

SIMULATION OF CRISIS AFFECTING CRITICAL INFRASTRUCTURES AND INDUSTRIAL PLANTS

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ABSTRACT

This paper proposes a model for reproducing human behaviors and it is devoted to evaluate the operation performance in case of crisis with special attention to cases involving multiple actors such as fire-fighters, police, ambulances, civil protection and national reserve. The paper present the general scheme and the data structure used to conduct experiments related to cases of flooding and hazardous material spills in industrial and urban areas.

Keywords: Crisis Simulation, Interoperable Simulation, Industrial Crisis, Decision Support

1 INTRODUCTION

Today urban areas have growth up to incorporate many industrial facilities; due to this fact population density near to industrial plants dealing with hazardous material increased drastically, as well as concreting and land use; these factors increase the risks for population to be involved in crisis due to natural and/or man-made disasters (Mengfan 2016; Harding J.). It is evident that the urban framework introduces additional challenges for first responders in order to operate in the area and coordination issues turn to be even more complicated than in usual operations. These phenomena are highly stochastic, affected by multiple interactions of many entities over different layers as well as strongly influenced by external (e.g. weather conditions) and human factors; so it is evident the necessity to use Modeling and Simulation to model the different elements of the real systems (Longo 2013) and anticipate their behaviors (Longo et al. 2008). In this paper the authors propose part of a larger model in use to simulate crisis, able to reproduce industrial processes and phenomena ingenerating the crisis evolution as well as population behavior and first responder actions.

2 CRISES IN INDUSTRIES AND CRITICAL INFRASTRUCTURES

The authors have broad experience in dealing with simulation of a crisis including explosions, hazardous material spills, fires, flooding, terrorist attacks, etc. (Bruzzone et al., 2008, 2014, 2016b).

In facts during these crises, multiple actors are present and they need to be coordinated: fire fighters, police, ambulance & health care facilities, national reserve, civil protection, etc.

This complex organizations could adopt different models for operating together and it is important to define the most effective and be aware of all the benefits from different structures, policies, regulations, operative plans and even technologies supporting these aspects. For instance, a major issue in a crisis dealing with an industry or a critical infrastructure is related to his impact on people; this means that transportation network could be compromised, often also power distribution is an issue to be solved as well as other urban layers. Moreover, gas distribution network in case of collapse of a critical infrastructure need to be secured in order to avoid further disasters or explosions. In this framework one of the major issue is related to people evacuation from dangerous areas (e.g. flooded or contaminated): this represent a major effort that could lead easily with hundreds of families or thousands of people to be moved within a town during chaotic moments. Another crucial aspect is related to the time scale that requires to address not only first response, but also several actions on short terms, required by the actors that deal with public safety and security.

The authors have currently specific simulation models and libraries for addressing these aspects including IA-CGF, ST_CIPROS, ST_CRISOM, PONTUS, etc. (Bruzzone et al., 2014, 2016a, 2017a). These simulators adopt interoperability through High Level Architecture Standard in order to guarantee the possibility to federate together different models and distributed with other systems (Kuhl et al. 2000); in this way it is possible to substitute the hazardous material spill model for real-time simulation devoted to training, with high fidelity simulators devoted to reproduce the contamination on the area for analyzing specific scenarios; at the same time, reliable models for fast time simulation could be used to run multiple replications in order to finalize in a preventive way the Standing Operation Procedures (SOP) respect specific period of the year (Bruzzone et al. 1996, 2017c). Interoperability is fundamental, it is useful also for evaluating the coordination respect different actors; indeed by this approach different simulators could be federated allowing each of the actor to play a scenario with others and to be trained on their Command and Control (C2) systems; from this point of view there are several researches for defining capabilities, new guidelines and standards to reinforce use of simulation within different major actors during a crisis.

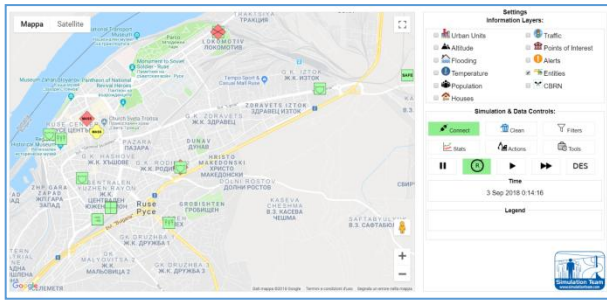


Fig.1 ST_CRISOM Simulation

The authors have recently completed different experimentations on projects dealing with crisis. First mention is about Decision Theater where different simulation models have been used such as ST_CRISOM, CIPROS, PONTUS within the Smart City funding program; the main crisis event was related to flooding in urban area with the possibility to diffuse contamination by depleting chemical tanks and facilities in industrial areas. In this case, the simulator addressed different criticalities:

- emergency management and evacuation considering the impact of flooding and contaminated waters,
- strategic planning in the given area to secure the situation by investments in infrastructures,
- industrial facilities additional safety elements,
- preventive crisis plans for first responders.

It is evident that this approach support also safety engineering and analysis devoted to prevent accidents and mitigate effect of crises. The experimentation allowed also to test decision makers' needs and expectations together with the City Authority and it was applied to Genoa case (major Italian port Town with less than a million inhabitants). The research tested also the possibility to interconnect the simulator with social networks to perform on-line acquisition of information coming directly from people (e.g. manhole blockage, river level, traffic jam, visible contamination, water level, etc.); the developed model fuses these information with other available data and spreads the input over time and space considering the constraints (Bruzzone et al.2017b).

Another application case is currently related to researches about use of these models for supporting collaboration between military units and civil agencies during such crises (Bruzzone et al. 2017a).

Also in these case ST_CRISOM, CRISOM, PONTUS, CIPROS of Simulation Team were tested and federated with other systems (i.e. jcats, pac, cora, hpac, dm, sword, arcaria-sword) by using different FOM popular among defense applications. In this case population has owned and controlled by Simulation Team as well as some specific crisis (e.g. flooding and industrial contamination or hazardous material spills).

Currently the authors are working in using these simulators in application to industrial cases to evaluate the impact of hazardous material spills and

corresponding preventive actions and emergency management. The recent collapse of the “Morandi Bridge”, a tragic event affecting Genoa (Harding 2018), makes the ST_CRISOM model, already tuned for flooding from previous Smartcity project, an additional way to provide support for mitigating the crisis and possibly restoring the affected areas. The bridge was an actual critical infrastructure, quite large, connecting Genova with its port. By the way, this specific area of the town statistically collected the highest rainfall in whole Italy (Acquatto et al.2017; Faccini et al.2018). In addition the bridge was crossing a very high density populated district and the major industrial zone with major facilities (e.g. Ansaldo Energy). This case introduces the destruction of a critical infrastructure that impacts the Port Terminals, the transportations over the region (East to West and vice versa) and in some way the whole mobility.

Over 600 people evacuated and large industrial complex need to be reorganized and relocated. In case of heavy rain falls, the ruins on the river could potentially increase flooding risk as well potential contamination of waters/mud, being the fall season the most dangerous period on this area. Inhabitants' high density, heavy concreting and soil consumption affect the simulation evolution through water speed as well as the impact on the river bed and channels created by urbanization (Duley 1939; Chanson 2004). Currently the authors are working on this case to evaluate alternative solution for transportations, alternative actions to address different risks taking care of preventive and mitigation effects; this paper presents some of the data structures used to model this case, especially ST_CRISOM simulator (Simulation Team Crisis Simulation, Organization and Management) that reproduces dynamics of a given complex scenario where a crisis evolves.

3 CRISIS SIMULATION

ST_CRISOM considers the human behavior of the population in terms of evacuations, reactions due to the emergency as well as to human factors (fear, stress, fatigue and aggressiveness). ST_CRISOM is a stochastic hybrid interoperable simulator using intelligent agents; indeed ST_CRISOM combines discrete event simulation of operations with continuous simulations of physical systems such as flooding.. Indeed ST_CRISOM uses the IA-CGF (Intelligent Agent Computer Generated Forces) to reproduce both civilian Populations as well as First Responders and Military units, Health Care, Civil Protection Agents & Public Infrastructures (Bruzzone 2013). CRISOM acts as a NCF (Non Conventional Framework) for IA-CGF and allows to reproduce Flooding Scenario and Industrial Contamination as well as Hazardous Material Spill over regional areas and impact on Town, Industrial Facilities and Critical Infrastructures. ST_CRISOM adopts HLA (e.g. evolved HLA IEEE1516-2010) standard to be federated with other Simulators using different RTIs.(e.g. Pitch RTI 5.3.2.1).

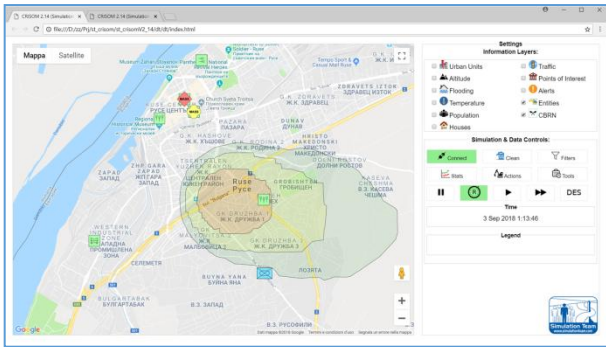


Fig.2 ST_CRISOM Simulation

4 PLAYERMESSAGE

ST_CRISOM uses a specific Interaction, defined PlayerMessage, for managing communications, lists and reports with other tools or simulators that have constraints is fully access HLA features.

Player Message in the FOM

```

<interactionClass>
  <name>PlayerMessage</name>
  <sharing>PublishSubscribe</sharing>
  <transportation>HLAreliable</transportation>
  <order>Receive</order>
  <semantics>CIPROS                                player
message.</semantics>
  <parameter>
    <name>Time</name>
    <dataType>HLAfloat64Time</dataType>
    <semantics>
      Time when the report has to be sent (if the time is not
      specified the report has to be delivered as soon as
      possible) or an order/instruction has to be executed (if
      the time is not specified the order has to be executed as
      soon as possible).
      Please note: The same info proposed here is available in
      the PlayerMessage content!</semantics>
    </parameter>
    <parameter>
      <name>Source</name>
      <dataType>HLAUnicodeString</dataType>
      <semantics>The Player who has to execute
      the order or the sender of the report (Player ID).
      Please note: The same info is available in the
      PlayerMessage content!</semantics>
    </parameter>
    <parameter>
      <name>Content</name>
      <dataType>HLAUnicodeString</dataType>
      <semantics>the content of the message.
      (JSON format)</semantics>
    </parameter>
  </interactionClass>

```

Player Message Examples

Examples of Format used by ST_CRISOM through Player Message in order to transmit to other systems specific info:

Code 36 Status Update of Critical Infrastructure

Update on the status of an industrial plant, tank or critical infrastructure during the crisis

```

[report id][unit id][time][location][Status: 0-100%][B]
# [order id], *Status Update, [unit_id], [time],
[location], [Status: 0-100%] , [free text] $

```

Code 37 Weather Update

Update on weather situation

```

[report id][type][pdi_id][time][location][wind speed
][wind direction][rain intensity mm/h][snow intensity
mm/h][range 1][mitigation 1][range 2][mitigation
2][range3][mitigation 3][fog/visibility m][B]
# [order id], *Weather Update, 7,[PDI Id], [time],
[location], [wind speed: m/s], wind direction, degrees,
[rain intensity mm/h], snow intensity [mm/h], [range 1,
km], [mitigation factors 1, 0.0-1.0], range 2, km],
[mitigation factors 2, 0.0-1.0],[range 3, km] [mitigation
factors 3, 0.0-1.0], [visibility, m], [free text] $

```

Code 38 River Report

Report on River status during the crisis

```

[report id][type][pdi_id][time][location][water
level][water limit] [B]
# [order id], *Weather Update, 2, [PDI Id], [time],
[location], [water level, m], [water limit, m], [free text]
$

```

Code 39 People Report

Report on Refugees, Evacuated People, etc.

```

[report id][source_id][type of report][time][location]
[number of refugees][adult males][adult females][young
people][people with impediments][Number of Red
Tags][Number of Yellow Tags][B]
# [order id], *Crisis Report, [source_id],[type report:
Refugees, Evacuation from Crisis Area Level A,
Evacuation from Crisis Area Level B, Evacuation from
Crisis Area C], [time], [location], [number of
refugees],[adult males],[adult females],[young
people],[people with impediments], [Number of Red
Tags], [Number of Yellow Tags], [Free Text]$

```

Code 40 Medical Evacuation Report

Report on Injured People and casualties as well as on arrivals on hospital

```

[report id][source_id][type of report][time][location]
[Number of Red Tags][Number of Yellow Tags]
[Number of Green Tags] [Number of
Wounded][Number of Casualties][B]
# [order id], *Medevac Report, [source_id], [time],
[location], [Number of Red Tags], [Number of Yellow
Tags], [number of Green Tags],[Number of Wounded
People], [Number of Deaths][Free Text]$

```

Code 41 Single People Report

List of people during the simulation.

[report id][peo_id][time][location][health status][age][gender][impedements][condition][fullname][education level][social status][religion][ethnic group][tribe][political party][B]

[order id], * Singel People Report, [peo_id], [time], [location], [health status: 0-100],[age],[gender: 1 male, 2 female],[impedements: invalidity percentage][condition: regular, to be evacuated, escaped],[fullname],[education level: String][social status: String][religion:0-8][ethnic group: String][tribe: String][political party: String] [free text] \$

42 Flooded Area Report

Report on flooded areas including contamination level

[report id][type][pdi_id][time][corner1][corner2][water level][water type] [B]

[order id], *Flooding Update, 2, [PDI Id], [time], [corner1], [corner2], [water level, m], [water type: clean-mud-contaminated-highly contaminated], [free text] \$

CRISOM Input Data

Please check the Annex Directories with file examples

DEM/DTM File

Digital Elevation/Terrain Model.

Format: TIFF (GeoTIFF)

CRS (Coordinate Reference System): EPSG:4258

Step: < 20m

Population File

Urbanistic Unit Population.

Format: csv

Structure:

| ID (1) | Name | Sex (2) | Nationality (3) | Age 0-4 | Age 5-9 | ... | Age over 100 | Total | Average Age |
|--------|---------|---------|-----------------|---------|---------|-----|--------------|-------|-------------|
| 1 | Crevari | M | POLAND | 2 | 2 | ... | 0 | 8 | 43,5 |

(1) Urbanistic Unit ID (only one for each unit)

(2) Value: M / F

(3) Value From the list of Nations (e.g. AFGHANISTAN, ALBANIA, ALGERIA, ANGOLA, ..., ARGENTINA, ARMENIA, AUSTRALIA, AUSTRIA, ..., BELGIUM,....etc.)

Educational Level File

Number of people for educational Level

Format: csv

Structure:

| Country (1) | Country (2) | Year | Population 0-14 years old | - | Primary School | Secondary School | University |
|-------------|-------------|------|---------------------------|--------|----------------|------------------|------------|
| ARGENTINA | ARG | 2015 | 10003060 | 630038 | 11750805 | 16010261 | 4066270 |

(1) From the Country List

(2) Argentina -> ARG

GDP per capita

GDP per capita for each country

Format: txt

Structure:

ARGENTINA \$20,100 (2016 est.)

GINI Index

Gini index for each Country

Format: txt (ASCII)

Structure:

ARGENTINA 42.7 (2014)

Infrastructures Description

Critical Infrastructure

Format: csv

Structure:

| Name | Address | Type (1) | Longitude | Latitude | People Capacity | Class (2) | Jobs Capacity |
|----------------------|-----------------------------------|--------------|-----------|----------|-----------------|-----------|---------------|
| I.C. HISTORIC CENTER | PIAZZA DI S.MARIA IN VIA LATA, 12 | KINDERGARTEN | 8.935974 | 44.40246 | 70 | average | 20 |

(1) The type: "Kindergarten", "Primary School", "Secondary School", "High School", "Private Kindergarten", " Private Primary School ", "Private Secondary School", "Private High School", "University", "museum", "park", "villa", "forte", "theater", "cinema", "beach", "caffe", "stadium", "shop", "trade center", "hospital", "police station", "fire station", "bank", "parking"

(2) "low", "average", "high"

Optional Fields:

| Hierarchy | Municipality | Province | Phone Number | Area | District |
|-----------|--------------|----------|--------------|------|----------|
| N.D. | Genova | GE | N.D. | N.D. | N.D. |

Natality

Sons Number per woman for each Country

Format: csv

Structure:

ARGENTINA,ARG,2015,2.3080001

Political Preferences

The preferred Political Parties (Chance to vote) for Sex (M/F), age groups (25-29, 29-34...), educational level

Format: csv

Structure:

| | Party 1 | Party 2 | Party 3 | Party 4 | Party 5 | Party 6 | Party 7 |
|----------------|---------|---------|---------|---------|---------|---------|---------|
| M | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.1 | 0.1 |
| F | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 0-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ... | | | | | | | |
| 50-54 | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| ... | | | | | | | |
| <14 years old | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| - | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| Primary School | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| High School | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |
| University | 0.1 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 |

Population Distribution

Population distribution in the urbanistic unit (optional), if the units are not included in the file, or the file miss, the population (houses distribution) is consider uniform.

Format: JSON

Structure:

```
{"features": [
  {"id": 29, "name": "Angeli", "population_center": [8.90664
  4, 44.415041], "population_sigma": [1.0, 0.6]},
  {"id": 58, "name": "Apparizione", "population_center": [8.
  993217, 44.403883], "population_sigma": [0.2, 0.5]}]}
```

The Fields:

- **id:** urbanistic unit ID
- **name:** urbanistic unit name
- **population_center:** the coordinates of the unit point with the maximum population density
- **population_sigma:** population distribution efficacious value

Population Incomes

Urbanistic unit average income

Format: csv

Structure:

Urban Unit, Average Income

Example:

```
1,21.34
2,19.93
3,16.446
4,19.803
5,19.165
6,24.061
```

Public Events

Week Events affecting Population

Format: csv

Structure:

| Type | Kind of Place | Longitude | Latitude | Day of the Week | Starting Hour | Duration [hours] | Description |
|---------------|---------------|-----------|----------|-----------------|---------------|------------------|----------------|
| entertainment | stadium | 8.95246 | 44.41645 | 6 | 12:00:00 | 2 | football event |

Religion Compatibility

Compatibility defining the chance to be friends or create family

Format: csv

Structure:

| | CHRISTIAN | MUSLIM | UNAFFIL | HINDU |
|-----------|-----------|--------|---------|-------|
| CHRISTIAN | 1.0 | 0.5 | 0.5 | 0.5 |
| MUSLIM | 0.5 | 1.0 | 0.5 | 0.5 |
| UNAFFIL | 0.5 | 0.5 | 1.0 | 0.5 |
| HINDU | 0.5 | 0.5 | 0.5 | 1.0 |

Religions

Country Population Percentage of each religion.

Format: txt

Structure:

```
COUNTRY, PERCENT CHRISTIAN, PERCENT MUSLIM, PERCENT UNAFFIL., PERCENT HINDU, PERCENT BUDDHIST, PERCENT FOLK RELIGION, PERCENT OTHER RELIGION, PERCENT JEWISH
```

Example

```
AFGHANISTAN,0.1,99.7,0.1,0.1,0.1,0.1,0.1,0.1
ALBANIA,18,80.3,1.4,0.1,0.1,0.1,0.2,0.1
ALGERIA,0.2,97.9,1.8,0.1,0.1,0.1,0.1,0.1
....
```

Rivers & Sewerage

Rivers, Aquifer, Sewerage and Manholes of the scenario

Format: JSON

Structure:

```
{ "node_id": 0,
  "node_coordinates": [
    44.39431220,
    8.942613601
  ], "node_links": [
    {
      "link_id": 7
    } ] }, {
  "node_id": 1,
  "node_coordinates": [
    44.407359497,
    8.9502578973
  ],
  "node_links": [
    {
      "link_id": 7
    },
    {
      "link_id": 8
    },
    {
      "link_id": 114
    } ] } ],
"links": [
  { "link_id": 0,
    "node_1": 18,
    "node_2": 20,
    "depth": 4,
    "width": 50,
    "type": "normal",
    "distance": 303.501
  },
  {
    "link_id": 1,
    "node_1": 180,
    "node_2": 79,
    "depth": 1,
    "width": 3,
    "type": "underground",
    "distance": 1161.451
  } ] }
```

The Fields:

node_id: node ID

node_coordinates: node coordinates

node_links: links connected to the node

link_id: link ID

node_1, node_2: the nodes connected by the link

depth: average depth of the river

width: average width of the river bed
type: link type (normal/underground)
distance: distance of the link in meters

Roads

The roads of the scenario

Format: JSON

Structure:

```
{ "nodes": [
  { "node_id": 0,
    "node_coordinates": [
      44.41520655,
      8.707437515
    ],
    "isolated": false,
    "node_links": [
      {
        "link_id": 195
      },
      {
        "link_id": 225
      }
    ]
  },
  { "node_id": 1,
    "node_coordinates": [
      44.42575053,
      8.736963272
    ],
    "isolated": false,
    "node_links": [
      {
        "link_id": 10
      },
      {
        "link_id": 195
      }
    ]
  }
]
}
"links": [
  { "link_id": 281,
    "node_1": 55,
    "node_2": 62,
    "type": "normal",
    "distance": 3525.494,
    "direction": 0
  },
  {
    "link_id": 1,
    "node_1": 200,
    "node_2": 88,
    "type": "normal",
    "distance": 182.210,
    "direction": 0
  }
]
}
```

The Fields:

- node_id:** node ID
- node_coordinates:** node coordinates
- node_links:** vector of links connected to the node
- link_id:** link ID
- node_1, node_2:** the nodes connected by the link
- type:** type of the road (normal/highway/railway)
- direction:** direction of the traffic:
 - 0 - bidirectional
 - 1 - from node 1 to node 2

-1 - from node 2 to node 1

Terrain Type

Terrain Type

Format: TIFF (GeoTIFF)

CRS (Coordinate Reference System): EPSG:3035

The Terrain Type must be compatible with the format used in the Copernicus Project (www.copernicus.eu)

Urban Areas

Urbanistic unit (polygons)

Format: GeoJSON

Structure:

```
{ "type": "FeatureCollection", "features": [ { "type": "Feature",
  "geometry": { "type": "Polygon", "coordinates": [ [ [ [ 8.83628, 44.423768, 0 ], [ 8.83644, 44.423748, 0 ], [ 8.836494, 44.423726, 0 ], [ 8.836726, 44.423661, 0 ] ] ] ] },
  "properties": { "stroke": "#555555", "stroke-width": 2, "stroke-opacity": 1, "fill": "#555555", "fill-opacity": 0.5, "name": "Porto", "id": 0 } } ] }
```

Weather Forecasts

Weather Forecast

Format: csv

Structure:

| Weather Station | Date & time | Rain intensity [mm/h] | Temperature [C] | Wind speed [m/s] | Wind Direction |
|-----------------|----------------------|-----------------------|-----------------|------------------|----------------|
| 1 | 12 Feb 2018 07:00:00 | 10 | 12 | 3 | 90 |

Weather Statistics

Typical values of the temperature, wind direction

Format: csv

Structure:

| Weather Station (1) | Temperature Correction Hourly (2) | Wind Direction (3) | Wind Speed (4) [m/s] |
|---|--|--|------------------------------------|
| 1. Christopher Columbus, Airport, 8.847598, 44.414878 | -3.6, -3.6, -3.6, -3.4, -3.7, -3.7, -2.8, -1.7, -0.6, +1.0, +3.2, +3.4, +3.7, +2.9, +1.8, +1.7, +1.6, +0.6, -0.6, -1.4, -2.7, -3.2, -3.5, -3.7 | 270, 180, 090, 090, 090, 090, 090, 090, 090, 180, 180, 270 | 6, 6, 5, 4, 3, 2, 1, 1, 4, 5, 5, 5 |

- 1) Weather Station that gives the weather forecast: ID, name, description, longitude, latitude
- 2) Change in temperature during a day compared to average temperature
- 3) Typical Wind Direction in each month of the year
- 3) Typical Wind Speed in each month of the year

Work and Commercial Activities

Workplace and attractiveness number of each urbanistic unit

Format: csv

Structure:

| Unit id | Unit Name | Workplace High | Workplace Average | Workplace Low | Attraction High | Attraction Average | Attraction Low |
|---------|-----------|----------------|-------------------|---------------|-----------------|--------------------|----------------|
| 0 | Porto | 750 | 1800 | 450 | 1.5 | 2 | 2 |

The Fields:

- Id and Name** of urbanistic unit
- Workplace** number of employed in this area subdivided in terms of income groups: low/average/high
- Attractiveness** of urbanistic unit: 0 – doesn't attract, 1 – average level, >1 - high level

CONCLUSIONS

The paper proposes an effective use of simulation to address crisis impacting urban areas in relation to critical infrastructure and industrial facilities; it is proposed an innovative agent-driven interoperable hybrid stochastic simulation and data structures to support interoperability and connection with other systems and simulators. The proposed approach represents a good opportunity to use simulator in synergy with other models, tools and systems to enhance training, planning, operational support as well as safety engineering. Currently the authors are using it for multiple case studies, extending further its potential and conducting additional experimentation on interoperability with other systems.

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