beyond the moon.
On SEE events, this crater is divided into four sectors: West, East, South and North:

- South – Sector 1: This is the place of Moon City Center,
- East – Sector 2: Manufacturing and mine area,
- North – Sector 3: Construction of Waste management facility,
- West – Sector 4: Lunar Habitat and launchpad.

The goals include the development of Space-based technologies to protect the Moon and its environment for success and survival, such as early warning systems, disaster safety, security, disaster detection and response, risk analysis, sanitation, health care, food, water and reliable and useful information and communication.
Those interests spark SEE's collegiate-level hands-on, on-line learning and participating together to build capability in distributed interoperable simulation and standards for a risky future of growth, challenge and exploration. As well as to solve problems and develop virtual prototypes, accelerating front-end model-based design (Elfrey 2017).

3. LUNAR ENVIRONMENT SIMULATION
For the proposals in the SEE 2017 mission, it was necessary to consider in this project, the extreme conditions of environment that can be encountered on the Moon to allow the survival of the astronauts ~~in~~ there.

3.1. Environmental Conditions

3.1.1 Gravity

The Moon's gravity is less than Earth's, approximately 1/6 of it, or 1.62 m/s² (Benaroya et al. 2002).

3.1.2 Pressure

Generally, the internal ideal pressure of the habitat is the atmospheric pressure of the Earth. Like diving, a dangerous aspect of the variable pressure is the formation and expansion of gas bubbles in the blood and lungs. The historical internal pressures used for NASA's programs ranges from 34.5 kPa (21,300 kg/m2 on the Moon) to 101.4 kPa (62,600 kg/m2), ideally about 69 kPa (42,600 kg/m2) to provide a habitable environment to astronauts (Ruess, Schaenzlin and Benaroya 2006).

3.1.3 Radiation / Meteorites

The surface of the Moon receives electromagnetic and ionizing radiation, the latter being divided into solar wind, cosmic solar rays and galactic cosmic radiation, meteorite impacts and extreme variations of radiation (Ruess, Schaenzlin and Benaroya 2006).

3.1.4 Atmosphere

The presence of gas in the atmosphere of the moon is very thin and is, for practical purposes, considered as being surrounded by vacuum (Johnson 1971)

3.1.5 Humidity

The ideal humidity for humans ranges from 30% to 60%, conditions of dry or itchy skin are aggravated by low humidity and to people suffering from asthma and other respiratory disorders, humidity should not exceed 50%, such high humidity can aggravate the symptoms and be an environment for fungi (Hinrichsen 2011).

3.1.6 Temperature

The temperature on the surface of the Moon ranges from about -153 °C to 107 °C at the transition between day and night, which occurs in cycles of approximately two weeks. The extreme temperature ranges -233 °C to 123 °C (Heiken, Vaniman and French 1991).

3.1.7 Sun light

The sunlight that reaches the lunar surface is constant, predictable and inexhaustible. Several sites around the Moon's South Pole receive more than 300 days of sunlight per year (Spudis 2003).

3.1.8 Resources

The Moon has a wealth of raw materials. The lunar regolith contains iron, aluminum, silicon, titanium, oxygen and traces of hydrogen, carbon, helium and nitrogen. The Moon may also have water frozen in dark polar craters (Spudis 2003).

3.1.9 Structural Requirements

Building a structure of a lunar habitat demands requirements that must be met, for instance, how to sustain loads with acceptable degree of safety with minimal ~~of~~ structural material, being the lightweight material, high stiffness and strength, ductile, durable, tear and puncture resistant and low thermal expansion and low maintenance. The structure should be designed to contemplate a short construction time, minimize direct man contact with equipment execution or handling, minimize costs/time with transportation, and compatibility with the internal environment (Ruess, Schaenzlin and Benaroya 2006).

4. GENERAL ARCHITECTURE OF THE SEE 2017 ENVIRONMENT

4.1 Technology and Framework

For a better basic understanding of the development, it is necessary to understand the technologies used as its basis.

4.2 HLA – High-level Architecture

In a simulation, each object is able to generate data to be used by other objects, which are defined by programs that make calculations and interactions with other programs of the other objects. For example, the astronauts in the Lunar Habitat consume oxygen and food, this information is generated by applications proposed to simulate these behaviors. As each object calculates its own information, a platform is needed to manage the data sharing between different programs of different objects. With the objective of solving the communication problem among different distributed simulation objects, it was developed a standard by IEEE 1516 named HLA.

There are several implementations of standard IEEE 1516, but the implementations commonly found in SEE editions are those developed by Pitch Technologies and VT MÄK, from which temporary licenses are made available to SEE participants. Both companies have implementations in Java and C++. Each team can choose to develop their federate in one of the two languages.

For the simulations to be made possible, it is necessary to configure the RTI (Run-Time Infrastructure), which is an intermediate software that receives the Federates objects and returns them to the other Federates (Möller et al.2012).

This configuration is done by a responsible Federate, giving rise to Federation, upon this, Federates can be instantiated to communicate with each other through the RTI. In the SEE, the Federation is defined by the Environment Federate developed by the NASA development team.

Our team, opted for the use of the Java language with the implementation and tools developed by Pitch Technologies, company that became the most popular among the SEE participants. The company offers several tools oriented on the IEEE 1516 standard, such as Visual OMT Pitch for editing Federation Object Model (FOM) files. In addition to those tools, the RTI developed by Pitch Technologies has a graphical interface, used to ease the view of information, and Web resources, to manage the simulation through the Pitch pRTI.

4.2.1 Federation Object Model

A FOM allows the interoperability between federates in a simulation supported by Object Model Template (OMT) specification. (Dumond and Little 2003).

It is based on object-model representation that can be loaded at runtime. In a FOM file, it is encountered mainly a definition of objects, datatypes and interactions. Usually it can be called as “the language of federation” (Möller et al.2014) because it contains the definition of data exchanges between the federates.

4.3 SEE HLA Starter Kit

To facilitate the development of the Federates in the SEE, members of the University of Calabria developed a framework in Java, the “HLA Starter Kit”. The project has been evolving over the years with improvements and updates based on the Environment developed by NASA. The code and project versions are available on GitHub[1].

The project implements annotations that simplify the work of mapping objects with the data defined in the FOMs. Moreover, it facilitates implementation of a federate with its configuration, federation integration, lifecycle, and default objects for all federates (Garro and Falcone 2017).

The class *PhysicalEntity* (along with its support) is one of the essential implementations of the HLA Starter Kit on the simulation operations, because it works as an interface to read positions generated by the federate. It also updates on the visualization application (DON) the respective simulation 3D model’s properties, like positions, rotations and others.

4.4 3D Models

In order to facilitate the understanding and visualization of the simulation, each team was required to build a virtual 3D model representing the team’s Federate. Those models were built in Software such as 3DMax and AutoCad, in “.obj” format and were loaded on the visualization application (DON).

FACENS team made use of the 3DMax and designed our 3 Models (Lunar Habitat, Lunar Habitat Rooftop and Astronauts) completely from scratch, bringing life to our thoroughly engineered Federates, complying with all the design and structural requirements.

5. LUNAR HABITAT AND ASTRONAUTS FEDERATES

Two Federates were built to support the simulation, the Lunar Habitat (LUHA) and another for the astronaut’s (ASTRO-LUHA). First a better format for the habitat in the lunar environment was studied, taking into consideration the vacuum and the difference of internal and external pressure, concluding for the circular/rounded format (dome like form) to minimize the effects of pressure and possible breakage of the walls. The habitat has halls, which separate/connect the modules, and it is equipped with a safety doors system, preventing possible faults or ruptures that could endanger the entire habitat. Each habitat houses up to four astronauts and it is connected with three more habitats, making their connection through the hall and sharing the Ambulatory and Laboratory in the center. There is the possibility of further expanding ~~it~~ on the lunar ground. Some parameters of resources necessary for the survival of the astronauts were adopted to establish the environments and elements of the lunar habitat and its functioning: water, electricity, atmosphere, food and social wellbeing. The Figure 1 shows exterior view of the Lunar Habitat.

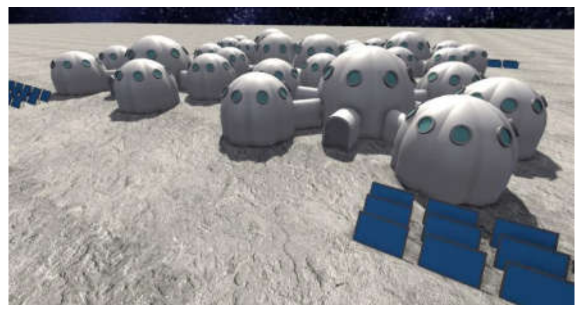

Figure 1. Exterior view of the Lunar Habitat.

Several spaces were proposed for ~~to~~ the Lunar Habitat. They can be seen in the list below with their main characteristics:

- Depressurizing chamber: entrance/exit of astronauts in mission on the moon and return/out of the tasks outside the lunar habitat,
- Bedroom: resting place of astronauts during the mission on the moon,
- Bathroom: personal hygiene care;
- Kitchen: to prepare meals,
- Storeroom: place to store food from the Earth;
- Service Area: space for washing, drying and ironing clothes,
- Warehouse: deposit of materials/tools;
- Fitness center: for physical exercise, important part of the daily routine of the astronauts, to prevent bone and muscle loss (Wild 2016).
- Games Room: space for hobbies and entertainments,
- TV and reading room: for reading and hobby;
- Office/Control Center: where astronauts have access to habitat’s data such as temperature, humidity, pressure, gas (oxygen, carbon, nitrogen, hydrogen and other) levels of each module, communication with the control

[1] https://github.com/SMASH-Lab/SEE-HLA-Starter-Kit

tower, and Earth, daily habitat reports, laboratory, outpatient and other reports,

- Machine room: space for the treatment of water and sewage, distribution and control of electric energy, distribution and control/treatment of the air of the habitat,
- Ambulatory: for periodic examinations of each astronaut, small emergencies (first aid),
- Laboratory: for experiments and scientific research under analysis,
- Greenhouse: supply and production of oxygen for ~~to~~ the habitat,
- Solar Panels: production of electricity for the habitat.

5.1 Lunar Habitat - LUHA

The LUHA project focuses on three main pillars for its execution, its relevant information, the interactions with others federates and the subscriptions that were sent and received.

LUHA has as information the basic conditions of a construction, such as: pressure, temperature, surface area, volume and humidity of the air, and information like energy consumption, oxygen consumption and carbon dioxide emission. Moreover, number of resident astronauts, along with their amount of food consumption, were also registered. For the execution of a simulation with several objects, the exchange of data is fundamental. The SEE HLA Starter Kit provides two types of communication and data exchange, the first named *interaction*, is based on sending data to a specific federate receiver. And the second known as *subscription*, is based on sending data to the federation, which is responsible for forwarding the information to all other federates.

LUHA interacts with two other federates in the SEE 2017, first the Astronaut Lunar Habitat (ASTRO-LUHA) developed by us, of FACENS Brazil team, and the second the Greenhouse developed by SOPHIA/Bulgaria team.

The interactions with ASTRO-LUHA, were based on the recipiency of the amounts of oxygen, carbon dioxide and food consumed by each astronaut. With this information LUHA summed up the total consumption of each input and sent an interaction to the Greenhouse, making the request for the desired quantity. After ~~the~~ LUHA is answered with the requested data, the Lunar Habitat distributes each product to the astronauts.

The subscriptions that the Lunar Habitat sends are their own data information and it also uses this feature to monitor the ASTROS-LUHA, making it possible to act upon receival of vital signals below the limits.

To visualize the movement of the astronaut inside the LUHA, the removal of the rooftop of the habitat was also implemented, for presentation purposes only, during the simulation, as seen in the Figure *2*.

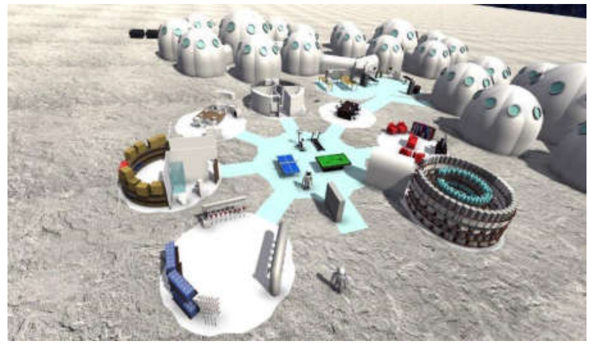

Figure 2 View of the Lunar Habitat without the rooftop.

5.1.1 FOM of Lunar Habitat

To represent the Lunar Habitat it was necessary to create two different objects one to represent the self-Lunar Habitat and the ~~an~~other ~~one~~ to represent the rooftop of Lunar Habitat. The reason to create an object to rooftop is because the federate that reads all federates in federation to generate the representation of simulation with models use the object class Physical Entity that makes the connection with the 3D model and the federate. Also, we would like to show the astronaut's actions inside of LUHA. With the idea of ~~to~~ moving the rooftop, the separation of object class that represents the LUHA enables us to see the astronauts walking inside of habitat. Otherwise the astronauts could cause problems to visualize what is going on inside of Lunar Habitat.

So, the defined properties utilized by LUHA in the final simulation are listed and its FOM definition in Figure *3*:

- Pressure: Internal pressure (in Pascal) in Lunar Habitat.
- Temperature: Represents the temperature (in Celsius) inside ~~of~~ the Lunar Habitat.
- Area: Total area (in m^2) of Lunar Habitat.
- Volume: The internal volume (in m^3) Lunar Habitat.
- Energy_consumption: Accumulated consumed of electric energy (in Watts) of the Lunar.
- Oxygen_consumption: Total consumption of oxygen in Lunar Habitat. (l).
- Carbon_dioxide_emission: The carbon dioxide emission in Liters (l)
- Air_humidity: Percentage of air humidity of Lunar Habitat
- Calories_consumption: The calorie consumption (in cal) in the Lunar Habitat.
- Maximun_capacity: The maximum number of astronauts the Lunar Habitat can house.
- Number_of_astrounauts: The number of astronauts currently inside of the Lunar Habitat.

Figure 3 Representation of Lunar Habitat to federation.

5.2 Astronaut in Lunar Habitat - ASTRO-LUHA

The Federate Astronaut Lunar Habitat (ASTRO-LUHA), was developed to simulate astronauts inside habitat, thus responsible for all the daily routine projections of an astronaut and his vital signs.

The Federate was concentrated in two main parts, being the first the calculation of astronaut's vital signs and energy/food consumption. And the second being the calculation of the path to be traveled by the astronaut to move within the habitat during the simulation.

Vital signs generated by the astronauts were: *pulse_oximetry*, *heartrates*, *temperature*, *blood_pressure_systolic* and *blood_pressure_diastolic*. These inputs were calculated based on researches, to provide realistic values of when a human is in motion or when he is standing still (Azevedo 2016).

Whereas data as: *amount_oxygen*, *amount_carbon_dioxide* and *amount_calories* were calculated using formulas depending on the distance traveled by the astronaut by time or a previously calculated default value if the astronaut is stopped (Helene 2005).

The calculation to find the best pathway to get from one point to another of the habitat map by the astronaut was carried out considering the fastest route, avoiding collisions with other astronauts and possible collisions with physical objects of the habitat. To solve this problem, a map based on the theory of graphs was implemented and applying the Dijkstra algorithm, which deals with the shortest path between two points.

With these definitions, it was possible to simulate several astronauts in the lunar habitat without much effort in varying numbers of astronauts. The data published by the astronauts were captured by the lunar habitats, which in turn was possible to update and perform actions based on these data.

In the simulation of SEE 2017, three astronauts who interacted and walked in the interior of the house were used. Astronaut numbers could vary in our federate, but this type of approach was not supported by the DON 3.1 software.

5.2.1 Properties declared in Astronaut's FOM

Based on researched data and produced data by the federate in the simulation. The FOM that defined an astronaut contained the following properties and its father's object classes in Figure 4:

- Pulse_oximetry: Pulse oximetry that a saturation of 100% indicates that hemoglobin is fully occupied by oxygen molecules. (SpO2);
- Heart_rate: The heart rate of astronaut (bpm);
- Temperature: It gives an indication of core body temperature. It is expressed in Fahrenheit degree (°F);
- Blood_pressure_systolic: Represent systolic pressure of the astronaut;
- Blood_pressure_diastolic: Current diastolic pressure of the astronaut;
- Amount_oxygen: Amount of oxygen breathed per second by LUHA-ASTRO (l);
- Amount_carbon_dioxide: Amount of carbon dioxide emitted per second by LUHA-ASTRO (l);
- Amount_calories: Number of calories spent ~~spends~~ per second ~~spent~~ by LUHA-ASTRO (cal);

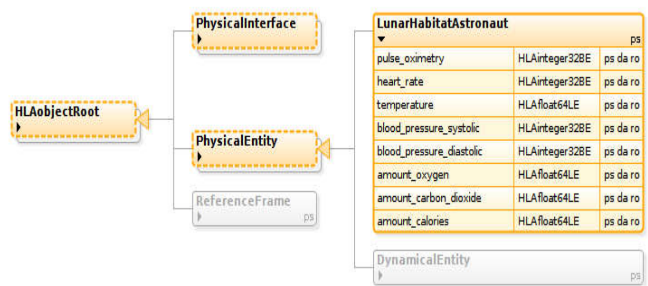

Figure 4 Final representation of an astronaut in its FOM file.

5.3 Interaction of Lunar Habitat with Greenhouse

The interactions between FACENS LUHA and the Bulgarian Greenhouse has as objective the resources exchange, to enable a self-sustainable lunar ambient. With this proposal, it was developed, via software, a simulation of resources exchange like food, oxygen and carbon dioxide, as seen in Figure 5.

First, the consumption of resources is generated by astronauts, so LUHA reads the astronauts federates to get those parameters. After that, LUHA checks the levels of resources and sends a resource request to Greenhouse. In turn, the resource request from LUHA is sorted out by the Greenhouse federate, which sends a response with the requested quantity.

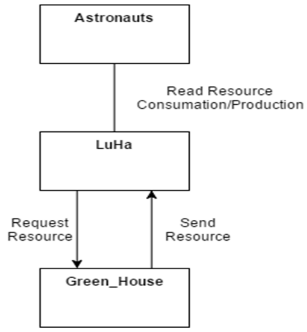

Figure 5 Diagram of resource exchange and consume.

5.3.1 FOM of communications between LuHa and Greenhouse

To be able to create this exchange and communication between federates, it was necessary to create interfaces to manage those interactions between them. The interface was defined by a FOM file, containing a new fixed record datatype called *Resource*, a new enumeration called *ResourceType* and two interaction classes, *RequestResource* and *SendResource*.

5.3.1.1 ReourceType Enumeration

ResourceType was defined to be able to know which kind of resource is been exchanged. It can assume values like *FOOD*, *OXYGEN* and *CARBON_DIOXIDE* represented by a *HLAinteger16LE*.

5.3.1.2 Resource Fixed Record

This fixed record is the object exchanged between LUHA and Greenhouse. It aggregates the properties *quantity* and *resource_type,* being the first represented by a *HLAinteger64LE* variable type and *ResourceType* an enumeration.

5.3.1.3 RequestResource Interaction Class

It defines a request resource between LUHA and Greenhouse. This class has as property a Resource fixed record. As can be seen in Figure 6

5.3.1.4 SendResource Ineraction Class

It represents a response of a resource request between both federates and it also is a *Resource fixed record*, as it can be seen in Figure 6

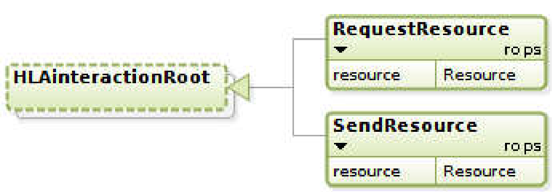

Figure 6 Interaction to exchange resources between LuHa and Greenhouse.

6 RESULTS AND VALIDATIONS

With all FACENS federates idealized and all the borders defined in FOM, as seen previously in Figure 3, Figure 4 and Figure 6, we could test with SOFIA team our interactions with Greenhouse. To validate, both federates were run simultaneously. When the astronauts were in idle status the consumption rate of food and oxygen was stable taking more time for LUHA to request resources from Greenhouse. However, when the astronauts were walking between rooms, it was possible to see an increase in frequency of resources request from LUHA to Greenhouse as expected. With those results, it was possible to check our LUHA, that read correctly data from the astronauts inside of it and the levels of oxygen and food were managed by LUHA federate as expected.

With the publication of information of the astronauts it was made possible to check, second by second, the correctness of values researched in previous topics about living people in a moon environment with the implementation of astronauts on simulation.

The tests with the Bulgarian team occurred several times before the meetings with all team participants of SEEE 2017. This way, we could check the values and fix bugs before the final test took place on April 26th, 2017. Our team participated in two locations one at FACENS in Brazil and another at Florida Institute of Technology (FIT) in the USA.

7 CONCLUSIONS

With the developed project, it was possible to create a basic simulation of resources consumption and planning how a long-term habitat would be. On it, several insights to solve the issues of building and living in an inhospitable ambient. Moreover, the project was a great co-working opportunity with the Bulgarian team, with their Greenhouse being able to integrate our habitat and exchanging resource between our federates, simulating production and consumption on the Moon simulation. However, this simulation did not consider parameters like water, material, and soil conditions. Those would be added in future researches and studies about these topics. On the other hand, aspects like meteorite problems were considered in the blueprint and structure of habitat.

ACKNOWLEDGMENTS

We from ~~the~~ FACENS Brazil team would like to thank Alfredo Garro and Alberto Falcone from University of Calabria for the patience and support with their SKF (SEE HLA Starter Kit) and explanations about several issues that we faced.

Also, we are proud to have participated in the last two editions of SEE (Simulation Exploration Experience), in which we had the pleasure of working with University of Calabria, Sofia University and University of Nebraska Omaha. We are very happy to have met for several hours to discuss about our interactions and projects, sharing knowledge and discoveries with one another.

We are grateful to University of Liverpool to receive us in 2016, to test our federates altogether with the other teams around the world. The same gratefulness goes to

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"ECOSHE" SIMULATOR TO ASSESS HUMAN ERROR PROBABILITY DURING INDUSTRIAL EMERGENCY CONDITIONS

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ABSTRACT

The system and activities complexity has a negative impact on the operator's reliability. During emergency situations, operators' reliability decreases much faster. This is a critical issue. The aim of the present research is to develop an integrated model for assessing the human error probability during emergency conditions. Internal and external environmental factors that affect human reliability, combining different HRA techniques, are analyzed. In addition, the research proposed the design and development of a pilot simulation system "ECOSHE" (Emergency Condition Simulator for Human Error). The simulation system returns a graphical and numerical report that analyzes human reliability conditions. It provides a valuable support to the decision makers to evaluate human conditions. The proposed model is applied in a real case study concerning a petrochemical company.

Keywords: Human Reliability Analysis, Simulation, Emergency Management, Safety

1. INTRODUCTION

Literature analysis shows that over the last 30 years, most industrial accidents are due to human errors Petrillo et al. 2017). About 83% of the accidents analyzed on a total of about 20,000 are due to human error. The Major Hazard Incident Data Service (MHIDAS) database identifies about 200 industrial accidents over the period 2005-2010. About half of these accidents are due to human inattention. Human error analysis is very important because errors can cause dangerous incidents and also negatively affect system performance (Salvendy 2012). For this reason, attention to issues of human reliability is constantly evolving (Mosleh and Chang 2004; Bruzzone et al. 2014). The study of human reliability during emergency conditions is particularly important because a wrong choice could cause disastrous consequences (Kobbeltvedt et al., 2005). Traditional HRA models evaluate human reliability considering internal and external environmental factors (De Felice et al. 2016). The aim of the research is to avoid emergency conditions by applying preventive actions. Often, this is not possible, due to the complexity of industrial systems, therefore it is necessary to better manage emergency conditions (Turoff et al. 2004). In this context, it would be useful to have a simulation system that allows to evaluate the human error probability, by analyzing internal factors and external factors affecting the operator. The strength of simulation models is the ability to evaluate different system conditions for different scenarios by comparing the results obtained (Bruzzone et al., 2015 a). Simulation is a very powerful tool that allows to evaluate system output and design improvement systems (Luke et al. 2005). The purpose of the research is the development of an integrated model to assess the human error probability during emergency conditions by evaluating internal and external factors that affect operator's reliability. The construction of the integrated model, involves the fusion of more traditional HRA models. In addition, the research model proposed the design and development of a simulation system "ECOSHE" to evaluate operator reliability during working hours. The output of simulator returns a series of reports that can be used by the decision maker to assess the degree of risk of the operator and to evaluate any improvement programs. The model is applied in a real case study: an emergency situation in a petrochemical industry. The rest of the paper is organized as follows: in the second section a brief analysis of the literature is presented. Section 3 describes the methodological approach adopted. The case study is presented in section 4, while the last section describes the conclusions.

2. LITERATURE REVIEW

Accident analysis models classify two causes of accidents: internal and external factors. Internal causes are due to system failures or human error, while external causes are related to environmental factors (Weber and Thomas 2005). The literature is rich of

HRA models, applied in emergency conditions and there are also several applications in case studies. In fact, in the recent years, the trend of publications in this field is increasing, because it has been realized that human error affects both operator safety and short-term system performance (Grosse et al. 2015; Bruzzone et al., 2015 b). A research was conducted on the Scopus database, the largest database of peer-review literature. The keyword used for the search is "Human reliability analysis". Only the articles were analyzed and the conference papers were omitted. The analysis showed that from 1970 to June 2017, 69837 articles were published. Scientific production is very wide and covers several scientific areas (engineering, medicine, social sciences, etc.). In addition, geographic analysis has highlighted a high number of articles from the United States (22773), the second most productive nation being UK with a number of articles of 7106, third it was Germany with a number of articles of 5350. Therefore, it is evident that US production is significantly higher than in other countries. By refining the research with a new keyword, "Simulation", the number of articles decreases considerably (4272). Again, the US drives the ranking, followed by the United Kingdom and Germany. The literature proposes three families of HRA techniques, each with advantages and disadvantages. A first generation family born in 1970, it evaluates the risk not considering operator's behavior. A second generation family born in 1990, it focuses on the internal and external factors affecting the operator, and third-generation family represents dynamic HRA systems and it is currently being implemented only in nuclear case studies (Boring 2007). Below some of the most used HRA methodologies in the literature are described. Technique for human error rate prediction (THERP) is a first generation HRA methodology, it builds a tree of events, and it quantifies the scenarios associated with each result with an error probability. The model simulates human behavior as a machine and ignores cognitive aspects (Kirwan 1996). Human error assessment and reduction technique (HEART) is a second generation methodology, which considers all the factors affecting the operator, calculating the human error probability (Kirwan 1992). The cognitive reliability and error analysis method (CREAM) is a second generation of HRA methodology that evaluates the effect of the context of risk of error. It pays close attention to scenario analysis and external factors. The model integrates individual, technological, and organizational factors and assesses the human error probability (Hollnagel 1998). Standardized plant analysis risk – Human RA (SPAR-H) is a second generation HRA methodology. It considers the context through the use of performance shaping factors PSFs (Gertman et al. 2005). In addition, there are several simulation models available in the literature, which allow to evaluate the output of predetermined scenarios.
Simulators are not traditional HRA models, but they use HRA theory dynamically (Bonabeau 2002). Below some of the most known HRA simulators in the literature are described. A simulation system for behavior of an operating group (SYBORG) is a qualitative simulator that studies the possible combinations of errors in a group of people working in a nuclear power plant (Takano 2005).
Probabilistic cognitive simulator (PROCOS) is a quantitative simulator that evaluates operator behavior and it analyzes his errors (Trucco and Leva 2007).
Simulator for human error probability analysis (SHERPA) is a quantitative simulator that evaluates the probability of error numerically (Di Pasquale et al. 2015). Cognitive Environment Simulation (CES) is a semi-qualitative simulator for controlling and managing emergencies at a nuclear power plant (Woods et al. 1987). A hybrid probabilistic model for evaluating and simulating human error in industrial emergency conditions (HEIE) is a quantitative simulator that calculates the human error probability considering all possible scenarios through a tree diagram (Petrillo et al. 2017). Traditional HRA models analyze human reliability, considering independently internal factors and external factors. It is necessary to consider the factors simultaneously to analyze all the possible influences on the human reliability. Specifically, the SHERPA model considers internal factors and external factors connected, but only analyzes the first 8 hours of work. So the SHERPA model can be used during nominal working conditions. The purpose of the research, is to develop an integrated model, considering traditional HRA techniques, to analyze the human reliability during emergency conditions. So the presented model considers more than eight hours of work, because during emergency conditions, the working hours for each operator can be up to 16 consecutive hours. HRA simulators analyzed in the literature review are all very effective with their strengths and weaknesses. The main problem is their difficulty in applying them. The aim of this research is to develop a simple and flexible simulation, called "ECOSHE". The use of the simulator does not require knowledge of HRA models. The operator must only enter information about the process being analyzed. The simplicity of the simulator allows a quick and effective use in each company, and allows to analyze the problems concerning the human reliability during emergency conditions.

3. METHODOLOGICAL APPROACH

The methodological approach is divided into several steps (Figure 1). The first five steps are related to the mathematical HRA model, while the last five steps are related to the simulator development. The dotted lines represent information flows starting from the theoretical model and arriving at the input and output of the database. The integrated model, considers internal and external factors, and it develops from traditional HRA techniques. The influence of internal factors was acquired by the HEART model, while the influence of external environmental factors was acquired by the

SPAR-H model. These two models have already been integrated by the SHERPA model, which considers the first 8 hours of work. But, the objective of the research is to analyze the system under emergency conditions, so it is crucial to extend the working hours over the eighth hour. The ECOSHE simulator is born from the need to use a simple, quick and fast tool to calculate the human error probability under defined conditions during an emergency situation. Literature analysis shows a significant amount of HRA simulators, however, they are very complex, so it is necessary to develop a new simulator customized for the integrated HRA approach.

Step #1 Emergency condition description. It is necessary to describe the general emergency scenario and the internal and external factors that may have contributed to the accident.

Step #2 Choose Generic Tasks. The generic tasks (GTTs) are the operations performed by the operator. Tasks are defined by the HEART model (Kirwan 1996). Scientific literature proposes for each task a reliability coefficient (k) for the first hour of work and for the eighth hour of work. The k coefficient is the human reliability value (Table 1). If the decision maker cannot choose a generic task, it is necessary to better identify and describe the incidental process, and then try to identify a generic task that most approximates the worker operations.

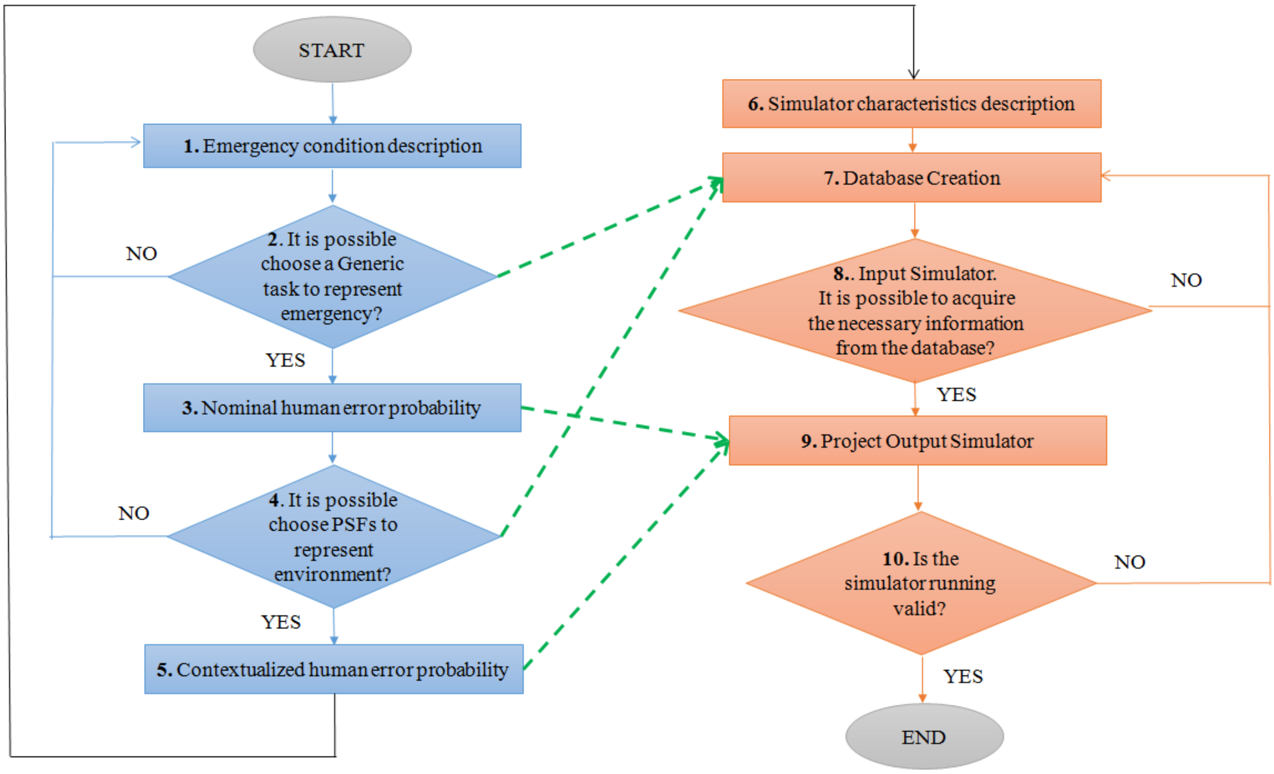

Figure 1: Methodological Approach

Table 1: Generic tasks

Generic Tasks	k_1	k_8
1. Total unfamiliar, performed at speed with no real idea of likely consequences	0.65	0.03
2. Shift or restore system to a new or original state on single attempt without supervision or procedures	0.86	0.58
3. Complex task requiring high level of comprehension and skill	0.88	0.72
4. Fairly simple task performed rapidly or given scant attention	0.94	0.87
5. Routine highly practised, rapid task involving relatively low level of skill	0.993	0.955
6. Restore or shift a system to original or new state following procedures, with some checking	0.992	0.993
7. Completely familiar, highly practised, routine task occurring several times per hour, performed to highest standards	0.9999	0.991
8. Respond correctly to system command	1	0.999

The decision maker chooses the GTT among those proposed in the literature. In particular, it chooses the GTT that looks more like the activity required by the operator at an emergency stage that could make mistakes. Generic tasks describe the influence of internal factors on human reliability.

Step #3 Nominal human error probability. Starting from the reliability values of GTTs, it is possible to calculate the nominal human error probability (HEPnom) following a Weibull distribution, with the following equation:

$$\begin{cases} HEP_{CONT} = 1 - k_1 \cdot e^{-\alpha(1-t)^{\beta}} & \forall\, t \in [0; 1] \\ HEP_{CONT} = 1 - k_1 \cdot e^{-\alpha(t-1)^{\beta}} & \forall\, t \in]1; 8[\\ HEP_{CONT} = 1 - k_1 \cdot e^{-\alpha(t-1)^{\beta}} & \forall\, t \in [8; \infty[\end{cases} \quad (1)$$

Where:

- HEPnom: nominal human error probability depends only on human behaviour;
- t: variable which represents the working time;
- β: parameter that represents the shape of reliability curve. The shape that best approximates human behaviour is a Weibull function with β=1,5;
- α: parameter depends on k1 value:

$$\alpha = \frac{-\ln(k)}{(t-1)^{\beta}} \quad (2)$$

Step #4 Choose Performance Shaping Factors. The choice of performance shaping factors (PSFs) is essential for model analysis, because PSFs introduce the influence of the environment (external factors) on the analyzed system. The SPAR-H model proposes a set of PSFs (Table 2) with their values (Gertman et al. 2005). If the decision maker is unable to identify the performance shaping factors that affect the operator, it is necessary to better identify and describe the incidental process, and then, try to identify the performance shaping factors that approximate the environmental system. The operator evaluates the value of the PSFs based on environmental conditions. The total PSF value (PSFcomp) is calculated by multiplying all of the PSFs previously analyzed:

$$PSF_{COMP} = PSF_1 \cdot PSF_2 \cdots PSF_N \quad (3)$$

Step #5 Contextualized human error probability (HEPcont). Combining the nominal human error probability with external factors (PSFs) the HEPcont is defined, representing the human error probability due to operator internal factors and external environmental factors:

$$HEP_{CONT} = \frac{HEP_{NOM} \cdot PSF_{COMP}}{HEP_{NOM} \cdot (PSF_{COMP} - 1) + 1} \quad (4)$$

Table 2: Performance shaping factors

Performance shaping factors values		
PSFs	PSF Level	Multipliers
Available time	Nominal	1
	Extra	0.1
	Expansive	0.01
Stress	Extreme	5
	High	2
	Nominal	1
Complexity	High complex	5
	Moderately complex	2
	Nominal	1
Experience	Low	3
	Nominal	1
	High	0.5
Procedures	Not available	50
	Incomplete	20
	Poor	5
	Nominal	1
Ergonomics	Missing	50
	Poor	10
	Nominal	1
Fitness for duty	Unfit	5
	Nominal	1
	Poor	5
Work process	Nominal	1
	Good	0.5

Step #6 Simulator characteristics description. After the presentation of the integrated HRA model, it is necessary to describe the purpose of the simulator. The aim of the research is to develop a simulator that allows to evaluate the human error probability considering internal and external factors. The key element of the simulator must be the ease of use. The user must be able to use the simulator by entering with the data process. No knowledge of HRA's theories is needed. In addition, the interface used must be lightweight, slim and easily readable by more fixed desktops like PCs, but also mobile (smartphone, tablet, etc.). The interface used to develop the simulation model is Microsoft Office Excel®. This program has been chosen since it is very simple to use for both the programmer and the user, it allows to develop a very lightweight, easily downloadable application on other devices and is also compatible with most computers, smartphones, and tablets.

Step #7 Database creation. The simulator's objective is to represent with a certain degree of confidence the human error probability in different conditions, considering internal factors and external factors. To represent all possible scenarios, it is necessary to create a large database that describes all possible scenarios and associates with each possible scenario certain values. Specifically, the database consists of all elements presented on the integrated HRA approach: list of generic tasks, list of performances shaping factors, and work time between 1 and 16 hours. The database should be complete, or when it uses the simulator, it could develop errors. The database is not blocked, but can be continually updated. Therefore, when the theoretical HRA integrated model is updated, it can simultaneously update the simulator database. In this way, the simulator becomes a dynamic and updated tool.

Step #8 Input Simulator. As previously defined, the user does not have to be an expert in HRA techniques, so he has to include only the process data.

The input interface of the simulator involves the insertion of three types of data (Figure 2):

- GTTs choice: The operator must choose the GTT on which he wishes to perform the analysis;
- PSFs assessment: the operator must evaluate the 8 PSFs that identify external environmental factors;
- Time: The operator must indicate the time analysis.

To simplify the use of simulator, a large database has been created within which all eligible values have been entered. Therefore, the user cannot enter random values, but can only choose between preset values. In particular, the values entered are those introduced in the theoretical model.

The GTT choice data refers to Table 1, PSF data values refer to Table 2 and for working times, a time range of 1 to 16 hours of work has been hypothesized.

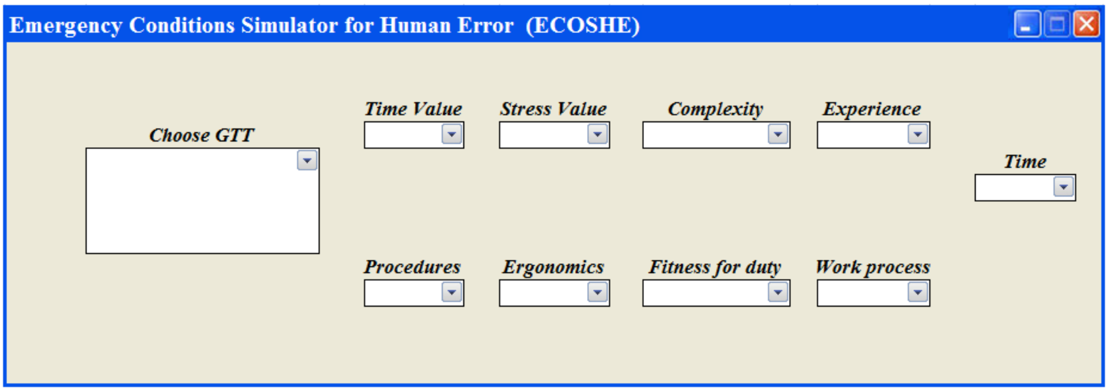

Figure 2: Input interface

Figure 3 shows the possibilities of choice. The logic of simulator assumes that when the user chooses an option within the selection window, the database automatically acquires the numeric values corresponding to the user's choice and it calculates the human error probability considering formulas reported in the methodological approach of the HRA model. In this case, the simulator input model was set by entering only certain values. Obviously the methodology is very flexible, so it is possible to insert new input values in the system considering the type of scenario being analyzed.

The Microsoft Office Excel® Macro functions were used to create the simulator interface. In particular, "Data Validation" function allowed to link the choice windows with the database, making the choice of options (Figure 3), while using the "Vertical Search" function, it was possible to associate the choice of the user with the corresponding value, to later calculate the output values.

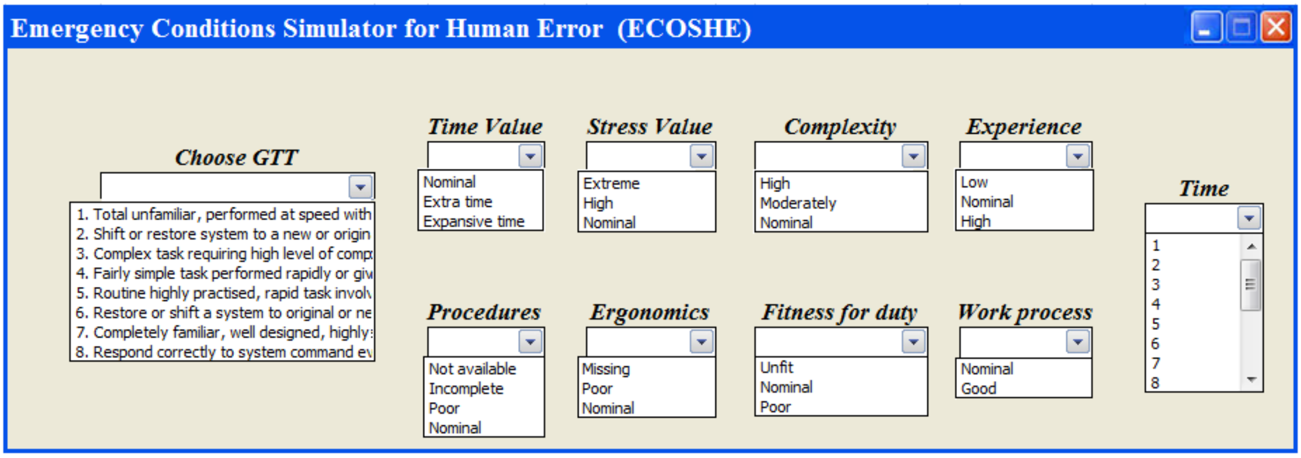

Figure 3: Input interface with choice

Step #9 Output Simulator. The simulator has to return HEPnom, HEPcont, and PSFs values. In this way, it can graphically diagnose the trend of human error probability and the influence of internal and external factors on human reliability. Additionally, the output of the simulator also shows the numeric value of the human error probability for a specific working time. The output values of the simulator are fundamental to generating comparison systems between old and new models, for example, to evaluate the level of improvement in terms of human reliability after optimization intervention. The presented simulator can be used by all the operators, because the user does not have to be an expert of HRA techniques, but only to know the analyzed process. The integrated HRA model is already inserted into the simulator and therefore the tool is extremely easy for users.

Step #10 Simulator validation. Before using the simulator, it is necessary to test it to verify the good of results. It took place by testing the simulator in different scenarios, and comparing the system output results with manual calculations. The aim of the validation is to verify if the numerical outputs of the simulator coincide with manual calculations. This allows to verify the correct programming of the excel macros. The results have been positive, because manual calculations and simulator calculations give the same results in different scenarios. In addition, 10 people with no knowledge of HRA used the simulator to see if errors could be made when selecting parameters. In some cases, critical issues emerged that were promptly solved. So the simulator as presented will appear correctly functioning and reliable. The ECOSHE simulator is a valuable tool, as it allows to assess the human error probability during emergency situations with a well-structured scientific approach that allows to consider internal and external factors that affect operator's reliability.

4. EXPERIMENTAL SCENARIO

This section presents the application of theoretical model presented above in a petrochemical company. Problems are amplified, because the risk is defined in a confined space. For this reason, it is necessary to define a specific model to quantify human errors. It is necessary to apply the integrated HRA model, evaluate all the necessary data, and then insert them in the ECOSHE simulator. The incident is the explosion of a chemical oven in a petrochemical company (Figure 4). A chemical accident has been chosen because the consequences of a wrong operator choice could have consequences for employees but also on the surrounding area. In fact, petrochemical companies are listed as "major risk incidents" by European legislation.

For a limited emergency, only the internal emergency plan is activated, while for the high-risk companies, such as petrochemical companies, an external emergency plan is also implemented, that provides the involvement of public agencies of environmental, health and social control. The explosion of a chemical furnace can cause deaths and injuries among employees resulting from burns, blows, and inhalation of harmful substances. Moreover, the consequences are also reflected in the external environment with toxic clouds that can affect a large population. It is important to analyze the reliability of the operator involved in early emergency management manoeuvres. Incorrect action, or an action that is over-done with an excessive amount of time, could have disastrous consequences. The aim of the study is to calculate, using ECOSHE simulator, the human error probability under certain conditions. If the probability of error is too high, it is crucial to implement suitable systems to limit this value. This study realizes a preventive study refers to the accident. The study simulates and calculates the reliability of the operator under particular conditions, to understand how and what could go wrong. The study is limited to the initial incident management by the team leader. The analysis does not consider interventions of health care and firefighters. As soon as the accident occurs, the safety officer launches the alarm, employees must follow emergency exit ways and health rescue tools, and firefighters are alerted. Meanwhile the team leader, after the emergency plan activation, has to do two fundamental actions:

- Depressurize plant: this action makes it possible to lower the system pressure and to safeguard the healthy systems from failures, due to the explosion of the furnace. In addition, the pressure rise could lead to further explosions making more difficult rescue operations;
- Drain gases into the torch: This operation eliminates all residual gases that could generate explosive atmospheres or toxic clouds that are highly dangerous for people in the circumstances.

If the two operations are performed correctly, the emergency term ends. Obviously, if fires or other dangerous events have developed, it is also necessary to manage these events to stop the emergency situation.

Figure 4: Scenario under study

The aim of the simulation is to identify the human error probability of the team leader that must perform the two actions previously described. The generic task that approximates operator's task is “*Shift or restore system* *to a new or original state*". In fact, all the actions carried out by the team leader aim to bring the system back to nominal conditions, or in any case to eliminate the emergency conditions. The simulator can schematically represent the analyzed process and circulate in red the incident event that was generated. In this case, the incident event is related to the explosion of a chemical furnace (Figure 5).

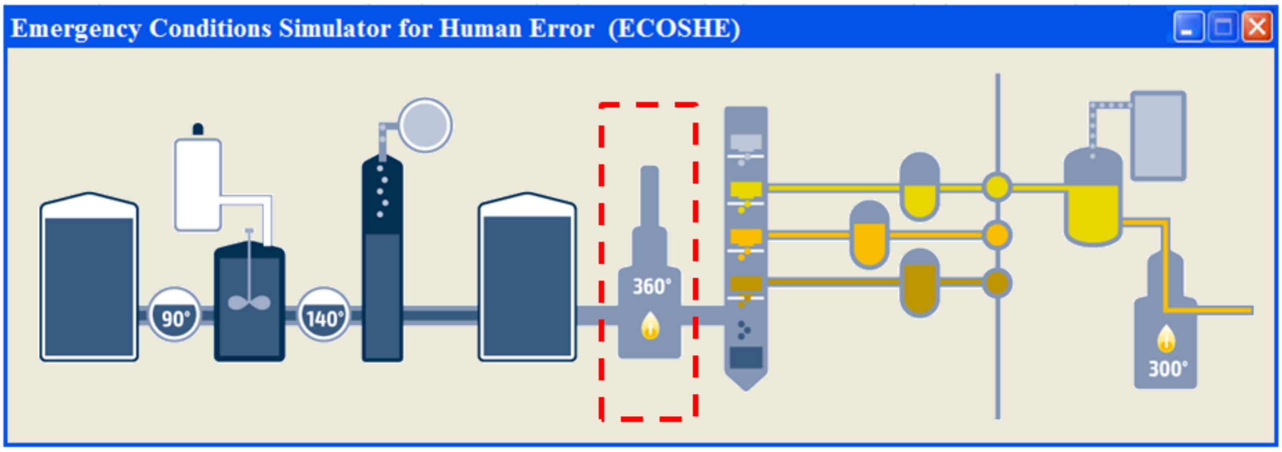

Figure 5: Failure schematization

Considering the HEART model, the choice falls on GTT 2. The description of generic task allows to identify the internal factors that affect the human error probability (Table 3). Obviously, for each type of action there are different GTTs with different values of human reliability. Table 3 shows the increasing unreliability values of the operator with the passage of time. For the first 7 hours of work considering k1 reliability, while the later hours of work considering k2 reliability, less powerful. The "β" value is 1.5. This value represents a distribution of human reliability that begins to grow in the early hours of work, then decreases as time passes. This distribution was chosen because it best represents the human reliability and it is the most used for HRA studies.

Table 3: Generic task selected

Generic Tasks					
GTTs	Limitations of unreability	k1	k8	α	β
2. Shift or restore system to a new or original state	0.14-0.42	0.86	0.58	0.021	1.5

It is crucial to define the values of performance shaping factors that represent the external factors that affect the operator's reliability. In general, if there is no data for some PSFs, a nominal judgment (value=1) is defined. Table 4 shows the environment judgment according decision maker.
The choice of performance shaping factor parameters is entrusted to the expert decision. So to achieve a consistent assessment it is necessary to understand the analyzed process. Operator's choice of time is the time available to the operator to make the right choice or action. From an interview with the operator this time is about 5 minutes. In the case study it was rated as "nominal". The operator experience is about the years of work of the operator and its degree within the company. In this case the operator has been working for 25 years in the company and is a team leader, therefore the experience is evaluated "high".

Table 4: PSFs value selected

PSFs	
Choice time	Nominal
Experience	High
Procedure	Poor
Stress	High
Complexity	Moderate

Procedures are related to standard works defined by the company to describe certain activities. In this case there are not many specific procedures, so it is evaluated "poor". The stress level of team leader is high, because the accident is quite serious and a wrong action could cause irreversible damage. Finally, the complexity of the operation is evaluated "moderate". After identifying external factors affecting the operator, it is necessary to fill in the various simulator fields the input data (Figure 6). Moreover, a further input value is the working time in which it wants to analyze the human error probability. For this simulation, it calculates the human error probability during the ninth hour of work.
After, entering with the input data, the simulator automatically returns the output data. If some value has not been inserted the simulator does not show the output of the system window, then the user is forced to enter the required data. In particular, the logic of the simulator allows to identify the internal influence values of the system (HEPnom) and the value of the contextualized human error probability, considering

both the internal factors and the external factors (HEPcont). Error probability values are graphically expressed through a histogram, while the values for the influence of the external environment are represented by a pie chart. Finally, the simulator expresses numerically the value of HEPcont for a specific work time. In the case study, it decides to analyze the contextualized human error probability during the ninth hour of work (Figure 7).

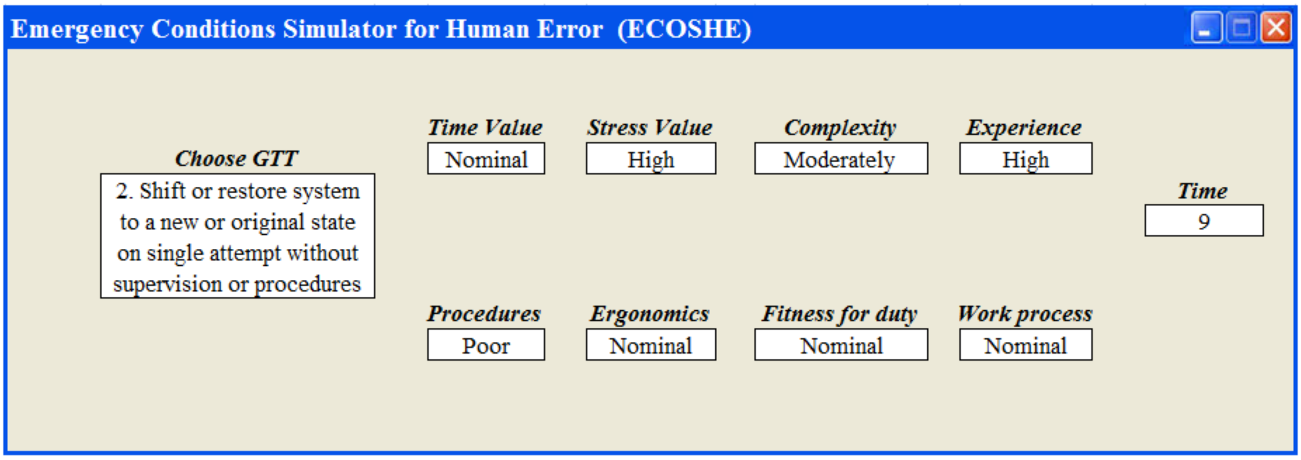

Figure 6: Input simulation values

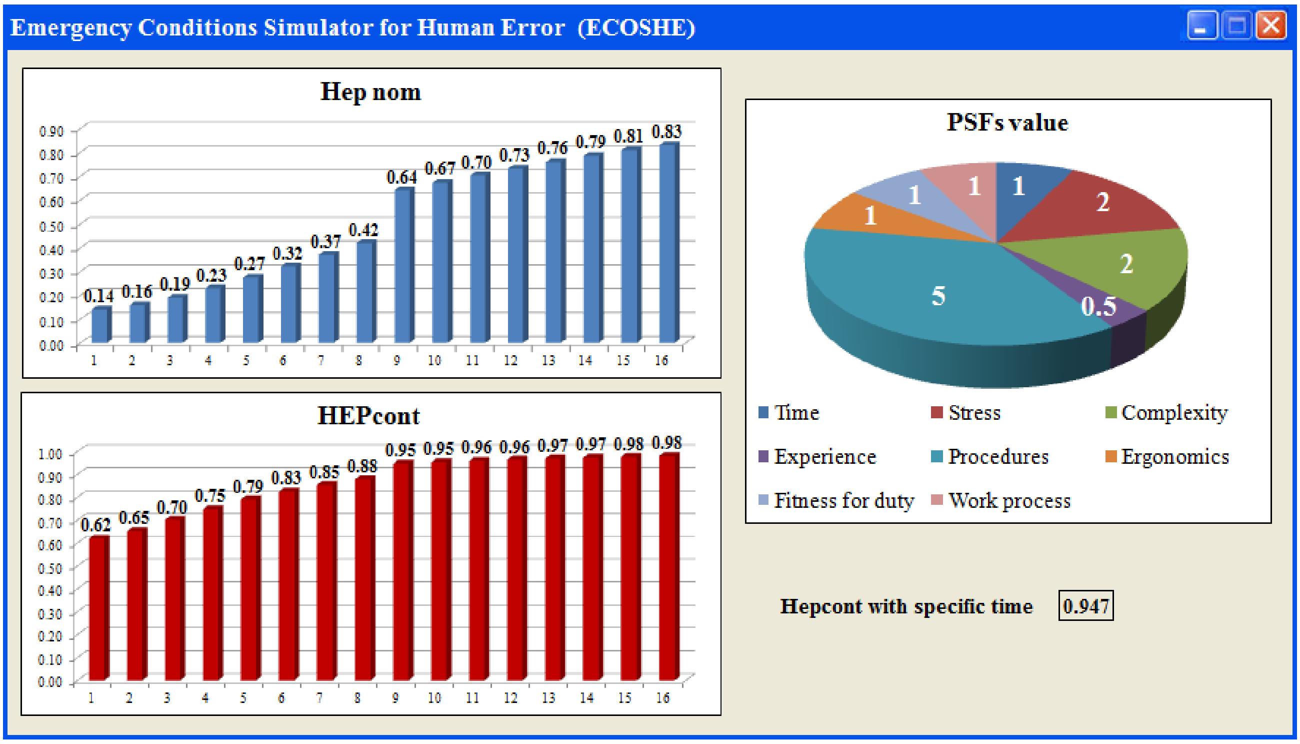

Figure 7: Simulation reports

Considering only the internal factors, the output of the simulator shows a growing HEPnom, in particular, there is a step between 8 and 9 hours of work until it reaches the 16th hour of working with a HEPnom with a value of 83.1%. This first result shows that the nominal human error probability for the considered action is quite high since the ninth hour of work and therefore human error begins to become more and more probably. Since human error in this case study can have serious consequences, it is necessary to review the process to limit the HEPnom. This first analysis only analyzes the internal influencing factors. It is also necessary to consider the environmental factors that worsen human reliability. Analyzing environmental factors, stress, complexity of the operation, and lack of procedures, it is evident that there are critical points. In particular, the stress caused by the complex emergency activity and the lack of procedures weigh a lot on the total value. While the operator experience takes on an extremely positive role. In fact, in some cases, PSFs may improve the value of HEP instead of worsening it. Environmental factors, combined with internal human factors, cause a growing HEPcont with a limit on the 16th hour of 98%. Again in this case, the contextual error probability is extremely high and needs to be lowered, because a wrong action could have disastrous consequences. Finally, the simulator shows numerically the HEPcont for the ninth hour of work with a value of 94.7%. The simulator's results show a negative situation because the human error probability is very high. To improve the situation, it is necessary to improve internal human factors, for example, by pausing between several hours of work. By adding breaks between working hours, the operator's attention level decreases more slowly. Or it could think shorter shifts, or even outsource emergency activities to a team that only work with this. These interventions would reduce the value of HEPnom. Or alternatively it has to improve the outside environment to limit negative influence. First of all, it is essential to develop precise and targeted procedures to identify the activities to be performed during the emergency. Also during the years, team leader must perform more than one emergency simulation to practice. In this way the human error probability decreases a lot, during a real emergency. The decrease in the PSFs factors limits the effects of the HEPcont.

Regarding the use of the simulator, it is evident that the application is very simple and the user must choose only inside the window the value that best approximates the conditions of the analyzed process. The user should not have knowledge about the theory of human reliability analysis, but only needs to know the process being analyzed to evaluate all internal and external factors that affect human reliability.

5. CONCLUSION

The human reliability during emergency conditions is a topic discussed in the academic world, because a wrong decision in that situation could have disastrous consequences. The research presents an integrated HRA model, that allows to evaluate the human error probability, considering the internal and external factors influencing human reliability. Traditional HRA models in literature, however, consider the internal factors and external factors separately. In addition, traditional HRA models analyze operator reliability in the first 8 hours of work. The search proposes the analysis for a greater turn of the standard 8 hours, because during an emergency situations operators can work for 16 consecutive hours. So the theoretical model overcomes the limitations of literature. The other purpose of the research is the development of a simulator that allows to evaluate the human error probability. Even in this case, in the literature, there are many simulators, but they are quite complex. The developed simulator, called “ECOSHE” (Emergency Condition Simulator for Human Error), is very simple and can be used by everyone. Furthermore, the construction of the model is standard, so the simulator can be modified to evaluate other scenarios, so it is very flexible. The research has presented the characteristics and phases of building the simulator. The proposed model has been used to assess the probability of error of an operator working in a petrochemical company during an emergency. Petrochemical companies are considered "at a high risk" by European law, so any wrong action by the operator could have disastrous consequences. For this reason, it is necessary to lower as possible the human error probability. All input values (internal and external) evaluated by the user, have been inserted into the simulator, which has returned the output values required for the evaluation of internal factors and external factors affecting the operator's reliability. The case study application has demonstrated the ease of use of the ECOSHE simulator and the validity of its results. Finally, some improvement activities were proposed to lower the human error probability that was critical for this case study. Future developments include an improvement of the HRA integrated approach and a simulator improvement. For the HRA integrated approach, the next step will be to use dependency systems among the various performance shaping factors considered during the analysis. Of course, this addiction will also be reported on the simulator. While further future development of the simulator will be the implementation of a more powerful graphics that allows to handle more complete and complex reports.

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VERIFICATION AND VALIDATION APPLIED TO AN INTEROPERABLE SIMULATION FOR STRATEGIC DECISION MAKING INVOLVING HUMAN FACTORS

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ABSTRACT
This paper proposes the methodologies applied to complete VV&A (Verification, Validation and Accreditation) of interoperable simulators to be used in an HLA federation to address Multi Coalition Joint Operations in scenarios affected intensively by human factors. The paper presents this case study and provide an overview of the different methodologies used and the processes carried out along the entire life cycle of the federation development. The example represents a quite challenging context considering the simulation of the human behaviors and the multiple use modes that move from CAX federate to intuitive application for being used directly by Commanders and their staff.

Keywords: *Verification, Validation, Accreditation, Human Behavior Modeling, Interoperable Simulation, Coalition Simulation, Decision Making*

1. INTRODUCTION

VV&A (Verification, Validation and Accreditation) is one of the most critical element in simulation projects (Amico et al. 2009); especially the concept of accreditation is often underestimated, while it represents the corner stone to guarantee the use of simulator; a top simulation expert with very large experience in industrial application and also in defense, was used to say that "Simulation Failure is usually not due to bad model development, but by missing the trust of the decision makers that should use it to take multi million dollar decisions" (Williams 1999). Indeed it is evident that a decision maker should develop trustiness in the capabilities as well as knowledge in the limits of the simulators that is supposed to use (McLeods 1984). In facts simulation requires significant efforts to be developed and it is usually applied to challenging problems where the decision could affect human life, big quantities of money, important consequences and even personal career (Mosca et al. 1994). Due to these reasons is fundamental to involve the users in the development process to guarantee that he will trust the simulation and its results even in case of critical decisions (Bruzzone et al. 2002 & 2001b).

In facts the decision makers use simulation for decisions, based on the confidence that they achieved along the VV&A processes by their engagement and understanding of the models and simulator capabilities.

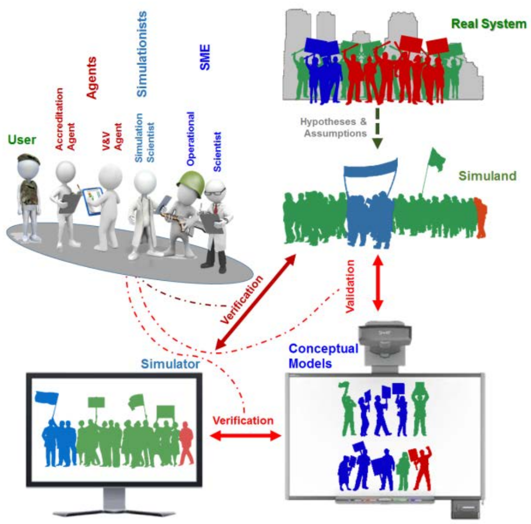

Fig.1 – System, Simuland & Model respect VV&A

It is evident the necessity to engage them since the beginning of development phases, for instance when the simulation goals are defined as well as the main factors and boundary conditions (Balci 1994).

In order to succeed in this case it is fundamental to be able to combine users, SME and simulation scientists into an effective team that share information and acquire a clear picture of simulation capabilities and limits based on intuitive and measurable achievements, even without entering into the technical details of the algorithms (Amico et al. 2000).

The case of simulation for training is a classic example where these principia should be applied, because in absence of full trustiness the impact of simulation training sessions results, drastically downgraded and training objectives risk to be missed (Bruzzone & Massei 2017). Considering these aspects it is very important to properly address the simulation development process matching it with the VV&A activities. Therefore this aspect becomes very challenging in case of complex models, among these the human behaviour models represent probably one of the most hard case considering the difficulty to have reliable data and proper model representing both emotional and rational elements.

Table I – VV&A Plan				
ID	*Title*	*Description*	*People Involved*	*Goal*
0	**Objective Review**	Objectives and Goal review, SOW (Statement of Work) check and WBS review (Work breakdown structure) of SIMCJOH VIS & VIC Development Process	Military SME, V&V Agent, Accreditation Agents, SIMCJOH VIS & VIC Partners	To Collect Feedback about original Objectives and Goals, Simulation Specification, Use Modes and Experimentation Preferences
1	**Conceptual Model Walkthrough**	Analysis of variables, flow charts and diagrams about the models reproducing the different objects and their interactions within SIMCJOH Federation	Military SME, V&V Agent, Accreditation Agents, Scientific SME, Simulation Scientists	To review the conceptual models and human behavior models
2	**Mission Environment Review**	Analysis of Mission Environment, Background Situation and Boundary Conditions	Military SME, Selected Military Experts, Scientific SME, Simulation Scientists, SIMCJOH VIS & VIC Partners	To review the context for the experimentation of SIMCJOH VIS&VIC
3	**Scenario Review**	Review of Scenario Description and cross check with Statement of Work and potential COAs (Course of Actions)	Military SME, Selected Military Experts, Scientific SME, Simulation Scientists, , SIMCJOH VIS & VIC Partners	To review the context for the experimentation of SIMCJOH VIS&VIC and correctness check on parameters of alternative COAs
4	**Data Collection Check**	Review of the collected data, acquired knowledge and taken assumptions by SME, Check of ROE (Rules of Engagement)	Military SME, Selected Military Experts, V&V Agent, Accreditation Agents, Scientific SME, SIMCJOH VIS & VIC Partners	To Check and Certify Data, ROE, COA and assumptions to model in SIMCJOH VIS&VIC
5	**Scenario Walkthrough**	Table Top exercise with SME on the Mission Environment executing manually the scenario and verifying variables, models, factors and data	Military SME, Selected Military Experts, V&V Agent, Accreditation Agents, Scientific SME, Simulation Scientists, SIMCJOH VIS & VIC Partners	To analyze scenario consistency as well as data and model capacity to deal with the mission environments and alternative COA
6	**Implementation Checks**	GUI Review, Checks on Independent Variables, Controlled Variables, Review of the Features and functions through User Interfaces	Military SME, V&V Agent, Accreditation Agents, Simulation Scientists, SIMCJOH VIS & VIC Partners	Validate the model input and output and verify the SIMCJOH VIS & VIC Implementation
7	**Code Review and Debug**	Execution Tests, Output review, interactive debug, face validation on Virtual Environments and Synoptic Interfaces, Limit Conditions review	V&V Agent Simulation Scientists, SIMCJOH VIS & VIC Partners	Debug the Software, Test the functions and review execution of single components
8	**Single Model & Algorithm Face V&V**	Face validation on Virtual and Synoptic Interfaces by Military SME	Military SME, Technical SME, V&V Agent, Accreditation Agents, Simulation Scientists, SIMCJOH VIS & VIC Partners	Review execution of single components and models, V&V of models and algoirthms
9	**Conceptual Model Validation**	Conceptual model Validation through review of Specifications, Objects and State Diagrams: review by SME	Military SME, Technical SME, V&V Agent, Accreditation Agents	To Collect Feedback about the conceptual models respect the original Objectives, Simulation Specification. To review Experimentation Preferences
10	**Integration Testing**	Testing for evaluate HLA integration and interoperability benefits	Military SME, Military Selected Personnel, SIMCJOH VIS & VIC Partners, V&V Agent, Accreditation Agents	To integrate the simulators in SIMCJOH Federation and to demonstrate interoperability benefits. Finalizing approval of experimentation proposal
11	**Preliminary Execution Testing**	Verification of SIMCJOH VIS & VIC Interfaces and Functions	Military SME, Technical SME, Simulation Scientists, Military Selected Personnel	To collect feedback and to verify SIMSJOH VIS & VIC interfaces and functions
12	**Execution Testing**	Verification of SIMCJOH VIS & VIC Features and Functions by allowing SME to make tests directly and using the simulators. Graphics analysis on Virtual and Synoptic Interfaces	Military SME, Technical SME, Military Selected Personnel, V&V Agent, Accreditation Agents	To collect feedback abput correct implementation of functions and features in SIMSJOH VIS & VIC
13	**MSpE, DOE, ANOVA**	Application of validation methodologies such as Mean Square pure error, analysis of variance and design of experiments in order to measure confidence band, experimental errors, optimal duration and optimal number of replications	SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To Measure confidence Band, experimental error, optimal duration and nymber of replications
14	**Technical Sensitivity Analysis**	Sensitivity Analysis devoted to identify the most critical factors for the mission environment and to estimate influence of different human behavior modifiers	Military & Technical SME, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To identify the most critical variable and the influence of the human behavior modifiers on simulation Measures of Merit (MOM)
15	**Interactive Sensitivity Analysis**	Sensitivity Analysis conducted to exploit the critical factors for the mission environment and the influence of human behavior modifiers	Military SME, Technical SME, Military Selected Users, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To accredit the Simulators and acquire user trustiness
16	**Final Interactive Experimentation**	Interactive execution and result analysis carried out on the scenario by Military SME supervised by Accreditation Agent. Graphics analysis on Virtual Environments and Synoptic Interfaces	Military SME, Technical SME, Military Selected Users, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent, Simulation Scientists	To accredit the Simulators and acquire user trustiness

The authors, in this paper, refers to the case of SIMCJOH VIS & VIC (Simulation of Multi Coalition Joint Operations involving Human Modeling - Virtual Interoperable Simulation & Virtual Interoperable Commander) simulators, developed to serve as core engine of SIMCJOH project where human factors represent the most critical element to be modelled (Bruzzone et al. 2015).

2 VV&A PRINCIPLES & CRITICALITIES

As already mentioned, VV&A represents one of most crucial elements of simulation development, Verification Validation and Accreditation (VV&A) both in decision making and military training domains.

In general the V&V (Verification and Validation) uses consolidated methodologies and procedures since its foundation and has further developed in a well defined set of procedures and methodologies along the years (McLeods 1984; Balci et al. 1996; DoD 5000.61, Youngblood et al. 2010; DoD MIL-STD-3022).

Along the years some different tentative have appeared to try to formalize a standard in this sector, therefore the high degree of tailoring required to successfully apply VV&A allowed just to define best recommended practices and guidelines as it happen with FEDEP and DSEEP (IEEE 2003, 2011). In particular, one of most successful attempts is embedded in the IEEE 1516.4 best practice; this document provides the description of all consequent conceptual phases of the VV&A efforts; those are overlaid to the FEDEP/DSEEP correspondent phases. Each phase is articulated into subsequent elementary activities which are then building the different chapters of the main VV&A documents: Accreditation plan, V&V plan, V&V report and Accreditation Report. The IEEE 1516.4 supports the process by providing a clear description of the temporal execution of the different V&V activities; vice versa, the MIL-STD-3022 standard as well as the 5000.61 Instruction have been developed by the M&S Coordination Office (formerly Defense M&S Office) to provide templates of the different VV&A documents as well as lists for definitions and concepts to be elaborated during development of simulators and relative V&V . Both approaches are paying attention to support the coordination of the multitude of different actors usually involved in the development V&V and use of the simulators. Despite the similarity and the synergy between the 3022 and the 1516.4, the two document mostly complete each other; therefore some differences are present making specific difference in the two approachesIn facts, the MIL Standard 3022 is developed for Stand Alone Simulators, while FEDEP and DSEEP are mostly focused on VV&A of federations that are networks of simulators.

Obviously in order to be successful it is fundamental to establish an effective and reliable cooperation among SME (Subject Matter Experts) covering the different simulation domains and simulation development team in order to share knowledge and data as well as to interact during the development (Szczerbicka et al. 2000; Sarjoughian & Zeigler 2001). In facts it is not only necessary to have expertise in scientific and technical domain, but it results pretty important also to combine experience from operational people that served on the field and that could contribute in understanding the context and defining priorities for the different elements to models (Bruzzone 2013; Milano 2014).

In addition, major elements are related by the necessity to conduct joint VV&A on the whole simulator when it is composed by different components, federates or objects; and this need to be done starting since the beginning of the simulation development and along its entire life cycle (Balci 1994).

This is due to the need to develop proper conceptual models (Validation) and to implement them correctly (Verification) keeping engaged the final users to generate trustiness on the Simulator (Accreditation). From this point of view data collection, knowledge acquisition and conceptual modelling are probably the key point on this process (Williams 1996; Amico 2000, Zacharewicz et al. 2008).

From this point of view, it is very interesting the concept of Simuland representing the pictures that experts have of the real system and that is used as mirror to develop the simulation conceptual model, sometime not exact or complete (McLeod 1986). In facts to complete V&V (Verification and Validation) of a model or simulator, it is required a reference real System and related data; therefore often this system is not directly measurable (e.g. fear present among the population), not very well known (e.g. an opponent weapon system or a emergent social behaviour) or even does not exist yet (e.g. the reliability of new doctrine); in all these case hypotheses should be adopted about the nature of the real system creating an intermediate world, defined Simuland, used to create the simulation as proposed in figure 1 that could introduce additional challenges (Bruzzone & Massei 2017).

In facts it is almost impossible to know exactly a real system and often the SME have just a partial knowledge of the scenario to be simulated and not very reliable data; so it could happen that along final phases of the simulation development process new elements arise improving the understanding of real system and correcting the Simuland.

All these aspects are generating an very complex context in case of simulation dealing with Human Behaviour that represent a major challenge even if interesting experience has been accumulated over the years (Cacciabue 2002; Bocca et al. 2006; Bruzzone et al. 2011; Di Bella 2015).

3 HUMAN BEHAVIOR MODELING

Human Behaviour Modelling (HBM) and Interoperable Simulation are proving their value as an effective combination to investigate impact of operations, plans and actions that affect the populations (Bruzzone et al. 2011a). In this sense it is fundamental the use of proper models representing not just people statistics, but even their complex dynamics and social interactions at different levels (Schmidt 2000; Stocker et al. 2002; Bruzzone 2013).

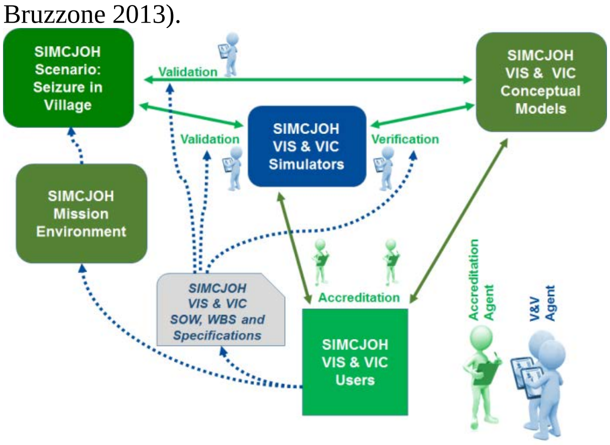

Fig.2 – V&V and Accreditation Agents for VIS & VIC

Indeed the use of agents driven simulation is very promising considering the possibility to create intelligent actors taking into account socio-psychological aspects (Bonabeau 2002; Bruzzone et al. 2011b). As anticipated, the VV&A methodologies and procedures are fundamental in simulation over many different areas of application including military, flight driving simulators (Zeltzer & Pioch 1996); therefore examples of VV&A activities exist in the context of industrial application of HBM (Aas et al. 2009, Jou et al. 2009, Song & Zhang 2010). In the proposed case study the simulation was adopting a MS2G (Modeling, interoperable Simulation and Serious Game) paradigm in order to be flexible for different use modes (Bruzzone et al. 2014a,2014b).

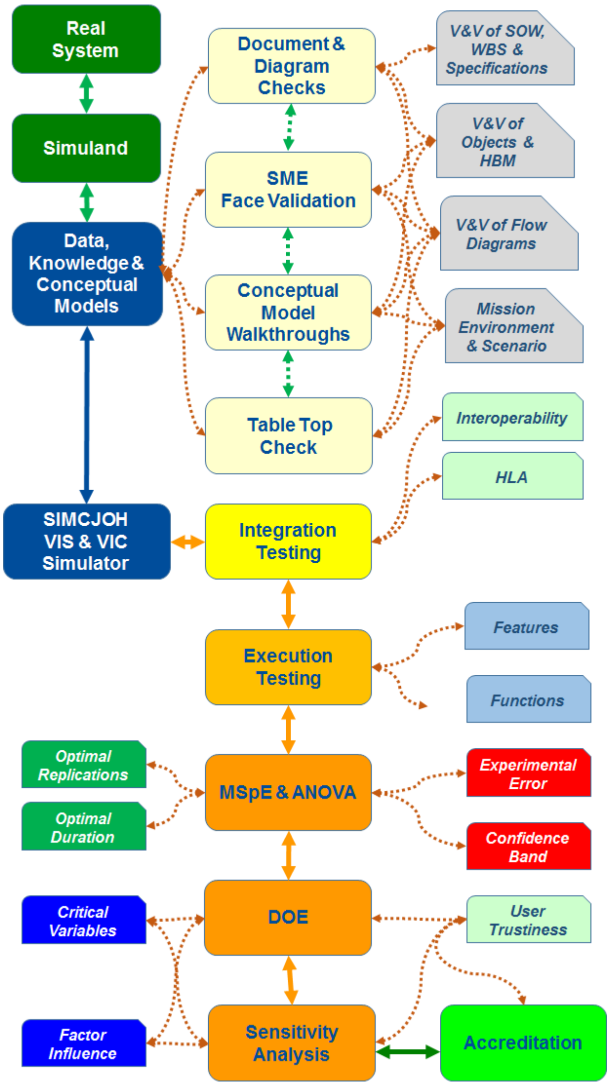

Fig.3– VV&A Methodologies & Techniques

4 SIMCJOH PROJECT & VV&A CHALLENGES

In facts SIMCJOH VIC & VIS (Simulation of Multi Coalition Joint Operation Involving Human Modeling, Virtual Interoperable Commander & Virtual Interoperable Simulators) have been developed according to the MS2G concept to provide support Commanders and their staff in strategic decision making. VIS & VIC allow to operate both in stand alone mode and federated in SIMCJOH HLA Federation derived from RPR FOM (Bruzzone et al. 2015a) to support training. In particular these simulators goal is to provide the Commander a virtual and immersive environment where to train his critical decision making skills while familiarizing with the scenario of operation. SIMCJOH VIS is especially oriented to the evaluation of the impact of the decisions undertaken by the commander on human factors, in facts population models; in facts the human behaviour models are central in SIMCJOH VIS & VIC and proper VV&A is required for successfully complete the initiative. The cores of SIMCJOH VIS & VIC is made of Intelligent Agents for representing population, interest groups, opposite forces that affect the decision taken by the commander. Indeed VIS & VIC federates could be part of the large SIMCJOH federation that include also SGA, NCS & GESI to cover scenario generation, entity level simulation and details of the communications and C2. SIMCJOH Project was coordinated by Simulation Team operating in synergy with Academia (Genoa and Calabria Universities), large companies (Leonardo & CAE) and hi-tech startups (CAL-TEK & MAST) to create an innovatie federation devoted to support Commanders operating on complex scenarios affected by human factors within a Coalition. The VIS & VIC are devoted to reproduce the population and people dynamics as well as the virtual staff of the commander and the OPFOR; so due to these reasons the Intelligent Agents (IA) react based on the dynamic evolution of parameters, which include, among others: fear, aggressiveness, deterrence level, trustiness. Commander decisions affect the evolution of these parameters, which, in return influences following commander choice. The SIMCJOH VIS & VIC resulted very interesting opportunities to apply different existing state of the art procedures and methodologies to drive the VV&A processes (Bruzzone et al.2015a).
Obviously in the proposed case the VV&A is complicated by HBM due to data availability and reliability as well as to the uncertainty on human factors (Bruzzone 2014b).

5 VV&A METHODS & SIMCJOH VIS & VIC

Along the first phase of the VIS & VIC development, is was created a mixed team composed by simulation scientists, V&V Agents, SME and operational people defined as SIMCJOH Champions devoted to cover the different aspects. Simulation Team scientists and researchers acted side by side with NATO M&S COE and specific expertise was provided also by CESIVA (Italian Army Center for Simulation and Validation), COI (Joint Operational Command of Italian MoD) and R&D Center of Italian MoD. the V&V and Accreditation Agents have been appointed based on available resources among simulation experts following the scheme proposed in figure 2. During early phases it was necessary to review the Experimentation Plan for supporting VV&A and for defining:

- Mission Environment
  - Terrain
  - Villages
  - Population Data
  - Coalition Data
  - OPFOR Data
  - LEGAD Constraints
  - Geo Political Boundary Conditions
- Planning Elements
  - Tasks
  - Alternative COAs
  - Desired Final Effects
- MOE/MOP
  - Metrics
- Exercise Plan

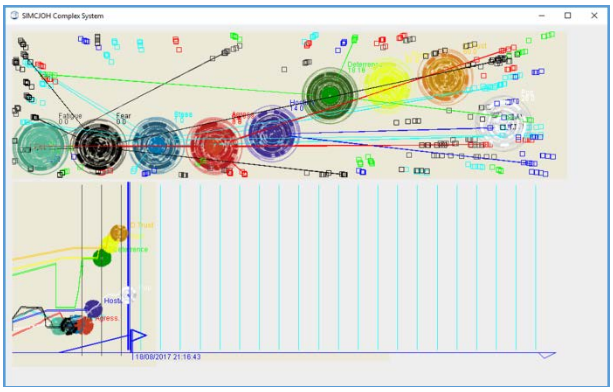

Fig.4– GUI for HBM Temporal & Dynamic Evolution

In particular it was adopted the VV&A Plan summarized in table I. This plan was executed by organizing period meeting allowing to identify errors and missed elements as well as the testing procedures to be used on the models; while the mission environment was finalized within few months moving the original Libya context to Lebanon due to the evolution of the geopolitical interests of the Sponsor Nation, the specific scenario to be used for experimenting the context required a lot of efforts (Bruzzone et al. 2013b). Originally terrorist attacks with hostages, evacuation at different levels and special force operations have been investigated to consider human factors and coalition challenges. Finally thanks to top military Commanders contribution the scenario was finalized on the case involving a squad seizure with media implication locally and domestically as well as with dealing with immigration crisis and special forces actions affecting population; this resulted quite challenging therefore guaranteed a good engagement of SME with Simulation Scientists and the scenarios were played with people in charge of real operation in the area over three full days.

In facts the experienced problems in addressing this strategic decision making context corresponds to the real system complexity and cannot be overpassed by simulation or software solutions due to the dynamic nature of the mission environment and related data. In facts the creation of the Mission Environment by SIMCJOH VIS & VIC Partners based on data and feedback provided by the users and the fine setting of variable lists and models carried out by SIMCJOH Champions during conceptual modeling and preliminary algorithms tests allowed to define the specific details for the experimentation. Concerning the VV&A of SIMCJOH VIS & VIC models, different techniques and methodologies have been used including face validation, review and walkthrough as well as dynamic techniques based on ANOVA, DOE & MSpE as proposed in figure 3 (Mosca et al 1994; Montgomery 2008). In order to verify users trustiness due to current data availability and experimentation plan it was decided to carried out a technical and an operational V&V session based on sensitivity analysis devoted to provide a more detailed analysis on the correlations and impacts of the different factores as well as on simulator effectiveness.

5.1 Objective Review

This phase has a great impact on simulation development process and it is usually based on reviewing documents such as SOW and WBS with SME and to correlated with original requirements, for instance it case it was carried out respect the original SIMCJOH VIS & VIC Simulator description. The definition of measures related to the human factors to be used for testing and experimentation resulted critical to finalize the experimental plan; for instance it was decided to define key performance indexes including among the others: fear and aggressiveness level on the population, size of the demonstration, perception of deterrence by different parties, local and domestic media perception; some of these factors are real and measurable (e.g. number of people in the a demonstration), others are just virtual, therefore their evolution along time and in relation with key events support the VV&A of the Simulators.

5.2 Conceptual Model Walkthrough

This informal technique allows to review the proposed models to be used and implemented in the simulator by interacting with the SME; considering the HBM this requires to adopt representations that should be easily implemented, but also intuitive for being accessible to psychology, sociology and military SME. In our case Flow diagrams have been extensively used as proposed in figure 3

5.3 Mission Environment Review & Scenario Review

As anticipated the definition of Mission Environment and Scenario is fundamental and does not represent a limitation for the models and the simulators; vice versa the proper definition of these elements and related boundaries allows to conduct an reliable experimentation that could replicated with measurable Measures of Merits that allow to finalize VV&A in this framework considering the needs of Strategic Decision Makers.

5.4 Data Collection Check

Data are a very critical, in terms of population and related parameters usually the information is pretty inhomogeneous and not aligned in terms of validity time and area; in addition confidential aspects and classification could introduce further challenges; due to these reasons it was decided to use just public domain data and it resulted critical to engage in the process the people actually in service in planning operations in the area; in this way it was possible to fine tune such data in consistency with realistic situations without using any sensible information.

5.5 Scenario Walkthrough

The use of SME and Selected Commanders allowed to execute manually the scenario before to finalize the simulation development to check conceptual interoperability among models and consistency among data and parameters.

5.6 Implementation Checks, Code Review and Debug, Single Model & Algorithm Face V&V

The techniques summarized in the table I allowed to finalize these technical aspects and to arrive to an execution capability able to deal with SME face validation. Obviously the single model/algorithm V&V does not guarantee the simulation validity, therefore it is an useful corner stone to check proper implementation and remove doubts about some single elements before to move to integration testing and overall execution.
In this phase the use of Animation, Virtual Reality and Dynamic Synoptic Representations is very important to be able to complete V&V of complex phenomena; VIS for instances proposes a graphic representation (see figure 4) including the human behavior levels (e.g.fear, fatigue, aggressiveness, stress, deterrence perception, media attitudes), change speeds & accelerations, history as well as the factors contributing to their evolution. Obviously these feature will be very useful even in following phases.

5.7 Conceptual Model Validation
Conceptual model Validation represents a mark on the VV&A allowing to check conceptual model development versus original requirements considering data collected and knowledge acquired along development life cycle; these aspects turn even more mature as soon as single model tests allows to select the most promising solutions to implement the simulation

5.8 Integration Testing
A major step from technical point of view is to demonstrate Interoperability Capabilities of the simulators. The SIMCJOH VIS & VIC integration tests have been carried out several time, before just among simulation scientists and then demonstrated interactively with different SME

5.9 Preliminary Execution Testing
This step was devoted to execute SIMCJOH VIS & VIC and test their features and functions. In facts SIMCJOH VIS & VIC Partners proposed the preliminary Interfaces, which have been reviewed and updated based on Military Users suggestions and comments.

5.10Execution Testing
This step was devoted to execute SIMCJOH VIS & VIC with the representative of SIMCJOH VIS & VIC Champions. In this way it was possible to allow them to directly test the simulators

5.11MSpE, DOE, ANOVA
These dynamic quantitative methodologies are fundamental to estimate experimental error and confidence bands considering the highly stochastic nature of the HBM; in this phase agents are involved on a technical basis preparing all documentation required for the following documentation and accreditation procedures

5.12Technical Sensitivity Analysis
These aspects allowed to identify critical independent variables influencing the simulator results in the specific mission environment; the processes allowed to fine tune the HBM parameters in technical phase

5.13Interactive Sensitivity Analysis
The interactive sensitivity was carried out after fine tuning of HBM parameters to share understanding on limits and capabilities of SIMCJOH VIS & VIC with SME; this allowed to develop trustiness on the models during the interaction with military users.

5.14Final Interactive Experimentation
The final step was devoted to finalize simulator accreditation by users and military experts by distributing and analyzing the experimental analysis results during an experimentation carried out directly by them. In SIMCJOH VIS & VIC the test was taking a whole day and was repeated other times to engage other military subjects, resulting pretty successful.

5 CONCLUSIONS
The SIMCJOH VIS &VIC Verification and Validation passed with success the face validation of Models and GUI and currently the project is moving forward for the dynamic testing during the experimentation; the integration test on HLA models was successful passed; the functional tests as well as final experimentation resulted pretty satisfactory receiving very positive feedbacks from military users. It is important to outline that the verification and validation based on experimental analysis was fundamental to create trustiness in the HBM embedded in SIMCJOH VIS & VIC. In facts the success of this aspects supported the fully achievement also of the whole SIMCJOH Project and its objectives.

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JOINT APPROACH TO MODEL HYBRID WARFARE TO SUPPORT MULTIPLE PLAYERS

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ABSTRACT

Hybrid Warfare is a concept that is continuously evolving demonstrating its impact on vulnerability of the modern society, especially related to social networks and innovative technologies. Obviously this subject is strongly related to many different fields including economy, politics. strategic communications & media, cyber defense, social networks; in addition the players on this game are required to master different techniques and subjects; due to these reasons this paper proposes an integrated approach devoted to combine different models and elements within a common simulation framework. The proposal provided by authors describes the model architecture as well as some model examples and an application field used to carry out tests and experimentations.

Keywords: *Interoperable Simulation, Multilayer Modeling, , Hybrid Warfare, Serious Games, Human Behavior Modeling, Strategic Communications, CIMIC*

1. INTRODUCTION

Nowadays the new technologies and social evolution are enhancing the impact of the phenomena that are usually defined as Hybrid Warfare (HW). In facts HW is based on *not linear actions*, as defined by HW SME (Subject Matter Experts) in terms of discontinuities respect crisis evolution in terms of actions carried out over very different multiple layers from military to economy, from cyber space to power grid. Indeed in HW considers the whole common interconnected comprehensive environment as the place where carrying out concurrent actions devoted to achieve desired effect by forcing the opponent to take favorable decisions without the need to be engaged in traditional warfare (Galeotti 2016; Blinka 2017). This approach has been extensively used in the past (Hoffman 2009; Murray et al. 2016); indeed, even if there are still concerns about the proper use of the term Hybrid Warfare itself, it is evident that the current world represents a very promising framework to experiment these techniques in new ways (Cayirci et al. 2016). In facts the use of modern media and communication channels, directly reaching the population almost without intermediate control, allows to diffuse real and fake news, information and strategic messages that could heavily influence the behavior of a Nation or an International Organization as it was impossible just few years ago.

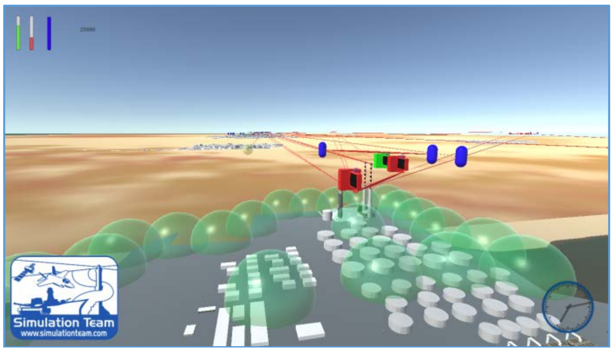

Fig.1 – I2MIRSEG Augmented Representation

A very good example is provided by the case of some recent USA election where it was scientifically measured the greater influence of web social networks respect TV media in terms of capability of targeting specific messages on the electors (Bond et al. 2012; Enli 2017). It is evident that the use of scientific models able to predict the reactions of Populations, as well as that ones of Institutions and Organizations, represents a strategic advantage; this concept is very well point out by General Gerasimov, titled the *father* of modern Hybrid Warfare (Gerasimov 2013 & 2016). This scientific approach makes evident the potential of Modeling and Simulation (M&S) for studying HW and for related Educating & Training (E&T) of the decision makers. Therefore, as anticipated, Hybrid Warfare is based on concurrent actions that evolve based on a not progressive approach in terms of escalation; in HW the actions are characterized by discontinuity in attacking, concurrently, different elements of an opponent such as finance, media, cyberspace, population trustiness, politics (Keeton et al. 2005; Bachmann et al. 2014; Krug 2017). In facts the players, in hybrid warfare, are requested to operate on multiple layers and to involve experts of the different domains to maximize the impact of the actions; due to these reasons the authors propose a joint architecture to address this problem that is based on interoperable simulation and leads to create a common framework for virtual experimentation. So the authors propose an innovative approach utilizing these concepts and a simulation architecture able to support its implementation. In facts there are already examples of simulators able to address HW Scenarios where multiple players could introduce their expertise and test hypothesis and settings to play simulation based table top exercises devoted to acquire expertise, share results.

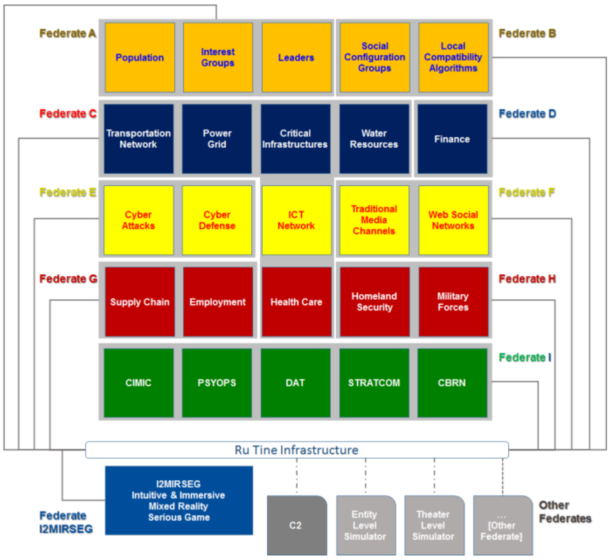

Fig.2 – Example of Proposed Architecture

Indeed this approach allows to evaluate reliability of available info and data by testing them on realistic virtual scenarios; in this way it becomes possible to finalize studies, comparisons and analyses based on validated and verified common simulation frameworks. In particular this paper proposes to use MS2G (Modeling, interoperable Simulation and Serious Games) as paradigm to develop new intuitive multi layer environments where different players could interact dynamically (Bruzzone et al. 2014b). NATO M&S COE is currently working in synergy with Simulation Team to engage major institutions and top experts of the different domains to further develop these concepts and to create examples of this common simulation framework for studying HW.

2 THE COMPLEXITY OF HYBRID WARFARE

Different kinds of complexity are present in Hybrid warfare; some ones are strongly related to the inner difficulty to identify the principia ruling some component as well as to model them (Cayirci et al.2016); a very good example is related to modeling economics as well as rational and emotional processes ruling this framework (Rosser 1999; Bossomaier et al.2000). Therefore other kinds of complexities are related to the high number of interactions among many entities that affect the system introducing emerging behaviors difficult to understand and predict (Bossomaier et al. 2009; Wolfsfeld et al. 2013; Know & Hemsley 2017). Obviously among the most complex elements it should be counted the population as well as human factors that is a corner stone in Hybrid Warfare (McCuen 2008; Baker 2015; Di Bella 2015; Lamb 2016). All these aspects result today much more sensitive to HW respect the past especially due to responsiveness and vulnerability of social networks, web applications, mobile solutions and IoT (Hashem et al. 2015; Turban 2015; Kramer et al. 2017; Larosiliere et al. 2017; Silva et al. 2017; Rahman et al. 2017).

For instance it is very interesting today to develop models about the diffusion of real and fake news through social networks and the related trustiness evolution (Bruzzone et al. 2013a; Paquet-Clouston et al. 2017). So far, it is crucial to model these elements and the present research track is focusing on the need to identify and model these multiple complexities and their interactions. It is fundamental to adopt an approach that enables the creation of innovative simulators able to reproduce these scenarios and to carry out virtually defensive and offensive HW actions evaluating their relative impacts.

3 NEW VULNERABILITIES TO REAL & MEDIA ATTACKS

Today, there is an “explosion” in terms of technological advances and new dependencies of the modern society respect to informatics, social media, satellites, power grid, etc. This aspects make the States and Population much more vulnerable at possible new types of HW attacks with catastrophic impacts (Davis 2015).
Therefore often it is not just necessary to conduct a real attack, but it could be devastating even to diffuse fake news driving fear and dissatisfaction among the population (Aro 2016).
This concept is much reinforced by the loss of credibility of most institutions and by their latency in reacting to these phenomena; it is sufficient to mention cases such as Iraq WMD (weapons of mass destruction) or Anti Vaccination campaigns to realize that people do not have too much trustiness versus Institutions and Organizations (Dadge 2006; Bennett 2016; Kadam 2017); from this point of view internet is a very effective channel able to diffuse so many information and to correlate them in a way that is possible to create consistent big data sets able to saturate the understanding critical capabilities of a large part of the population. In addition this context is reacting very quickly to the actions, in facts while in case of traditional media (TV, Radio, Newspapers) it was required a lot of time and efforts to diffuse a message, the interactive nature of the web allows the individual to be targeted personally, but also to react actively by investigating and interacting with friends and opinion leaders. Syria Civil War presentation to media is a very good example of this fact (Fisk 2017) and the “media war” on-going from the different actors with their specific interests are pretty evident to an expert eye as their ineffective approach respect young generations moving on the web that have a different perception (not necessary more correct): a basic evidence of these aspects is related to the neglected mentions to “Oil” in most official media while addressing the political and military issues on Iraq Kurdistan despite the presence of large deposits and the large quantity of media material used to attack the different info targets on the web.
The point is that when after trustiness is gone it becomes very hard to recover; in this situation an agile and smart player could diffuse easily fake news and reinforce their credibility by properly preparing the web context in advance, for instance posting preliminary info and constructing source and expert credibility; these

techniques have been experimented in entertainment industry with interesting successes based on this kind of promotional campaigns such as happened for "Lost" and "District 9" (Jones 2007; Kapstein 2014).
Coming back to the Hybrid Warfare, it results evident that attacks does not have to real, but it could be just carried out on media layer: just think on what could happened if you diffuse fear about a pandemic among the population (e.g. health care structure saturation, transportation and service shutdowns); this was experienced with the campaign on Anthrax letter (Nunn 2007).
From other point of view cyber attacks could result able to crush the power grid for some timeframe (e.g. fridges and telephone not working, phones disabled, ATM and credit card network down, computers not available etc.) or in obscuring the satellites (e.g. GPS not working, communications breakdown) for realizing easily the whole picture of the situation (Ottis 2008; Kallberg 2016).
In facts it is expected that in future the different actions characterizing hybrid warfare will be conducted in strict synergy to maximize their impacts on forcing the opponent to accept the conditions imposed by the attackers in order to reduce the damages and maintain stable his society and infrastructures. So in future cyber and media attacks could be combined with attacks on other layers and it could be necessary to create models able to reproduce these combined phenomena.
In such kind of scenarios, it is very important to be ready to face the possible critical events in order to minimize the damages and to guarantee the keep control of the situation, solving the problems as fast as possible. Furthermore, the multitude and variety of the possible actions that could be carried out over the different layers represents a big challenge that requires multiple models and skills to be connected together.

4 MULTILAYER & MULTIPLAYER ARCHITECTURE

Obviously the difficulties in modeling all the different elements, the uncertainty affecting these contexts, as well as the mutual influence of many factors, suggest the development of new interoperable simulation solutions to support decision makers as well as experts. Indeed the use of simulation allows to obtain results that are of great benefits in the analyses of these phenomena by recreating possible scenarios and evaluating risks and vulnerabilities; by this approach it becomes possible to investigate the influence of alternative hypotheses and boundary conditions respect to scenario evolution and to evaluate different approaches.
As it emerged in studies in this sector the innovation, creativity, as well as previous experiences, have a crucial role in the study of Hybrid Warfare (Gerasimov 2013).

Fig.3 – SPIDER CAVE used as I2MIRSEG Solution

So, any instrument able to share this kind of knowledge will represent a strategic advantage; in addition to this fact, the synergy among users, experts and simulation scientists guarantees to advance the researches and understanding of HW as well as to improve model capabilities in addressing such complex subjects.
In general, it is evident that this context is a complex system and that simulation is the prime methodology to deal with it, however the authors consider pretty difficult and hard to maintain the development of a large stand-alone simulation system. In addition the very eclectic nature of HW context requires to engage many different SME that are often not familiar with M&S techniques nor with HW; so in order to develop and validate the models it is necessary to create an environment that should be able to be intuitive and direct in presenting the scenario evolution to all these different subjects (Bruzzone et al.2017). In this framework the use of models and technologies to develop effective capabilities, new doctrines and to develop valuable training programs is fundamental; in particular the proposed approach is based on the idea to create a mosaic made by interoperable models able to be combined as tiles to cover an extensive part of the Hybrid Warfare and even to propose to users an interactive and intuitive environment based on modern Serious Games (Raybourn 2012; Bruzzone et al.2014a, 2014b).

5 ARCHITECTURE & PLAYERS

The metaphor adopted for this simulation is the "mosaic": a mosaic where each component or layer, such as power grid or web social networks, serves as a tile able to interoperate with other ones. So it is evident that the risk in this approach is to be unable to play the game if some tile is missed. In order to avoid this problem meta-models should be adopted to cover each subject and substituting missing tile in order to be able to finalize the execution of the simulation in all conditions (Bruzzone et al. 2009). Meta-models should serve as simplified representations of specific domains; each of them should use the same objects, attributes and interaction adopted by the overall simulation in order to be interchangeable within the interoperable federation of simulators.

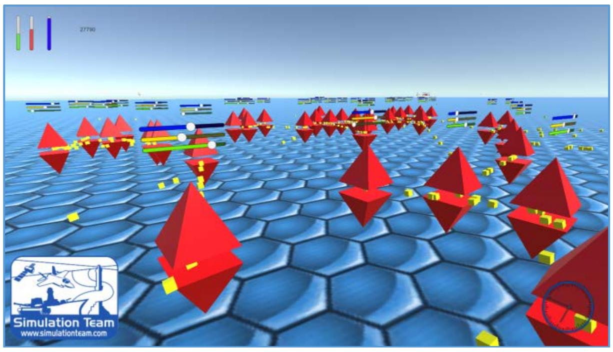

Fig.4 – Cyberspace representation with Node Attributes

This approach enables to adopt different meta-models, more or less detailed, based on the need or, even, to substitute them by sophisticated models or simulator when required. A very important element of this approach is to guarantee the possibility to integrate also other simulators, already available, as well as real equipment in use, to present the situation to decision makers in a familiar way. Due to these reasons the authors suggest to define as interoperability requirement the adoption of IEEE 1516 "evolved" that is the updated version of HLA standard (High Level Architecture).
In order to be able to run a such complex federation, it is fundamental to automate the execution of the different federates; in facts the use of man-in-the-loop on this subject will result in requiring many simulation operators connected to run a single experiment and it will increase drastically the execution time probably requiring to operate real-time; in addition to these elements this traditional approach introduces also subjective components due to the human player status that could compromise the validity of experimental campaigns. Vice versa, in this context it is fundamental to be able to run fast time simulations in large number to create a virtual expertise over this new subject; this could be achieved by introducing IA (intelligent agents) driving the simulation (Bruzzone 2013). Therefore the SME Players are still a fundamental element of this simulation, but they need to act based on the concept of the man-on-the-loop, supervising the operations without getting lost in details (Magrassi 2013). Indeed, in this case, the players are expected supervise the simulation execution, while it is running fast time, just to assign high level tasks to the IAs as well as to introduce general attribute changes. Due to these reasons, it is necessary to include in the models, advanced IAs able to deal autonomously with the scenario evolution based on their own perceptions and their specific objectives. Simulation Team and M&S COE accumulated large expertise in this field by using the IA-CGF (Intelligent Agents Computer Generated Forces) in several of these subjects such as PSYOPS (PSYSOP Simulation, Psychological and cultural Simulation Of Population), CIMIC (CAPRICORN Federation, CIMIC And Planning Research In Complex Operational Realistic Network), Strategic Decision Making (SIMCJOH Federation, Simulation of Multi Coalition Joint Operations involving Human Modeling), etc. (Bruzzone et al. 2009; Mastrorosa et al. 2012; Di Bella 2015).
Indeed the impressive IA-CGF capabilities in human behavior modeling to support population simulation, as well as their native HLA structure, suggested the authors to adopt them as core engine in this application; therefore the open architecture of the proposed federation guarantee to integrate even other tools and solutions (Bruzzone et al. 2012). Obviously it is fundamental, from this point of view, to provide users with an understandable picture of the scenario evolution, so it is evident that an additional and very important element of this federation should be an Intuitive & Immersive Mixed Reality Serious Game (I2MIRSEG).
This module is devoted to create a synthetic environment intuitive for the different players representing the scenario dynamically evolving.
Most players are expected to evaluate and interact directly with the I2MIRSEG federate and to get many information through a Mixed Reality (MR) interface presenting terrain and entities as well as additional information as proposed, as example, in figure 1. In this MR representation propose the overall situation that could rely on different model tiles embedded in multiple federates and open to interact with external simulators. So, by this approach the overall simulation is a federation while the tiles will become parts of the federates, each of them will have objects with attributes and interactions to be shared within the federation to be used effectively.
It should be considered the fact the many of the domains to be covered could have already expertise subdivided in different heterogeneous pieces and framed in different formats, including not digital or computerized models.
These aspects suggest to proceed progressively in creating the meta-models corresponding to the different tiles by implementing the existing knowledge into them. Even very simplified models should be adopted when necessary to guarantee consistency, usability and maintainability.
Indeed the data availability could result sometime critical to finalize validation and verification as well as to guarantee the capability to keep updated the models (Amico et al.2000).
For each tile, it should be defined the set of objects representing the key elements as well as their attributes and the interactions to be adopted to modify them. For instance for the federate incorporating the cyber-tiles the following objects could be included with relative attributes:

Cyber Defense:
- Defensive Team Resources
- Defensive Team Responsiveness
- Defensive Team Efficiency
- Defensive Team Effectiveness
- Anti Virus Diffusion
- Anti Virus Resilience
- Anti Virus Level

Fig.5 – Sensitivity Analysis

Cyber Attack:
- Attack Team Resources
- Attack Team Responsiveness
- Attack Team Efficiency
- Attack Team Effectiveness
- Virus Dynamism
- Virus Initial Injection
- Virus Infectivity
- Virus Resilience
- Virus Level

Specific interactions should be activated to allow to increase or decrease each of the scalable variable attributes by defining impact, lead time and duration; so for instance if it is decided to increase the number of the defensive team resources it could be used the interaction:

modify_defensive_team_resources(dm, lt, dt)

dm change in number of defensive resources
lt lead time required to start the to increase the resources
dt delta time required to complete the increase on the resources

In similar way, interactions should be used to change the level of cyber assets to be targeted by a virus or the initial injections of the virus. The players in this game expected to interact with the scenario through their specific tools and simulators as well as through the common I2MIRSEG covering different domains; for instance in the proposed case, it is expected to engage SME with different operational issues, including among the others:

- STRATCOM
- CIMIC
- PSYOPS
- Cyber Defence
- Defence Against Terrorism (DAT)

6 MULTI LAYER SCENARIO

In order to conduct the experimentation it is defined a scenario derived from previous researches carried out on these subjects (Bruzzone 2013; Bruzzone et al. 2016a); the scenario involve a region with different towns where a threat network operates acting on different ways: cyber attacks, use of small drones against critical infrastructures, coordinated attacks on media. The current scenario involve a complex mission environment including different critical infrastructures interconnected such as power grid, water resources and oil supply chain; the region is within a desert, so the water treatment facilities result particularly critical for the town. In this scenario a wing of small quadcopters is available as IED to the terrorist to deliver explosives in coordination with a cyber attack based on introducing viruses acting on data integrity to disable the defensive capabilities of the critical infrastructure compound. At the same time the threat network could diffuse over different media channels and web social networks real and fake news about the critical situation of the region and the vulnerabilities. In case of successful attack this fear will be further reinforced by additional media material creating a direct impact on water and oil distribution as well as on power availability in the houses. This is an example where different actions could be applied to create pressure on the opponent without forcing the situation to move into a real armed conflict even if the resource in use by the threat network as well as his attack coordination capability make it evident that the aggressor is much more than an isolated group of terrorists. In thi case, the IA-CGF are used to model the population that act autonomously based on their predefined life cycle (e.g. sleep, wake up, breakfast, moving to work, working, lunch, working, moving back home, relax, dinner, entertainment) in regular conditions and react to the crisis; in facts, for the agents the life cycle is not fixed and in case of perceiving critical events or changes in boundary conditions they react based on their perception and their own characteristics including psychological factors, human behavior modifiers and previous experience; the adopted model have been integrated with the IA-CGF, therefore the IAs reproduce not only the people, but also their social networks and the corresponding interest groups (e.g. a leader, a religion, a social class, a generation, an ethnic group, etc.) for guarantee a proper representation of the social dynamics (Bruzzone 2013). In this case, in addition to population models, it is present also an ICT network mapping the IoT interconnected, for each of these element and each of the links are defined variables mapping the levels of confidentiality, availability and integrity; these variables could be attacked by virus or other cyber actions as well as restored by automated defenses or cyber defensive resources; the events on the cyber layer interoperate with that ones on the physical space including power grid, water resources, strategic communications, etc. The threat network is hidden among the population and false alarms are generated as well as spill of information captured by HUMINT, ELINT, web watching and other intelligence resources. In facts threat network members have their multiple operational statuses including dormant, stand by, planning, preparing, acting and they move on the terrain as the regular people; they could be hidden or detected and/or tracked and often they interact with regular people as well as with the ICT network based on their access capabilities.

For the proposed scenario, the critical infrastructures are concentrated into a safe compound facing the sea and protected by different automated and traditional assets that are coordinated by a control room and a security systems. The autonomous systems include UAV and USV available for patrolling the area and investigated on suspects in case of alerts, in addition the area is protected by an air defense system, EW capabilities, surveillance systems & cameras and security guards.

In facts specific IAs are in charge of controlling these entities and units that interoperate autonomously in the mission environment based on high level tasks. As anticipated, the IEDs used by the threat network are small quadcopters operating individually or as a swarm and potentially directed by different control systems (e.g. prefixed GPS coordinates, inertial system). The simulation operates fast time and real time, making possible to slow down or accelerate execution speed by the user, to better understand the dynamics of the events. As I2MIRSEG support it is adopted the SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering), a virtual immersive interactive interoperable cube where virtual and augmented reality are integrated to propose the simulation to the user. Indeed, the SPIDER has been developed as CAVE (Cave Automatic Virtual Environment) by the Simulation Team to be interoperable through HLA with all the IA-CGF NCF (Non Conventional Framework) and it represents an effective solution to achieve a clear operational picture of the whole situation (Bruzzone et al. 2016b). This interactive CAVE allows also to investigate details on specific assets, entities or elements of the networks by touch screen technologies as proposed in figure 3. The immersive IA-CGF NCF used for this simulation could also propose to users a virtual representation of the cyberspace, augmented by presenting the dynamic evolution of integrity, availability and confidentiality characteristics of each element, as proposed in figure 4.

7 DYNAMIC EXPERIMENTATION

A preliminary experimentation has been conducted on the test scenario to support dynamic VV&T (Verification, Validation and Testing) considering the following general independent variables:

A Virus Resilience
B Virus Infectivity
C Anti Virus Diffusion
D Anti Virus Share

Last parameters represent the ratio between strong and regular Anti Virus installed on the ICT resources. The target functions included three different factors:

- CPT (Cyber Penetration Time): Time required to compromise the Critical Infrastructure ICT Network
- CPV (Combined Physical Vulnerability): Number of Critical Infrastructures disable due to the combined Cyber and Physical Attack
- PTD (Population Terror Diffusion): Diffusion of the terror among the population due to the combined media and real attack to water and power resources

The experimental error of these target has been investigated through the temporal analysis of the Mean Square pure Error while a CCD (Central Composite Design) has been experimented to finalize the sensitivity analysis (Montgomery 2008). In figure 5, it is proposed the sensitivity analysis expressed in terms of contrasts respect CPT target function; in this case the values above zero represent direct influence of the corresponding variable on the output while the others result to have a negative proportional influence; the analysis confirms the consistency of the overall model and the high number of combined factors influencing the target functions confirms the complexity of the problem.

8 CONCLUSIONS

This paper proposes a joint approach for creating a synthetic environment able to simulate Hybrid Warfare scenarios; the case proposed represent a first example among many possible examples and the related preliminary experimentation confirmed the potential of this approach and the validity of the models. Currently the authors are working to involve different SME and Institutions to extend these models both in terms of coverage of the domain and fidelity of each component within this area of research. The future goal of this initiative is to create a joint team of top experts able to support these developments as well as to continue to add new tiles to this simulation frameworks including both new simulators and legacy systems.

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CFD & NUMERICAL MODELS VALIDATION: FROM PREDICTIVE TO EFFECTIVE DESIGN TOOLS. GLASS INDUSTRY REAL CASE: WASTE GAS STRATEGIC RECIRCULATION

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ABSTRACT
It is estimated that in 2005 emissions to air consisted of 6.500 tons of dust, 105.000 tons of NO_x, 80.000 tons of SO_2 and 22 million tons of CO_2. The glass industry contributed to about 0,8 % of total EU emissions. From this analysis it becomes evident that the major environmental challenges for the glass industry should be the reduction of NO_x emissions and the energy saving. The biggest efforts of the glass industry service providers, like Stara Glass S.p.A., are in fact aimed towards this direction. The process involved in the glass industry is very rich in variables and it is always easier to measure a parameter than to predict it, but with a huge amount of real data, obtained from field measurements under different conditions, it is possible to refine more and more the predictive calculation models to make them really functional, that is, to obtain results that are largely overlapping with real ones. The Computational Fluid Dynamics (CFD) method has been applied for the analysis of the Waste Gas Strategic Recirculation (WGSR) system coupled to a regenerative system, in particular for tracking the flue gas until the combustion completion, while the numerical model has been applied to study the radiant gas emissivity to investigate the contribution of WGRS to the increasing of heat transfer performance of the regeneration system. This paper describes the validation process of the calculation methods used, both numerical and CFD, to make them real design tools and not just forecasting tools.

Keywords: Primeglass LIFE project, glass furnace, regenerators, waste gas recirculation, CFD, reduction of NO_x emissions.

1. INTRODUCTION

In the last decade the glass industry has come to a turning point; if in the past years the first and only concern of glass manufacturers has been the product quality, nowadays, with the rising costs of energy supplies and the pollution legislation becoming increasingly restrictive on nitrogen oxides, this is no longer sustainable.
Glass production still has to abide to quality standards but, at the same time, it must pursue efficiency of the process and be more sustainable.
The average expected lifetime of a furnace for glass production ranges from 5 to 8 years with non-stop production and the difficulties of managing such a complex process are the main factors which led the producers to be traditionally quite conservative towards innovation or experimentation.
This aspect though is rapidly changing and it is believed that a numerical approach, fully validated and verified, could play a crucial role to assess the current technologies and to deliver the guidelines for the future developments of many aspects related to glass manufacturing.
For this reason in the last years the systems design was characterized by the research of new solutions in order to optimize the process performance, mostly under the environmental and the sustainability point of view.
One of these aspects, which will be discussed in the next pages, is the fluid-dynamic analysis of the WGSR (Stara Glass Patent) coupled with a regenerative end port furnace for glass production.
The WGRS has been developed within the PRIMEGLASS European Project (LIFE12 ENV/IT/001020 – www.primeglass.it) coordinated by Stara Glass S.p.A. (www.staraglass.it) in partnership with University of Genova and Stazione Sperimentale del Vetro (Venezia) with the aim of providing technologies for reduction of NOx emissions and energy consumption.

2. END PORT FURNACES

In End Port furnaces two ports connect the melting tank at the front with two identical vertical regenerative chambers at the back (Figure 1). Under each port, up to three burners can be fitted so the flame travels from one port toward the opposite wall of the melting tank then making a U turn to be discharged through the other port.

This horseshoe shaped flame is one of the main advantages of this kind of furnace since it is characterized by long time of residence of the flame which guarantees a good heat release profile. Inside each regenerators thousands of refractory bricks are piled up in stacks to form a honeycomb-like structure several meters high called “checkers”. In order to perform the heat recovery, the flow path is switched from one chamber to the other at constant intervals (typically every 20 minutes). As the waste gases are discharged through the port they flow downwards the chamber cooling down by radiation with the checkers, which can hold back the heat power to deliver it back to the air (this time flowing upwards the same chamber) when the cycle swaps.

This system allows to obtain highly preheated combustion air with a high heat recovery efficiency level (60-68%, against a theoretical limit value of 75-78%) and its ceramic structure easily allows the reaching and the duration in time of very high working temperatures (Figure 2).

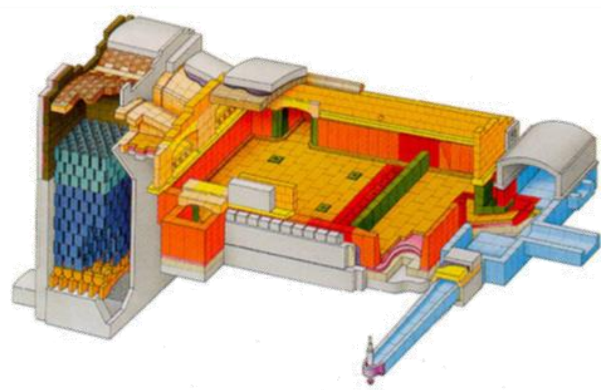

Figure 1: 3D view of a typical End Port furnace

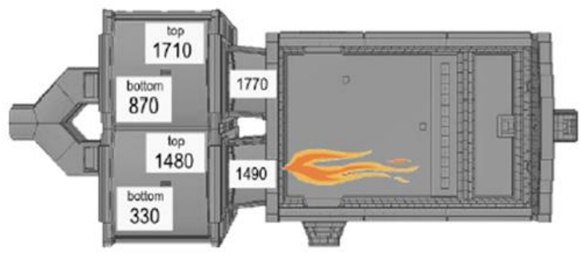

Figure 2: Typical temperature distribution on an End Port furnace

3. NITROGEN OXIDES NO_X

NO_x are atmosphere pollutant that can aggravate the condition of people affected by asthma and they are one of the causes of acid rains. NO_x formed in combustion processes are generally produced according to three main mechanisms:

- *Prompt NO_x* are formed in the first part of the combustion, where there is strong presence of highly aggressive intermediate substances that also attack the nitrogen.
- *Thermal NO_x* are formed in presence of high temperatures and oxygen concentration. Therefore it is precisely because of the high temperatures reached during the intermediate combustion phases that the nitrogen molecules (N_2) dissociate in atomic nitrogen which is, however, extremely responsive in contact with oxygen, which is atomically dissociated, leading to the formation of NO. The next drastic drop in temperature that takes place far away from the burner flame, freezes the above-described reaction by preventing the reassignment of nitrogen and oxygen, thus discharging downstream the NO by-product.
- *Fuel NO_x* derive from nitrogen already present in the fuel composition.

As underlined above the combustion process gives rise to the formation of these pollutants, in fact the main target of the new technologies is the reduction of the emissions of these compounds by the usage of primary techniques that directly concern the non-formation of NO_x, or secondary techniques, by which already formed NO_x are abated through typically expensive and cumbersome catalytic systems that most glassmakers prefer to avoid.

Regenerative furnaces represent the state of-the-art of the glass production since thanks to their combustion air heat recovery levels (1200-1300°C compared to 1400-1600°C of waste gas) they bring the energy recovery quite close to its thermodynamic limit. On the other hand, the higher is the combustion temperature, the larger is the NO_x production. So from this analysis it is natural to concentrate efforts, both computational and design-based, on the reduction of NO_x emission in end-port furnaces.

4. WASTE GAS STRATEGIC RECIRCULATION

Very high temperature combustion, like the one happening in furnaces for glass production where combustion air is preheated beyond 1200°C, generate high concentrations of thermal type NO_x. It is scientifically that a combustion process, even at very high temperature, developed in an environment that presents an oxygen concentration lower than the atmospheric one (21%), will produce a lower amount of NO_x.

Within the Prime Glass project (a project co-financed by the EU) a method that allows to apply the waste gas recirculation technique to regenerative glass furnaces has been tested.

The WGSR system, by means of a strategic exhaust gas injection inside the regenerator during the air phase, operates to concentrate the exhaust gases close to the sole of the portneck, generating in this way a layer of flow poor in oxygen in correspondence of the primary combustion zone.

As shown in Figure 3, the design of the WGSR circuit allows to control the O_2 distribution inside the portneck and in the initial part of the combustion chamber.

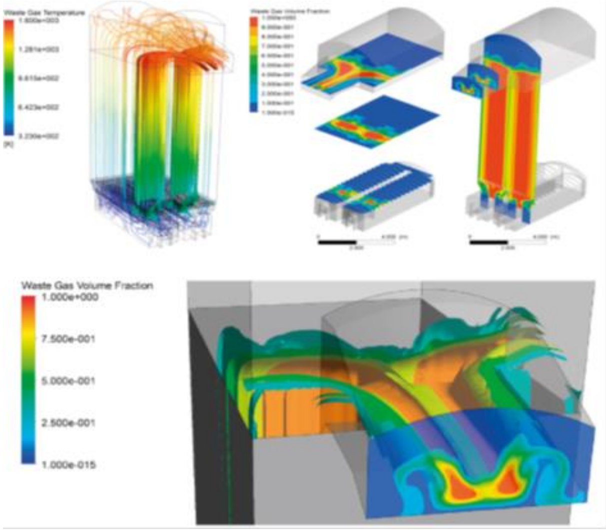

Figure 3: CFD analysis of the waste gas fraction inside the air phase regeneration chamber.

The system is realized by a physical connection between the two regenerators trough a circuit positioned in the lower part, under the portnecks by the furnace side. A portion of flow is diverted from the exhaust phase regenerator chamber and it is forced by a high temperature fan towards the base of the air phase regenerator chamber (Figure 4).

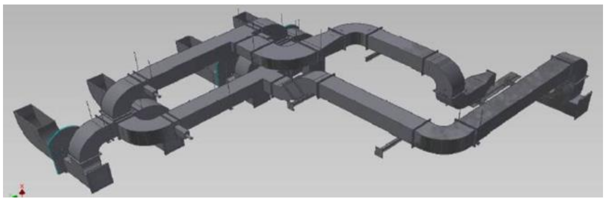

Figure 4: 3D view of a typical WGRS system.

To make the WGSR functional, it must be tailored to each furnace's geometry and operational conditions: to optimize the exhaust gases distribution at the outlet, a CFD methodology has been developed with the aim of monitoring the interaction between different sub-systems (regenerators, ducts, portnecks, etc.) and the exhaust gases (Figure 5).

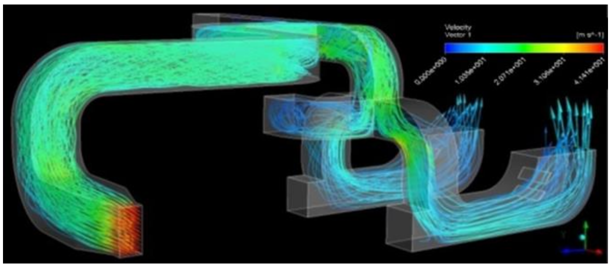

Figure 5: CFD analysis of the exhaust gases distribution in the WGRS system ducts.

A large campaign of CFD analysis and field tests has been performed, allowing the validation of the design of the WGRS system deflectors (Figure 6) in order to minimize the oxygen concentration in the combustion chamber zone where air and fuel meet first, thus optimizing the technology efficiency and obtaining NO_x abatements higher than 30% .

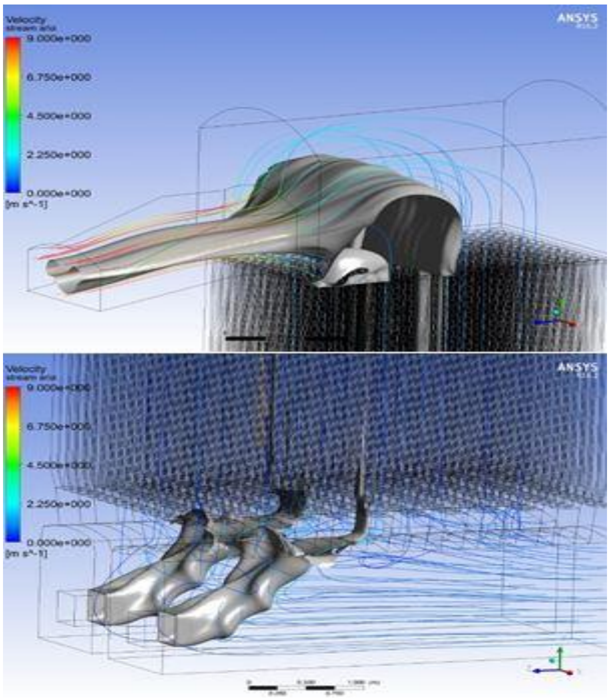

Figure 6: CFD analysis of the deflector efficiency on exhaust gases.

5. APPLICATIONS AND VALIDATION

As already mentioned, during the development of the Prime Glass project, the experimental activities were largely supported by numerical studies. The calculations were performed with ANSYS-Fluent software to analyze the full path of air and waste gases inside the regenerators cycles in two different phases, the first without the WGSR system (Figure 7), and the second, with a small modification to the regenerators model, with the contribution of the system (Figure 8).

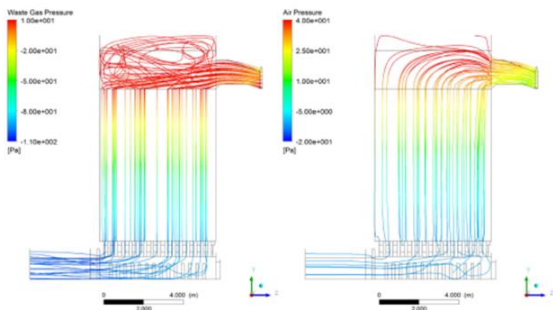

Figure 7: CFD analysis on a conventional regenerator system (exhaust gas phase on the left, air phase on the right).

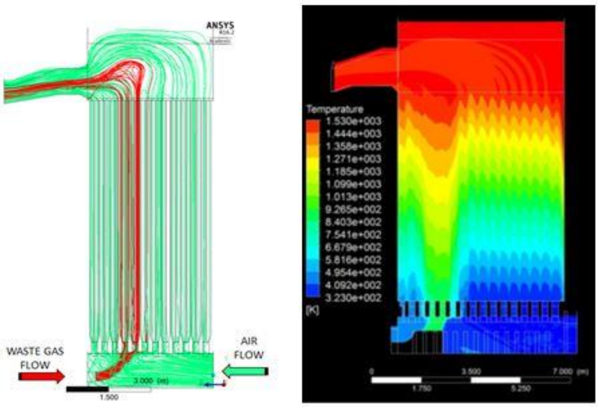

Figure 8: CFD analysis on a regenerator system with WGRS system: exhaust gases streamlines and mixture temperature in the air phase chamber.

5.1. Oxygen concentration

After the installation of the system (built in accordance with the guidelines provided by the CFD approach described above) several campaigns of measurements were performed on site and, as clearly summarized in Figures 9 and 10, the agreement between the real concentrations values and the numerical previsions is fully satisfying.

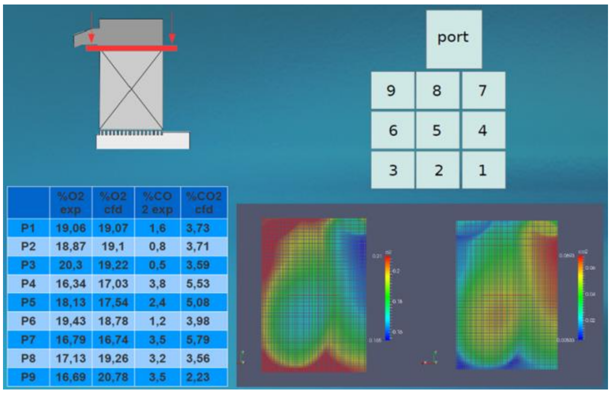

Figure 9: Experimental measures and CFD results comparison on a control surface at the top of the checkers.

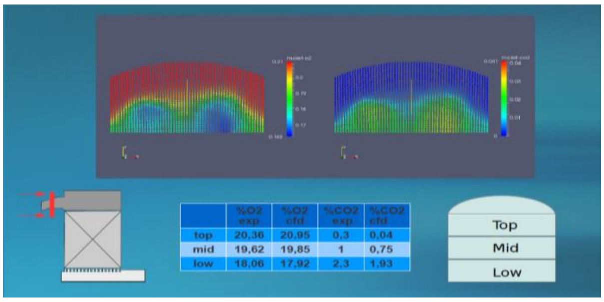

Figure 10: Experimental measures and CFD results comparison on a control surface on the portneck outlet.

Comparing the CFD forecasts with the results obtained through the measurements it has been noticed that the hypothesized distribution of the oxygen in the oxidizing flow at the outlet is realistic and very close to the reality.

5.2. Heat transfer effect

A secondary aspect of the WGSR is linked to the heat transfer effects related to the passage of the radiating gases contained in the exhaust gases, CO_2 and H_2O vapor, in the heat recovery system during the air phase. These molecules, characterized by a polarity, allow the flow to receive heat for radiation, with the effect of maximizing the chamber efficiency.

In order to investigate this phenomenon, a model for the evaluation of the emissivity properties of CO_2 and H_2O vapor has been developed. The emissivity model is introduced, as a supplementary tool, in a mono-dimensional transient model originally developed for the simulation of regenerative system without the WGRS system adoption. The regenerative system model divides the checkers volume into three equal sectors. The three sectors of the cold chamber (regenerator during air phase) work with different flow rates, flue gas fractions and inlet temperature in order to simulate the effects of the strategic gas recirculation system, as shown in table 1.

Table 1: Input data and temperature output results of the regenerator system 1-D model applied to plants with and without WGRS system.

		Total Volume [m3]	Surface [m2]	Mass flow [kg/s]	Temperature [K] Inlet	Outlet
Reference Case		100	2900	3.77	420	1241
Case with gas recirculation system	TOT	100	2900	4.52	478.1	1291
	S-1	33.3	966.7	1.13	420	1256
	S-2	33.3	966.7	1.13	459.5	1325
	S-3	33.3	966.7	2.26	516.4	1292

To validate the regenerator system model with the emissivity properties tool, the preheated air temperature was chosen as comparison parameter. The results of the analysis done on site are very clear: without the WGSR the air temperature reaches 1300-1260°C, but with the WGSR it grows up to 1360-1310°C (Figure 11). The contribution of the WGSR increases the air temperature of about 50°C; this value is perfectly superimposable, in absolute value, to the one resulting from the calculation above. This goal we reached allowed us to validate the model for the evaluation of the emissivity properties of CO_2 and H_2O vapor, and to use it as a design instrument and not only as a provisional instrument.

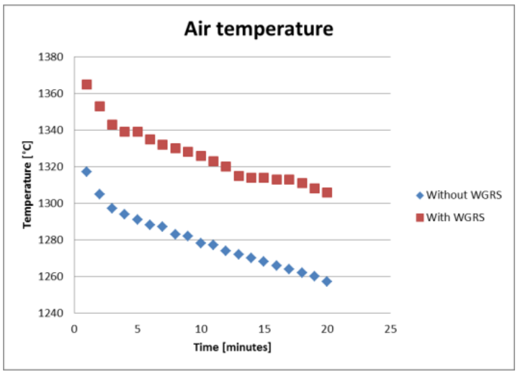

Figure 11: Air temperature during whole cycle

6. CONCLUSIONS

The purpose of this paper was to demonstrate the validation of the calculation methods used (both numerical and CFD), in order to make them real design tools and not just forecasting tools.

The process of the glass industry is very rich in variables, it has always been easier to measure a parameter than to predict it, but with a huge amount of real data, obtained from field measurements under different conditions, it was possible to refine more and more the predictive calculation models to make them really functional, that is, to obtain results that are largely overlapping with real ones. The results from the two methods described in this paper are in fact in a very acceptable match.

The CFD calculation has proven to be a valuable tool for the analysis of the WGSR system coupled to a regenerative system, in particular for the tracking of the flue gas passing through the checkers, until the moment they leave the top chamber.

The same works for the numerical model for the radiant gas emissivity: it has been validated comparing the results with data coming from the field measures.

The WGSR system in addition to its primary function of NO_x abatement can also increase the heat transfer performance of the regeneration system, compared to the system without WGSR.

In conclusion the numerical approach effectively supports the design strategies and allows the achievement of a deeper understanding of the current technology, suggesting new perspectives of improvement.

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The numerical simulations presented have been performed using the hardware and software platforms available in the University of Genova (Savona campus), while all the experimental data presented have been provided by Stara Glass and Stazione Sperimentale del Vetro. For the support throughout the development of the model, their R&D department must be also greatly acknowledged.

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HUMAN BEHAVIOR AND SOCIAL INFLUENCE: AN APPLICATION FOR GREEN PRODUCT CONSUMPTION DIFFUSION MODELING

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ABSTRACT

This paper presents an application of an Agent Based Simulation for reproducing the behavior of a network of individuals living in a city. The work presented aims to simulate green product consumption and its correlation within green values among a group of individual. Each individual is reproduced with an intelligent entity, equipped by personal feeling and emotions that changes in time according to the influence received from his network (family, social networks, and other communication systems). The information flow depend on the daily activity of each individual that perform some action based on his characteristics (i.e. going to work/school, watching television, and navigating in social networks). Finally, a case study is presented with real data from a real city; and green value function is linked to a mode choice for simulating the individual probability to buy standard food versus ethical food.

Key Words: *Agent Based, Consumer Behavior, Green Products Consumption Simulation, Agents, Communication Channels Simulation, Social Networks*

1 INTRODUCTION

Many hypotheses exist about the modern drivers of consumer demand and the growing influence of ethical and environmental issues since over 20 years (Strong 1996; Crane 2001; Peloza et al. 2013); indeed the food industry is even further sensitive to these elements and there are interests in investigating these aspects to develop new models (Jensen et al. 2011). The complexity of this context touches many different issues, from operational ones (e.g. logistics and production processes) to marketing and promotion often dealing with human factors (Schröder et al. 2004; Siro et al. 2008; Bruzzone et al. 2009a). It is evident that the complexity of each of these elements and their mutual interactions with human factors make it very challenging to develop quantitative analysis on this framework, therefore the importance to create models and simulators dealing with these issues results to be a strategic advantage for planner and decision makers (Bredahl et al. 1998; Vermeir & Verbeke 2006; Bruzzone et al. 2009b). Due to these reasons, the authors propose the development of an agent based simulation able to model this context and support analysis of green product consumptions.

2. ETHICAL & PRODUCTS

Despite the widespread attention in ethical consumption is receiving, consumers show little interests in actually purchasing ethical products, such as organic or fair-trade produces. For instance, Futerra (2005) found that whilst 30% of consumers claims themselves to be ethical consumers whereas only 3% of them actually put into practices. Such intention-behavior gap reflects the situation that the benefit of product ethicality is at a lower hand against the practical concerns, such as price, accessibility, and quality issues, in the decision-making process (Devinney, Auger, & Eckhardt, 2010). Yet, there is an increasing evidence suggesting impression management reasons as main key factors to promote ethical consumption. For instance, Griskevicius, Tybur, and Van den Bergh (2010) demonstrated that eliciting consumers' status motives increase their desire for green products. The use of social norms (e.g., joining fellow citizens to save waters) increase also the likelihood for pro-social choices (Goldstein, Cialdini, & Griskevicius, 2008; White & Simpson, 2013). These empirical findings raise a question for investigation "*what type(s) of consumers will appreciate the social benefits of ethical products more than other consumers*?"
Based upon an instrumental altruism perspective, the authors conjecture is that consumer's social network position (e.g., how many connections they have and how central and active they are in the network) affects to what extent they will appreciate the social values of ethical products (Andreoni, 1990; Kahneman & Knetsch, 1992; Zahavi, 1975). Firstly, people who are at the central positions within their social network generally play as the roles of opinion leaders or lead users, which involve them having frequent social interactions with other members within their social node (Kratzer & Lettl, 2009). So, these types of consumers would have a higher need for impression management whereas the engagement in ethical consumption results to be one of major means that consumers do frequently (Crane & Matten, 2016). In facts agent based modeling has been applied in different area of marking to capture the aggregate dynamics originated from interactions among individual consumer (Delre et al. 2007; Goldenberg, Libai, and Muller 2010) as well as to examine these impacts on consumer's choice (Haenlein & Libai, 2013). The authors decided to simulate the complex behavior of such social systems by using agent driven simulation,

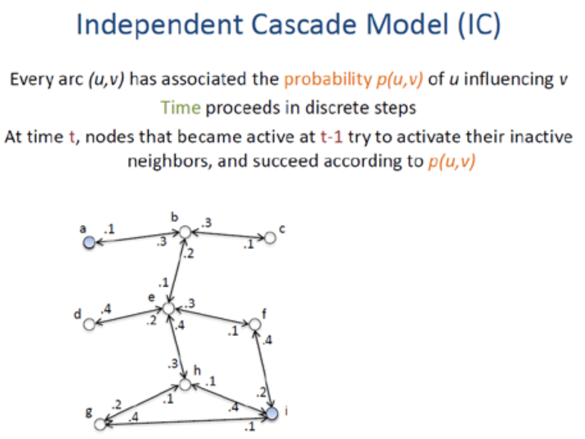

Figure 1 Weighted Network Model Example

This approach is able to reproduce how a consumer's social network position influences the ethical food choices considering stochastic factors as well as human behavior modifiers (Bruzzone et al. 2011). The contribution of this paper is mainly twofold: firstly, it is devoted to contribute to the ethical marketing literature regarding the moderation role of social network position and other communication channels on consumer's perception about the social values of ethical products.
By identifying this, it is likely to capture how social values of are weighted among different types of consumers and to provide implications to marketing practitioners regarding how to present the social values of ethical products. Second goal is to analyze and demonstrate the potential of M&S (Modeling & Simulation) as support for marketing scientist in testing and validating their hypothesis within a synthetic environment. Indeed social systems, communication channels and time are proved to be, at least, three of the four main key drivers required to analyze the diffusion of new product in marketing science (Mahajan, Muller & Bass, 1991).

3 STATE OF ART AND MODELS

Hereafter, different researchers and models, developed along the years, are summarized in order to identify the most promizing approaches to be used today by applying modern M&S methodologies to food consumption.

3.1 Social Network Centrality and the Needs for Impression Management

Consumer's social network position is defined as the relationship between himself/herself and other individuals or groups within the network. In terms of analysing the consumer's network position involves two main types of centrality in this research. The first of which is *betweenness centrality* that is defined as the least number of times that an actor needs to take in order to approach another agent (Freeman, 1979). More precisely, *betweenness centrality* captures the extent to which an actor facilitates the information flow within the network, not sheer number of connections he/she possess. Consequentially, when a high *betweenness-centrality* actor leaves the network, the efficiency of the network itself suffers in terms of information flow (Kratzer, 2009). The second type is the *closeness centrality* which is defined as the number of connections that a person possesses (Borgatti, 1995). Consequentially, when a consumer is in a high degree of *betweenness* and/or *closeness centrality* position, he, or she, will be involved in frequent social interactions in everyday life. Such situation requires a person to present a positive image in front of others, so that the authors argue that these types of consumers have a high need for impression management in their everyday life (Goffman, 1967). Impression management, corresponding to maintaining a good image in front of others, is found as a key factor that motivates consumer's ethical product choices. This pattern reflects the instrumental altruism facet in people's altruistic behaviour (Andreoni, 1990; Kahneman & Knetsch, 1992; Zahavi, 1975). More specifically, purchasing an ethical product, though implicitly, signals the buyer a positive pro-social or moral image (Semmann, Krambeck, & Milinski, 2005; Wedekind & Braithwaite, 2002; Catlin & Wang, 2013; Mazar & Zhong, 2010). Such symbols, in people's beliefs, would have positive effects on people's social life, such as being reckoned as a trustworthy member of the group.

3.2 Human Factors & Social Networks

Extent researches demonstrate these lay beliefs drive, unconsciously, people's ethical product choices. For instance, Griskevicius et al. (2010) demonstrated that by motivating consumers attaining a high social status, the likelihood for them to choose green products over the regular counterparts increase as the former helps signal a positive social image.
It is clear that social networks are very influent in human behaviour as well as in consumer behaviour; that's the reason why simulation results very helpful in study such complex systems. One of the most effective way to simulate social systems is by making use of graph theory and modelling the entities and their connections by means of links and nodes. Considering a social system like a graph, it is possible to define the following characteristic of a node:

a) **Number of connection of each node**: there are nodes that have an higher number of links/connections (i.e. number of friends, number of different website visited, blog etc.)
b) **Activity of each node:** there are nodes that are more active than others; indeed some people use the web more frequently compared to others for instance due to their need of appearance
c) **Centrality of each node:** There are nodes that are leaders, for example blogger or people that have a central position in social network

In addition, for simulating the information flow and its impact on different kinds of people it is necessary to consider the following aspects:

- **Information flow is bi-directional**: indeed each user is enable to read and publish
- **Information flow can be ignored or it can produce opposite effect in the current opinion:** sometimes, some information, observed by people with a different point of view, generates an opposite effect and reinforce

an opposite opinion, while, in other cases, it can be simply ignored

On the other side, considering the link that represent the connection of each individual, it should be considered the following characteristics:

a) **Strength:** It depends on the influence of each connection (family is the most powerful, while other sources are less influent, i.e. blogs)
b) **Dynamical behaviour:** social connection changes over time

3.3 Simulation Methodology

Simulating Human Behavior is a complex subject and it has a great potential in many areas. Usually, it is important to reproduce the evolution of emotions (i.e. fear, stress, fatigue) and other variables such as political consensus, trustiness in institutions that are result of political choices. In this paper the authors are focusing their attention in simulating individual functions that are influencing the consumer behavior choice, in particular related to food.

To capture how consumer's social network, influence their ethical food consumption, the authors used agent driven simulation paradigm based on Intelligent Agent Computer Generated Forces (IA-CGF) libraries that have been developed by Simulation Team along the years (Bruzzone et al. 2011). Indeed several researches have been carried out by Simulation Team to reproduce human behaviors over towns or regions. Such models were used for different proposes, such as for epidemic evolution, for analyzing urban disorders and for country reconstructions.(Bruzzone, Novak & Madeo, 2012; Bruzzone, 2013; Bruzzone et. al, 2014)

By this approach the population is simulated as composition of single intelligent individuals living in a simulated town or region, represented by people objects interacting with their interested group (e.g. green movement, youth, universities students etc.) as well as to entities and objects that operate on the field (e.g. radio station, supermarket, etc.) as proposed in figure 2. Each people object has a social network with other ones as well as multiple connections to the interest group that are also interconnected by positive and negative relationships (Bruzzone et al. 2011). Each agent is characterized by an intelligent behavior that make him moving inside the town and perform other activities (i.e. buy food, going to work, move in the free time etc..). In the proposed simulation model, the behavior of each individual is the result of the interactions among different layers:

- ***Individual Layer***
- ***Family Layer***
- ***Social & Media Layer***

Indeed as in real life, individual are not stand-alone entities, but they live close into a family and they are connected within real world and in internet as well as by other communication instruments that condition their choices and their feelings; indeed family interactions, social network information flow, advertisement and other media constantly influence each human being. Simulating all these information is quite challenging since these stimulus doesn't have the same impact: for example, usually, the family opinion is more powerful compared to a post that appears on Facebook™. On the contrary, information received from the social network is pretty huge being very intensive especially when a person use the mobile phone frequently and he is really active in browsing blogs and web networks. Indeed social network simulation should take in account the differentiation among the different connections of the networks, considering that there are some links that are stronger and more influencing than others. In this case it is proposed to adopt a weighted network, as a network where the connections among nodes have weights assigned to them; these models have been used firstly in system biology application and then adapted in large scale social systems (Can, Özyer, & Polat, 2014; Bruzzone 2013). The weight of each connection allow to reproduce the different strength of each connection, allowing to reproduce the different characteristics of each individual. In figure 1 is reported an example of a weighted network applied to a single individual:

4 SOCIAL NETORK & PEOPLE MODELS

Hereafter is described the process for generating individual, families & social network before the simulation start. Indeed the simulator generates single individuals, at first, and then it aggregates each one into families and social network, based on a weighted graph.

4.1 Individual Layer Definition

Each individual is characterized by the following parameters, assumed to be known, based on statistical distribution:

a) Individual Parameters:
   - Age
   - Sex (M/F)
   - Level of Education
   - Religion
   - Area of the city where he/she lives
   - Area of the city where works/go to school
   - Area of the city for extra activities, leisure, free time
   - Incomes
   - Occupation Type(e.g., white collar, blue collar, etc.)
   - Political orientation
   - Ethnic group
b) Individual Human Modifiers

The simulator computes and updates the value of specific individual human modifiers that are resulting from the scenario evolution, individual perceptions as well as from his previous history and current emotional status. Simulation Team have developed these models for military and civilian domains by correlating human feelings like fear, stress, aggressiveness, fatigue and trustiness with different events and actions.

Table I: Key Variables

Variable	Explanation	Influence
Green Value	A unique comprehensive parameter addressing green values	Individual Parameters, Family Composition, Green Habits
Web Dynamism	Individual frequency in reading and publishing information according to its status (i.e. working, free time etc..)	Group of People, Social Network Positions, etc.
Social Connectivity	Number of connections of each entity	Individual parameters, Family and Stochastic Links
Web Influence	Influence of social networks, blog post and information received from the web (both in reading and in publishing)	Individual Parameters, Social Network Position
Price sensitiveness	How sensitive is the specific individual to Prices	Depending on Family Income and willingness to spend on food
Media Influence	Influence of traditional media and communication systems on the person	Individual Parameters, Family & Social Network Position

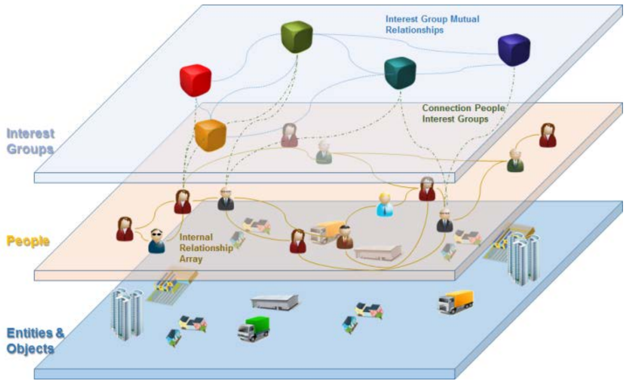

Figure 1: Multi Layer Approach for simulating Individual

for instance these have been applied in case of urban riots, social tension escalation, fear diffusion, and political consensus (Bruzzone et al.2011). These values are constantly updated and vary according to events that occur during the simulation run and according to the information exchange among each node and the network; these human factors could be evaluated both at individual level as well as aggregate level. For the aim of this paper in the following are reported main relationships.

4.2 Family generations: Strong Relationships

In this phase the individuals are aggregated stochastically in a graph according to their family components; such operation is based on compatibility algorithms and it could be also performed by using real data about families, if available. Once the families are generated, the system calculates some interesting indicators useful for validation and to check family characteristics such as :

- **Number of Sons**
- **Family incomes** as sum of the incomes of the different individual composing a family

These relationships are represented by means of graph theory, where each node represents an individual and each arc represents a connection. In particular the weighted graph has been used in order to define Stronger and Weaker connections. Familiar connection are obviously stronger and have more influence compared to other ones

4.3 Social Layer generations: Weaker Relationships

In this phase, the individuals are grouped in the social networks by means of a compatibility algorithm. Obviously the system is open to receive real data from social networks, but currently the social network is just stochastically generated among the different individuals.
Each individual is characterized by several parameters that are stochastically generated based on its Individual and Social Characteristics.
In this modelling approach the focus is in particular on following characteristics:

a) Social media number of Connections
b) Social media activeness, defined as "to what extent they share their personal life on social media"
c) Media and other information channels

In this layer the individual are connected to the information channels that are represented by nodes. Each individual is considered connected to such networks, by a specific weight according to its individual parameters.

5 MODELLING INDIVIDUAL CONSUMER CHOICES

Discrete Choice Models are useful to analyze and predict the individual choices when the set of choice is constituted by a finite number of alternatives. Such Models make use conventionally by Random Utility Model (RUM) that have been proposed for the first time by (Block & Marschak, 1960). These disaggregate models have been widely used for the simulation of individual choices in particular for what concern transportation and travel choices. (Ben Akiva & Lerman, 1985); indeed these choices are often based by a finite number of transport alternatives such as:

- Start a trip or not
- Definition of the departure time
- Choice among Public transport or private transport according to the set of available alternatives (i.e. bus, car, plane, train etc..)
- Route choice

In general, each individual in general have different set of different choices that may depend by different parameters, for example: age, income, availability of a private car, individual value of time, type of the trip. For an extensive description of these model is possible to take in account interesting previous models developed in this field since decades(Ben-Akiva & Lerman, 1985; Ben Akiva & Biedlare, 2003).

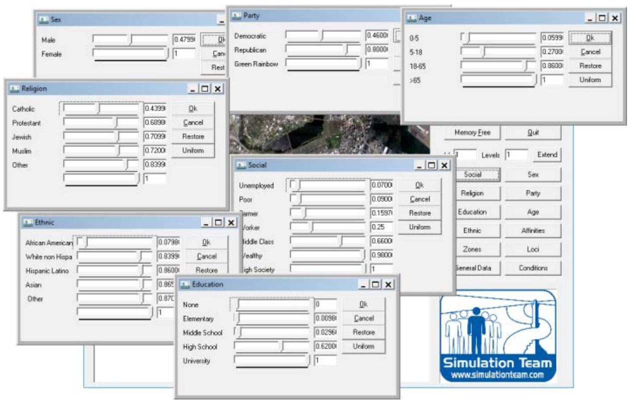

Figure 2: IA-CGF Individual People Characteristics

Considering the consumer choice, such models have been widely applied, also considering the Behavioral Decision Theory (BDT). (Swait & Adamowicz, 2001).
In general discrete choice model Discrete are derived from utility theory and in this case is applied a simple binary Logit is applied (Matejka et al.2014); the common requirements for discrete choice models are:

- The set of alternatives must be collectively exhaustive; this imply that each individual and group of similar individuals have its own set of alternatives from where to choose
- The alternatives must be mutually exclusive
- The set must contain a finite number of alternatives

Each individual is expected to maximise its *utility* derived from the different options that are available among the possible choices in set C. In this casem each individual i has option among 2 choices:

a: Standard Food
b: Ethical Food

Each of these options provide to the single individual the *utility* from the two options: U_a and U_b with:

$$U = V + \mathcal{E}$$

V = Systematic Utility
$\mathcal{E}$ = Error Term (Assumed to have a logistic distribution) for simulating the error on perception of each single individual and irrational behaviour.

So the probability of choosing an alternative n for each individual i is given by:

$$P_{i,n} = \mathrm{G}(\, x_{i,a,} x_{i,b,} \underset{*}{\gamma}_{i,}, \beta_i)$$

$x_{i,a}$ is a vector of attribute of alternative a
$x_{i,b}$ is a vector of attribute of alternative b
$\underset{*}{\gamma}_{i,}$ is a vector of characteristic of person i
β_i is a set of parameters giving the effect of variables on probabilities

$$U_{i,n} = \beta_{i,n} \cdot \underset{*}{\gamma}_{i,n} + \mathcal{E}$$

$$V_{i,n} = \beta_{i,n} + \underset{*}{\gamma}_{i,n}$$

So, the probability of choosing a green product a, and/or a standard product b, for each individual i is defined by:

$$P_{a,i} = \Pr\left(-V_{a,i} + \mathcal{E}_{a,i}\right) > \Pr(-V_{b,i} + \mathcal{E}_{b,i})$$
$$P_{b,1} = \Pr\left(-V_{a,i} + \mathcal{E}_{a,i}\right) < \Pr(-V_{b,i} + \mathcal{E}_{b,i})$$

Table II: Information Channels

Media Channel	Variables	Description
Radio	Probability to hear it	Probability to see television according to his day life
Television	Probability to see it	Probability to see television according to his day life
Social Networks	Individual network Influence	Structure of the social network in time
Advertising Board	Probability to see it	Location of the Advertising Board in the city and probability to pass in this street calculated by means of simulation
Marketing SMS	Probability to receive it	It depends if each user subscribed marketing data sharing agreement

$$P_{a,i} = \frac{1}{1 + \exp(-\beta_i \cdot V_{a,i})}$$
$$P_{b,i} = \frac{1}{1 + \exp(-\beta_i \cdot V_{b,i})}$$

For modelling customer green choices, the authors have considered the following additional parameters that have been correlated to each single individual.

$\gamma_{i,n} = \beta_1$ ·Income + β_2 · (Green – Standard Product Cost)
+ β_3 · Green Values
+ β_3 · (Social Influence from social Network)
+ β_4 · (Familiar and Friendship Influence)

These parameters have been hypothesized considering specific assumptions and the choice manipulation is based on the following parameter:

- Price gap among (Ethical food and Standard Food)
- Accessibility of the ethical food based on a set of assumptions as proposed hereafter
-

Indeed, all other parameters are assumed known, based on the following considerations:

- Social media activeness
  - Definition: to what extent people share its own personal life on social media
  - Hypothesis: a positive significant relationship between social media activeness and green consumption owing to the need of showing-off or impression management (Griskevicius et al., 2010)
- Green Value (Haws, Winterich, & Naylor, 2014)
  - Definition: The tendency to express the value of environmental protection through one's purchases and consumption behaviour.
  - Hypothesis: a positive significant relationship between social media activeness and green consumption.
- Price sensitiveness (Lichtenstein, Ridgway, & Netemeyer, 1993)

Table III: Accessibility level of Ethical food

WORKERS	*High Accessible (d≤1 km)*	*Medium Accessible (1km<d≤3km)*	*Low Accessible ((d>3km)*
White collar	50%	30%	20%
Blue collar	10%	20%	70%
Students	30%	40%	30%

- o Definition: the degree to which the consumer focuses exclusively on paying low prices.
- o Hypothesis: a negative significant relationship between social media activeness and green consumption.

- "Willingness to spend on food"
  - o Within a person's budget living expenses, there is a need to prioritise how much he/she would spend on foods, clothing, entertainments, etc.
  - o This parameter is complementary to price sensitiveness
- Ethical food choice are available only in (a) big supermarket chains, (b) a few specific shops in the city/ town centre
- Citizens (of different social status categories) are be "centred" into particular zones (work place & residential area)
- As a result for the case study some coefficients have been tuned as that one in the table below:

6 A PRELIMINARY CASE STUDY

For this first experiment have been performed a simulation with real data from the city of Genova, in particular have been considered:

- 10 zones of the city
- 10'000 individual
- Around 6.000 families

Each individual has been defined by its own parameters generated stochastically based on aggregated open data available from Genoa databases; the family and social networks have been created based on compatibility algorithms in consistency with the reference parameters.

Simulation duration have been to one 1 year. The simulator allows to evaluate the green consumption level of the different members of the families and the probability to buy ethical food respect different accessibility levels and different prices. Obviously a very critical aspect in developing this model is to finalize tye VV&A (Verification, Validation and Accreditation) processes. it is evident the critical aspect devoted in validating these issues in real and historical cases and in checking data reliability; due to these reasons the author are actually conducting dynamic virtual experimental campaigns on numerical case to achieve preliminary validation of the proposed approach; ANOVA technique and experimental error temporal evolution analysis are the methods to be used to check consistency of the stochastic factors included in the models (Montgomery 2008). In facts up to now the validation and verification is still based on SME (Subject Matter Experts) face validation.

7 CONCLUSIONS

This paper proposes a preliminary investigation devoted to match intelligent agents with social network simulation in real cases respect green food product consumption. It is evident the complexity of the phenomena related to this context as well as the uncertainty affecting the human factors and, consequently, the efforts required to fine tuning the model parameters. Therefore it is important to outline that the adopting of agent driven simulation based on stochastic discrete event approach enables to model these complex scenarios and could result an interesting support to improve the understanding of this context. As anticipated the authors are working on VV&A and it is expected that these new models, as soon as validated, could result as a strategic advantage in supporting decisions in this application areas. Currently the authors are working on finalizing the certification of numerical data sets for the proposed scenario based on examples inspired by real historical case studies; these data will be used to complete dynamic and statistical VV&A of the proposed simulator with support of SME.

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POPULATION MODELLING FOR SIMULATION OF DISASTERS & EMERGENCIES IMPACTING ON CRITICAL INFRASTRUCTURES

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ABSTRACT
The authors have been involved in a series of initiatives devoted to design a federation of simulators devoted to support Disaster and Crisis Management.
In facts disasters are one of key threats to the modern society and their devastating effects caused a lot of losses in terms of human lives and economy along last years; considering their complex nature of these phenomena combining many different elements, it is evident the opportunity to integrate models and simulators into a common interoperable framework. This paper proposes an innovative approach to this issues as well as an overview of existing simulators, models and databases available for this purpose. The final goal is to create an open architecture to support crisis management by evaluating COAs, damages, risks , evacuation plans and population impacts & reactions.

Keywords: Interoperable Simulation, High Level Architecture, Disaster Simulation, Intelligent Agents, Decision Support Systems

1 INTRODUCTION
During the years several studies have been carried out for addressing disasters, emergencies and crisis management trough simulation and modern M&S advances are providing new opportunities in this sector(Bruzzone et al.2015a; Gupta et al. 2016). The use of M&S (Modeling and Simulation) allows to address multiple needs including the capability to estimate the preparedness level and to boost training and education, as well as to reduce vulnerabilities and address risk assessment (Zaharia et al. 2009, De Hoop & Ruben 2010). In facts it could be very useful to create simulation frameworks able to combine together the disaster dynamics that usually is related to physical models (e.g. a toxic agent diffusion, an earthquake impact on buildings or a flooding over a region) with the operational aspects (e.g. standard operation procedures evacuation planning, relief operations) and to reproduce the whole scenario (Bruzzone & Kerckhoffs 1996). In facts by this approach it could be possible to evaluate and validate existent operative procedures respect some crisis scenario as well as to define new ones; in such context the use of agents based simulation could be crucial to properly reproduce the interactive behaviors of the actors involved in this mission environment (Mustapha et al. 2013; Bruzzone et al.2014a). So the authors propose hereafter an approach and related experimental plan to address CDM (Crisis Disaster Management) through interoperable simulation.

2 CRISIS AND CHALLENGES
In reference to crisis scenarios, unfortunately, it results evident a consolidated statistical positive trend respect the increase of frequency and scale of natural disasters in many areas of the world (Guha-Sapir et al.2004). In facts, the climate change, population growth together with urbanization, industrial activities and environmental impacts, are creating major causes that are expected to reinforce these events in the future (Milkov 2017). In particular, the urbanisation is rapidly changing the distribution of population around the world; for instance, since last decade, more than one half of the world population lives in cities and this trend is continuously increasing (UN 2014). Many of these towns are located in coastal areas resulting vulnerable to the growing impact of extreme weather conditions (Bruzzone et al.2014b, 2017c).
In addition the climate change and urbanisation jointly influence stability and are likely to increase the pressure on public authorities to faces these challenges as well as to task military forces for operating in large urban environments in response to instability situations such as:

- Man-made disaster, e.g. explosions, toxic agent contamination (Bruzzone et al.1996b, 2014c, 2015b)
- Large scale natural disaster, e.g. earthquake, flood, tsunami (Bruzzone & Massei 2006; Diaz et al.2013)
- Mass migration (Bruzzone et al.2017b)
- Epidemics & Pandemics (Bossomaier et al. 2009)
- Inner city turmoil (e.g. social unrest, riots) and armed conflicts (Ören &Longo 2008; Bruzzone et al.2011a)

This obviously suggest the opportunity to develop new Decision Support Systems (DSS) based on interoperable simulation to address these needs being able to combine multiple models (Bossomaier & Green 2000).
It should point out the above mentioned disasters generates even more negative synergies with the emerging actual geo-political scenarios where a large number of social and political instabilities are creating

very critical environments (Hsiang et al. 2014). In facts the rising number of fragile states at risk of instability and civil conflicts as well as the increase of terrorist attacks are factors that make even more difficult the crisis management (Duffield 2014).

3 MODELING ADDRESSING DISASTERS & CRITICAL INFRASTRUCTURES

This aspects becomes even more crucial when the crisis affects critical infrastructures that could generate domino effect which can further reinforce damages, casualties leading social collapse (Brassett et al.2015).

In this case, it is necessary to evaluate the impact of industrial facilities releasing hazardous material or generating huge explosions, as well as water resources unavailability, and communication network or power grid collapse (Griffiths 2012; Diers & Donohue 2013, Bruzzone et al. 2014a; Burgherr et al. 2015; Tremblay 2016). In facts, these infrastructures are requiring many years to be finalized, requires big investments and are characterized by limited life cycles; so it fundamental adopt a scientific approach in order to harmonize the plan of new installations respect dynamic evolution of the needs and of the existing resources over a long time horizon covering several decades (Zio 2016). In facts, it is necessary to be able to evaluate quantitatively the potential impact of natural disasters on these critical infrastructures as well as the mutual interconnections leading to risk of "cascade failures" (O'Rourke 2007; Szymanski et al.2015). It is evident the benefit of adopting a technical approach able to address both analysis of the current overall resilience and planning the future one considering their lifetime. (Bruzzone et al.2008; Francis & Bekera 2014). Indeed the reduction of the risks of such events represent a main goals of International and National Organization & Agencies as well as very important subject for major industries working.

4 MODERN M&S SOLUTIONS FOR CRISIS MANAGEMENT

Considering the high degree of stochastic factors and variables as well as the high number of mutual interactions among many different elements, M&S results the most promising methodology; however it is necessary to adopt interoperable simulation solutions able to address these multiple aspects; in facts by using interoperable simulation standards it becomes possible to define guidelines for creating a common framework including available models, new simulators as well as support tools already in use for crisis management (Bruzzone et al.2015a). In facts in this context the necessity to use simulation is fundamental to properly reproduce not only the crisis and damages to infrastructures, but also population response and effectiveness of countermeasure actions based on their dynamics.

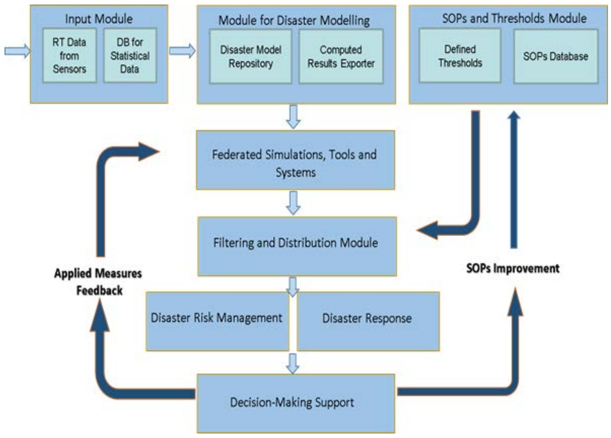

Fig.1- Architecture of the CDM System

So, due to these aspects, the authors suggest to create a CDM System integrating interoperable combined solutions; in fact is proposed to mix different tools, models, simulators and Intelligent Agents (IA) for reproducing the crisis as well as population behaviour (Bruzzone et al.2011b, 2014b). The most promising and effective approach to create an interoperable federation of simulators should be based on use of modern reliable interoperability standards, such as High Level Architecture (HLA) IEEE 1516; indeed this allow to integrate the different components and to orchestrate all the available simulation models in an unique framework available for the different stakeholders (Kuhl et al. 1999). By this approach it could be possible to federate together with the simulators also other modules, components and, even, real equipment; so the resulting federation could act as an unique solution consistent and reliable that could be used for different purposes such as Training and Decision Support. In facts the necessity to create new solutions available for being used by the different authorities in relation to crisis management is a fundamental step forward for reinforcing the fidelity on data, models and analysis approach in this sector as well as to enhance the effectiveness of educational and training in this field (Bruzzone et al.2009; Massei et al.2010; Raybourn 2012). Indeed, the innovative benefits provided by such federation include the capability to include and test each specific expertise required to deal with this different crises (e.g. hazardous material spills vs. flooding) and on the different operational areas (e.g. containment, evacuation, communication, strategic planning). In facts, simulation allows also to evaluate the capabilities needed to properly face specific disasters, as well as to identify the actions to create and enhance the operational interoperability within the different players (e.g. military, firefighters, civil protection, police, health care, NGO, etc). Currently the authors are active for combining different simulators and tools as federates into an HLA interoperable simulation by using available models such as IA-CGF, IDRAS, JCATS, ST_CIPROS, ST_CRISOM & SWORD (Prochnow et al. 2000; Browers et al. 2003; Bruzzone et al.1998, 2011b, 2015b; Ruiz et al.2013).

The main idea behind these activities is to define guidelines to support the easy and reliable integration of existing tools and models within this simulation as well as to demonstrate the potential of this approach by experimentation and support to exercises.

5 NATO EXPECTATIONS FROM DISASTER SIMULATION

In facts the above mentioned issues results pretty interesting for developing an experimentation and testing research devoted to evaluate the potential of modern M&S solutions in this field.

The authors are currently involved in researches, test campaigns and experiments in international context, to proof simulators capabilities and their ability to be federated in HLA. In particular, NATO is interested in this simulation activities.

Indeed, NATO's primary contribution in case of disaster is the coordinating, liaising and facilitating functions. Within and outside the Euro-Atlantic area, NATO is working with other major actors, including Governmental and Non-Governmental Organizations. By combining civilian and military crisis management and disaster response instruments NATO is effectively contributing to a Comprehensive Approach. The goal is to anticipate and enhance the Alliance and Nations' civilian and military capabilities for crisis management and disaster response. (Milkov 2017)

With the increased probabilities of civilian/military cooperation being required, enhanced understanding and trust will be needed between civilian and military entities, including non-governmental stakeholders, to ensure effective and efficient strategic coordination, planning and execution of disaster relief operations in support of protecting critical infrastructure. In this regard, NATO seeks to develop distributed and network capabilities for training and education to be integrated and contribute to the growth of existing National capabilities (Nikolov 2015).

5.1 Joint Research Activities

Jus to addresse these issues, the NATO-STO (Science and Technology-Organisation) has tasked NMSG-147 with the specific goal to develop the "M&S support for Crisis Disaster Management & Climate Change Implications". The group, chaired by CMDR CoE (Crisis Management and Disaster Relief Centre of Excellence) in Sofia, Bulgaria, includes several Participating Nations and Organizations: Germany (Co-Chair), Austria, Bulgaria, Italy, SLO, USA, M&S CoE (Modelling and Simulation Centre of Excellence) , JCBRN CoE (Joint CBRN CoE), ACT (Allied Command for Transformation), JFTC (Joint Force Training Centre), different Universities in Bulgaria, Germany and Italy, as well as industries.

The intended purpose of this group is to elaborate the theoretical, methodological and technical framework for the establishment of a holistic crisis decision-making support mechanism (Nikolov et al. 2016).

The project has three main directions for analysis CDM in NATO in order to improve the E&T (Education & Training) and support the Decision Making Process in the Alliance:

- Analysis of Disaster Risk Management (DRM) Processes, preceding the development of the Operations Plan, represents the first direction:
  - o Fast and accurate Disaster Risk Analysis;
  - o Comprehensive approach and correlation assessment among hazards;
  - o Prevention and Preparedness Measures proposals.
- Assessment of the Disaster Response, during NATO operation, is 2nd directions,:
  - o Fast and accurate Disaster Assessment (DA);
  - o Dynamically generated proposal for Response Plan.
  - o Lessons Learned Process (LL)
- Development of modules for realistic modelling and presentation of different disaster types is the 3rd direction devoted to the purpose of education and training, experimentations, tests and validations.

The methodological approach of this group respect to this study is orientated to NATO-CD&E (Concept Development and Experimentation) procedures. NATO-CD&E offers the right methods to incorporate M&S in scientifically valid tests / trials / experiments, thus give an agreed common ground for sustainable results.

At the end of the study, these achievements are expected to be used as a basis for:

- Development of 'Standing Operating Procedures'
- Development of technical (simulation) suites / federations
- Justification for investment of financial resources
- A baseline for further studies on simulation of crisis management tools and models

6 EXPERIMENTATION PLANNING

In the proposed study it is intended to conduct test trials to actually federate existing disaster models in accordance with the above mentioned architecture. These trials became CD&E-experiments with an independent analysis according to NATO-CD&E procedures.

The first experiment was conducted in March 2017 and it was designed as a 'Discovery Experiment'. The aim was to demonstrate the capabilities of existing disaster and C2-simulation tools as well as to federate as many as possible of these modules.

The results were impressive, however it was found that only few disaster models were available and able to be federated in HLA; so in this occasion simulations tools, such as SWORD, ST-CRISOM, HPAC, KORA, MILSIM/EDMSIM, COBRA, ICMS and EMERSIM have been tested. The second experiment is coming soon in October 2017 and it will serve as a continuation of the first one, with the same aim and seemingly more federates. ST-CRISOM, among others, will play a significant role here as point out in the following for population modeling.

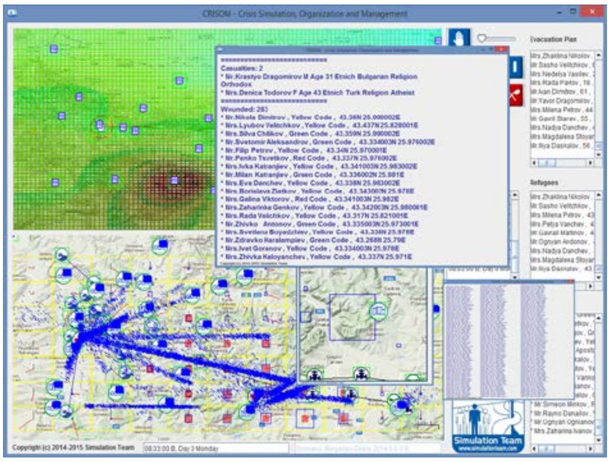

Figure 2 - ST_CRISOM Interface

Other two experimental tests are planned to take place during the 2018. Those tests, so called ‘Refinement experiments’, are devoted to evaluate the performances of the described architecture with its modules. In facts, a ‘Demonstration/Life-Field’ experiment is planned during Viking’18 exercise and a final validating experiment will happen in the first quarter of 2019 as Final Demonstration of the results from the NATO group.

7 FEDERATION, FEDERATES & SCENARIO

One of the goal of this research is to address the technological issues related to CDM and technological evaluations about interoperability among the simulators will be conducted. Major issues are related to evaluate the different FOM (Federation object Models), RTI (Run Time Infrastructures) as well as the effective features of existing models and the federation/federate computational issues during the experimentation. Obviously, HLA allows to integrate into the federation also new models together with legacy systems and it could be possible to add additional entities if available.

It is important to outline that one major goal of this initiative is also to create a framework enabling interactions among M&S scientists and Operational Subject Matter Experts. This collaborative simulation environment is very important especially because crisis management usually combines military and civil resources that have different background, procedures, technologies and priorities; so they could heavily benefit from working together on a common validated framework and they are both required to complete effectively the VV&A of the simulation (Balci 1997; Amico et al.2000). In facts, the check about conceptual interoperability among the different conceptual models will result a major benefit as soon as technological interoperability will be guaranteed; a major step in this direction will be passing he integration test during the planned experimentations. In facts the authors are currently working in cooperation with a pool of experts from different background (military, scientists, developer) to finalize the details of the proposed federation and to understanding how to use it to properly and effectively to demonstrate it for crisis management. From this point of view it is necessary to identify what data have to be shared and what interactions are required among the different federates. In order to proceed with the concept validation, the experimentation and testing on the models, the authors have defined a specific scenario; in particular the mission environment is set in an European Country and it should be possible to address different kinds of crisis such as: Flooding, CBRN (Chemical, Biological, Radiological and Nuclear) Threats and Fires. These subjects are quite articulated and combine different elements such as GIS data sets (Geographic information system), Flooding and Hydraulics Models, CBRN simulators, Fire simulators and Population Simulation. In general the Federation should demonstrate its capability to estimate the effects of alternative decisions on the whole system including the population behaviour: for instance the effectiveness sin placing sandbags during a flooding or the responsiveness of the resources in applying evacuation plan during the simulation.

8 MODELING IMPACTS ON POPULATION

In the proposed experimentation the modelling of impacts on Population and its dynamic reactions to events and crisis is a major issue; in facts it is hereafter proposed a specific simulator devoted to address these issues: ST_CRISOM (Simulation Team Crisis Simulation, Organization and Management). In facts ST_CIRSOM includes meta-models of disasters (e.g. flooding or CBRN event) and use Intelligent agents to simulate the human behaviours and reaction of the population (Bruzzone et al.1998, 2015a, 2017a).

ST_CRISOM adopt a Multilevel and Scalable approach (tactical/operational/strategic) and is able to simulate individuals within a large region with a different level of aggregation, down to the single entity; indeed it is possible to simulate from a region up to an entire country. Evaluation of boundary conditions affecting the disaster evolution are crucial and often need to be estimated and/or extended based on partial data; due to this reason ST_CRISOM considers the 3D landscape (orography) of the terrain to properly diffuse several boundary conditions (e.g. wind, rain, temperature) in space and time and to reproduce complex phenomena such as flooding, CBRN or hazardous material spills that have impacts on population behaviour. ST_CRISOM is equipped by an acquisition tool, developed by Simulation Team, able to import data from GIS databases to feed the simulation.

The population and GIS information are elaborate with the simulation by meta-models devoted to estimate the diffusion of the crisis. For instance to distribute the rain over an area and related flooding, the simulator considers the impact of showers as well as rivers behaviour; the weather forecasts are elaborated over the region, respect time advance and boundary condition (e.g. wind speed and direction, pressure), as proposed in figure 2.

Figure 3 – ST_CIPROS MS2G

This process allows to generate the dynamics of rain taking into consideration the stochastic elements; so the rainfalls are simulated and it becomes possible to quantify their impact on the different kinds of terrain based on its specific characteristics. In facts ST_CRISOM processes multiple layers reproducing both the terrain and the specific elements present on it as well as their functions such as :

- Rivers, Mountains, Lakes, Sea , etc.
- Buildings, Quarters, Villages, Towns, etc.
- Hospitals, Power Plants, Point of Interest etc.
- Pipelines, Power Lines, Cables etc.
- People, Social Networks, Interest Groups, etc.

Furthermore, ST_CRISOM simulates the human behaviour by reproducing the single individuals as well as their social network by using IA (Bruzzone et al. 1999, 2011b); the HBM (Human Behaviour Models) are attributed to people objects driven by the agents that consider different specific social parameters such as families, ethnic groups, level of instruction, social status, religion, political party, health status, age, gender, presence of impediments, etc. Population could be generated based on local statistics through Monte Carlo Simulation or acquired from databases.
The population is simulated by means of IA-CGF (Intelligent Agent Computer Generated Forces) developed by Simulation Team and their social psychological factors such as fear, stress, aggressiveness; these characteristics evolve dynamically during the simulation according to the events perceived by people objects as well as to the actions that they have carried out (e.g. escaping); the simulation engine is based on stochastic discrete events and allows to generate the scenario dynamics and to interoperate with other simulators as well as interacting with users; in facts each time a disaster occurs, the simulator reproduces its evolution and computes the list of the entities that are involved in the crisis; concurrently the agents related to people objects as well as to the entities (e.g. ambulances, first responder units) drive the simulation evolution; in this way it is possible to evaluate Key Performance Indexes (KPIs)such as the casualties, areas affected by the crisis, logistics requirements, responsiveness parameters, etc. In addition, ST_CRISOM provides reports about people to be evacuated or to receive health care support including relative details (i.e. name sex, age, health status etc); such information could be aggregated in different ways to support training (e.g. evacuation list organized based on town quarters or streets).
ST_CRISOM is able to also manage units and entities devoted to countermeasure directly controlled by itself or to interoperate with other ones provided by other federates; these are visualized and have an impact on the different agent behaviours; obviously this represent an interesting opportunity in the federation to be developed allowing to let other constructive simulators at different granularity level to move units on the terrain creating interactions with population and crisis evolution.
Currently ST_CRISOM operates as HLA time constrained and time regulating federate with the capability to run real time as well as faster-than real time; in facts this simulator has been experimented in conjunction with other simulators developed by Simulation Team (i.e. IDRASS, DIEM-SSP, IA-CGF NCF, NCF EQ, TRAMAS Katrina Like, DIES IRAE, SIMCJOH VIS & VIC).
Another module is represented by ST_CIPROS (Simulation Team Civil PROtection Simulator) proposed in figure 3. ST_CIPROS is as another element based on MS2G (Modelling, interoperable Simulation and Serious Games) paradigm and it provides an immersive interactive framework for the decision makers and their virtual staff to take decisions and to evaluate the consequence of alternative COAs (Bruzzone et al.2017a). In the following paragraph the result of the experimental analysis conducted during the development of ST_CRISOM and ST_CIPROS are presented.

8.1 VV&A

A basic experimental campaign for ST_CRISOM Project has been conducted to address Verification, Validation and Accreditation (VV&A) of the simulators. Due to the non-linearity and the stochastic nature of the phenomena investigated, a careful experimental design is necessary for quantifying experimental error (Montgomery 2008). In particular the methodology used in this case is the analysis of the Mean Square oure Error (MSpE) to evaluate the temporal evolution of the experimental error due to the stochastic components. The MSpE analysis have been conducted on the output of the simulation, in particular for some KPIs such as the number of Casualties, Number of Injured People, Quantity of Refugees and Evacuated people. The simulation is focused on flooding for a duration of three days for each run to cover the whole crisis; ten replications, with the same boundary condition have been used for considering the variance due to the stochastic components.
The results of the experimental campaign summarize the ANOVA based on evolution of the MSPE over simulated time for the three proposed output (figures 4, 5 and 6).

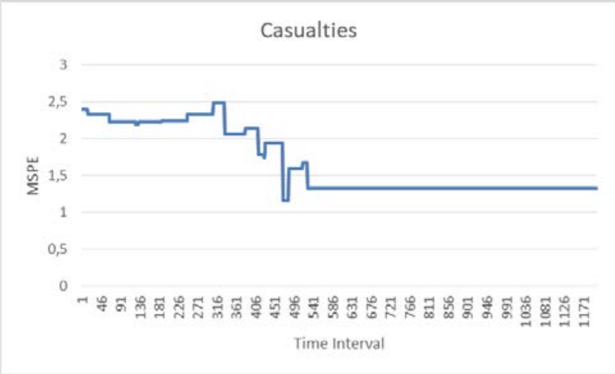

Figure 4 MSPE for the Casualties over time

Figure 5 MSPE for the Wounded People over time

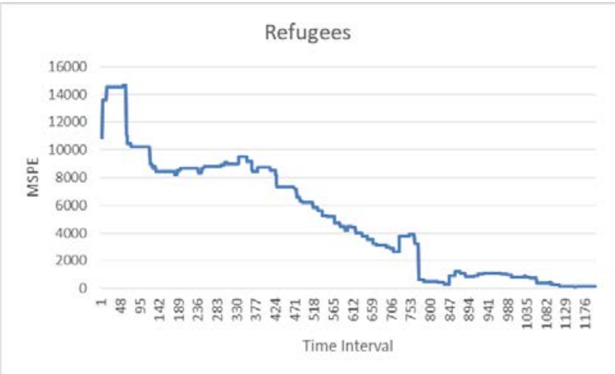

Figure 6 MSPE for the Refugees over time

In particular, from the analysis it is possible to assess the consistency and fidelity of the simulators. In facts, it is possible to measure the common trend of output variances that stabilize providing an estimation for confidence band of the output functions.

9 GIS & DATA FOR DECISION SUPPORT

The complexity of the above mentioned framework require to acquire a large quantity of data to cover both the different layers of the terrain as well as the social aspects. This issue turns even more critical in case of regions with high density of people as well as in large metropolitan areas that represent a crucial scenario for future analysis respect crisis management. Indeed, in near future, the availability of modern Decision Support Systems (DSS) for crowded urban areas respect crisis management is expected to be a requirement for both civilian and military decision-makers. Therefore these DSS are expected to don't be restricted just to crisis management, but to be required to support also other operational planning (e.g. logistics). In facts, since several years, NATO has activated a research on this direction devoted to create data sets to be used to investigate the challenges carried.

In the proposed scenario the simulation of such urban area results very interesting and require data; indeed a metropolis Geographic Information System (GIS) such as the 2035 virtual "Archaria" megacity, created by M&S COE and Fabaris for the NATO Urbanisation Experiment 2015 and Urbanization Wargame 2016 is expected to include potential critical elements in support of training and planning processes in the context of civil protection. In facts this kind of GIS provides a real awareness on the terrain, including information about city traffic layer, hospital and beds, emergency rooms, police stations, military barracks, webcams, etc. These data are integrated within the GIS into a Common Operational Picture (COP) available to the emergency agencies and Citizens are enabled to actively contribute to the information cycle by feeding the DSS with their reports, post, chat, tweets, etc. (Lo Presti et al. 2016).

Due to these reasons "Archaria" is a good example of data source to feed the simulation and reinforce the validity of the scenario; in facts the military personnel is used to train and analyse scenarios by virtual and constructive simulation that could require high granularity information. In facts the traditionally the military simulation systems and models reproduce mostly military units, platforms, orders, movements, logistics of military forces; just in some case and by some specific customisations, it is possible to simulate civilian forces, organised in hierarchic structures (the so called "order of battle" ORBAT), therefore normally these simulators does not model with same accuracy the impacted populations. So it is evident that this research need to fill up this gap by combining different simulators and data sources. The GIS could act effectively to cover the disaster region with special attention to the urbanized area in terms of information about the terrain, data on emergency, civil protection & military forces as well as details on the political, military, economic, social and industrial infrastructures. In facts it is possible to perform interesting analysis on the distribution of the population on the territory in different daytimes, thus providing data to simulate the effects of each disaster on the examined rea.

10 CONCLUSION

Close cooperation in the crisis management and disaster response domain requires forming appropriate military and civilian capabilities. These capabilities includes information and intelligence sharing, developing and operating early warning systems (in support of creating a common situational awareness), as well as conducting crisis & disaster planning and response & preparedness for Climate and Disasters impacts on critical infrastructures (Nikolov et al. 2016).

So an M&S Architecture effective in this field should have its initial operational capability established soon in order to be operational in time to support the planned NATO Crisis Management Exercises as well any regional Network projects or exercises and trainings; so it is evident the strong motivation of this research. In Effectively, by integrating these aspects, the NATO Force Structure would be better prepared for the next climate and disaster challenges and these systems will effectively support the and national building resilience. Indeed the proposed federation should create new capabilities and reinforce existing ones by improving operational interoperability based on a simulation able to combine together military and civilian models; in facts the use of these software solutions within an HLA federation is expected to support the capability development as well as Education and Training for joint civilian-military operations by engaging decision-makers, leaders and personnel.

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Late Abstracts

(ABSTRACT)

TRANSITION OF A MONOLITHIC LEGACY M&S TOOL TO A FULL SERVICE ORIENTED ARCHITECTURE (SOA) AND PRACTICAL USE CASES

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ABSTRACT

This paper describes the evolution of a powerful simulation tool, used for Decision Support in Anti-Submarine Warfare, developed by the NATO STO CMRE, from a monolithic legacy architecture into a distributed SOA architecture.

The new architecture combines Web Services, High Level Architecture (HLA, the NATO standard for Simulators interoperability) and Tactical Data Links (TDL, used for interoperability with Command and Control systems) to grant the maximum interoperability with existing and future NATO Simulators and Command and Control systems.

Acoustic Propagation Models and Environment are supplied by Web Services while the simulation engine and the optimizer use HLA and TDL to interface with the real and the simulation world. The resulting set of tools is fully modular and scalable and is applicable to a wide range of different applications.

Three application cases will be presented, these include: a Decision Support Tool that can run on an enterprise blade server, whose services are provided to final users through a JavaScript frontend application, an Underwater Glider Simulator running on a workstation and finally an Embedded Sonar Reverberation and Performance Prediction tool integrated into an autonomous vehicle embedded CPU.

(ABSTRACT)

DIGITAL CULTURAL HERITAGE: HOW TO USE THEM? SOME APPLICATIONS ON FLORENTINE ARCHITECTURE

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ABSTRACT

The digitization of Cultural Heritage has undergone an impressive technical and procedural evolution in the last years, but there are still relevant open issues. In particular, the focus on digital Cultural Heritage is rapidly moving from how to produce 3D contents to how to use – or re-use - them.

GeCo is a laboratory of the University of Florence, whose mission is the use of geomatic techniques for 3D acquisition and display of Cultural Heritage, considering objects with sizes ranging from small archaeological findings or art crafts to the urban, architectural and environmental scales. A particular aspect of interest is to improve the techniques for acquiring complex architectures, for their dimensions or irregular morphometry.

In this contribution, three cases of 3D Digital Architecture of peculiar buildings in Florence will be presented: the Battistero di San Giovanni, the Galleria dell'Accademia and the Fortezza da Basso. The main focus is the continuous updating and integration of the methodologies for 3D digitization of Cultural Heritage, with a closer attention to the use of the obtained outputs and their re-use in different contexts.

The survey projects were carried out by using integrated survey techniques, such as photogrammetry, laser scanning, UAV systems, classical and satellite topography. The 3D point clouds obtained provide an accurate metrical representation, aimed both to the evaluation of seismic and structural risks and to provide typical architectural drawings (plans and sections) for the building documentation and its future management.

Digitization of complex objects still has challenging aspects, in terms of workflow optimization in function of the survey aims. On the other hand, it's no more possible to focus the attention only on geometry representation: it is mandatory to consider and to carefully plan the best solutions for using the 3D models and opportunely communicate the contents on web channels.

In conclusion, this overview on outstanding Florentine 3D Digital Architectures, presents some applicative use of 3D architectural models as useful tools for heritage management, design and planning, thematic data, geo-referencing and in communication projects, in which both virtual and solid models can be used.

PHASE SHIFT IN MARINE ECOLOGICAL SYSTEMS – WHAT MANAGERS NEED TO KNOW AND HOW SIMULATION CAN HELP

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EXTENDED ABSTRACT

It is well established that phase shifts – usually to a degraded and undesirable state – can occur in ecological systems (Scheffer et al. 2001, 2009; Petraitis 2013). In marine systems they are known to arise in coral reef (Arias-González et al. 2017; Fung, Seymour, and Johnson 2011; Mumby, Hastings, and Edwards 2007), kelp-bed (Johnson et al. 2011; Ling et al. 2015; Marzloff, Little, and Johnson 2016), and open ocean systems (Wouters et al. 2015).

Discontinuous phase shifts present a particularly acute problem for managers because they are characterized by hysteresis and the existence of alternative stable states under identical conditions. Once a tipping point is reached and a system transitions to a new (and usually less desirable) state, it can be virtually impossible in practical terms and within typical levels of resource availability to apply management intervention to return the system to its preferred state (Marzloff, Little, and Johnson 2016; Johnson et al. 2017). By definition, it is usually insufficient for system recovery if environmental conditions are returned to those prior to the phase shift.

Effective management requires:

1. knowledge of the potential of an ecosystem for phase shift;
2. capacity to distinguish 'normal' fluctuations in an otherwise properly functioning ecosystem from phase shift;
3. knowledge of whether any phase shift is likely to be continuous or discontinuous (i.e. whether the system can exist in multiple stable states under identical environmental conditions);
4. estimation of the magnitude of the hysteresis in management terms in the case of discontinuous phase shift; and
5. capacity to recognize when a system is approaching a tipping point and to determine interventions to avoid phase shift.

In this talk we will provide examples of phase shift in kelp beds, coral reefs, and open ocean systems, and outline how simulation has helped provide answers to requirements #1,3,4, and 5 listed above (e.g. Melbourne-Thomas, Johnson, and Fulton 2011; Melbourne-Thomas et al. 2011a,b; Gurney et al. 2013; Marzloff, Little, and Johnson 2016). We will show how consideration of the characteristic length scale (Habeeb et al. 2005) of ecological systems can help interpret change observed in real ecosystems and to distinguish natural fluctuations from phase shift (requirement #2) (Johnson 2009; Johnson et al. 2017).

Finally, in terms of requirement #5 (i.e. capacity to warn of tipping points before they occur), we will discuss existing evidence from marine systems (Rindi et al. 2017; Wouters et al 2015) of so-called 'critical slowing down' (Dakso et al. 2015; Scheffer et al. 2009, 2012), and a new approach currently underway to ascertain the utility of information theoretic measures (Barnett et al. 2013; Bossomaier et al. 2016) as early warning of phase shift in ecological systems.

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Author's Index