SPECS: A mustering simulation tool for the evacuation of Passenger Vessels

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Abstract:

Ship evacuation, in case of disaster, is of a main concern today. This is particularly true for Passenger Vessels, for which is critical, but will probably become a requirement for other kinds of ship. The owners and regulations are demanding the yards to be aware of the evacuation process and to take it into account within the design stage. A simulation tool can let the designer able to optimise the evacuation paths while finding out bottlenecks, influence of obstacles and adequacy of space design together with the role of crew.

The paper will introduce a quick review of the present international regulations. An overview of the tools used in aerospace and civil engineering industries will also be introduced. The evacuation process itself can be seen as a crowd flow moving into a defined and closed stream of spaces. A simulation tool must include:

- The description of spaces: geometry, ship position (as non horizontal decks due to the disaster), ship state (fires, blocked paths) emergency signs.
- The actors (passengers and crew): health, moral, intelligence, group behaviour (family) and awareness.

The implemented method in the SPECS project is based on the multi-agent approach. Each agent is provided with a complete autonomy allowing choice of the direction and speed to reach goals which are updated on a time step basis upon external conditions such as obstacles, other agents vicinity and so on. A set of human behaviours is included in the model leading to real rational and non-rational decisions as far as each agent has its own perception of the real world.

The paper concludes with the foreseen test plan and perspectives such as embarkation-disembarkation, crowd flows around ship show rooms or red code situations on board military vessels.

1. Introduction

On one hand, the demand for passenger shipping has been increasing in the last years. Both leisure cruise liners and ferries (high speed crafts but also regular Ro-Ro) are concerned. On the other hand, safety on board is of a main concern and becomes a strong requirement. Under market and regulations pressure, the ship owner requires today a better assessment of the capabilities to evacuate the ship. Some rules include a demand for simulating the evacuation process. In these conditions, the designers need simulation tools to check the evacuation procedures and to optimise them as well.

SPECS (Ship Passengers Evacuation: Concepts and Simulation) is a French national funded project whose partners are Chantiers de l'Atlantique (shipbuilder for cruise liners and high speed crafts), Bureau Veritas (Classification Society) and IRCN together with two subcontractors who also contribute to the project: MFRDC (Consultant) and University of Plymouth). The objective is to provide the yard's designers with a tailor-made tool that can meet their needs and their internal organisation of the design process.

The outputs from the simulation will be focused on two kinds of results:

- Checking the evacuation path against geometrical recommendations in the rules,
- Quantitative (evacuation times, people density in critical areas…) and qualitative (bottle necks, misplacement of obstacles…) items.

After an overview of the regulations and the existing methods in other industries or from research works, the present paper will introduce the multi-agent approach implemented in the SPECS project (model, agents description, human factors to be included). It will be concluded by the various perspectives offered by a such development.

2. Regulations overview

In regulations we can distinguish two different types:

<u>Prescriptive regulations:</u>
The means by which a certain level of safety can be attained is determined. No choice is left to the operator as to how to attain this level.

<u>Performance-based regulations:</u>
A specified safety goal must be reached, regardless of the technical solutions put into place.

For passenger ship evacuation, two main regulations have to be applied:

2.1 SOLAS

The most important international conventions dealing with maritime safety is the International Convention for the Safety Of Life At Sea, known as SOLAS [3], which covers a wide range of measures designed to improve the safety of shipping.

This convention shall apply to ships entitled to fly the flag of states the governments of which are contracting governments and engaged on international voyage.

According to the SOLAS Convention (chapter I, Regulation 2):

Passenger is every person other than

- the master and the members of the crew; and
- a child under one year of age.

Passenger ship is a ship which carries more than twelve passengers.

In the SOLAS rules, the evacuation process is divided into phases as shown in Figure 1:

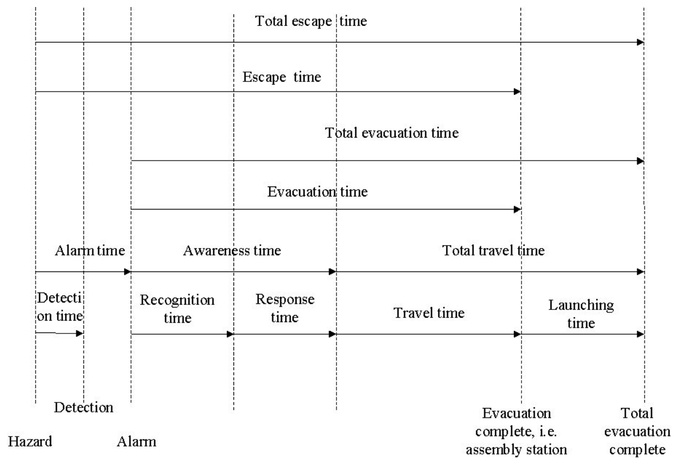

Figure 1: Definition of various time names used in SOLAS rules for the evacuation process

In SPECS the simulation will cover "Evacuation time" and possibly "Total evacuation time".

Regulations, which deal with the evacuation process, are:

- Chapter II-2: construction- fire protection, fire detection and fire extinction
  Part B – fire safety measures for passenger ships
- Chapter III: life-saving appliances and arrangements
  Part B- ship requirement

The recommendations mainly refer to the description of procedures, number and functionality of the escape devices, drills, crew training and so on. But part of them deals with the escape route requirements. They point out that the escape routes shall be as direct as possible, not obstructed…, and their accessories (handrails, handholds, unlocked doors …) localisation means ("you are here" plans, arrows, deck numeration…) are well described.

Ro-ro passenger ships constructed on or after 1 July 1999 are required to undergo an evacuation analysis at an early stage of design (Chapter II-2).

Present and future (July 1st 2002) SOLAS Codes do and will not includes additional instructions about arrangement of means of escape: "the widths, number and continuity of escapes shall be in accordance with the requirements in the Fire Safety Systems Code".

2.2 HSC Code

The Maritime Safety Committee, at its sixty-third session (16 to 25 may 1994), adopted the International Code of Safety for High-Speed craft (HSC Code). Furthermore, amendments to the Annex to the 1974 SOLAS Convention, by the addition of a new chapter X on Safety Measures for High-Speed Craft, adopted by the 1994 SOLAS conference (May 1994) make the HSC Code mandatory.

The following definitions are included:
Category A craft is any high-speed passenger craft:
- operating on a route where it has been demonstrated to the satisfaction of the flag and port States that there is a high probability that, in the event of an evacuation at any point of the route, all passengers and crew can be rescued safely within the least of:
  - the time to prevent persons in survival craft from causing hypothermia in the exposure in the worst intended conditions,
  - the time appropriate with respect to environmental conditions and geographical features of the routes, or
  - 4 hours; and
- carrying not more than 450 passengers

Category B craft is any high-speed craft, other than a category A craft, with machinery and safety systems arranged such that, in the event of damage disabling any essential machinery and safety systems in one compartment, the craft retains the capability to navigate safely.
High-speed craft is a craft capable of a maximum speed, in metres per second (m/s), equal or exceeding: $3.7\nabla^{0.1667}$ where $\nabla = \textit{displacement corresponding to the design waterline}\ (m^3)$
Passenger craft is a craft that carries more than twelve passengers.

Among main recommendations one can highlight:
- Public spaces should be designed to protect passengers and to help them moving in case of evacuation.
- Seats should not obstruct access to, or use of, any essential emergency equipment or means of escape.
- It deals with the evacuation conditions: exits position, exit doors opening, exits number, exits marks, passages dimension…in day light or in darkness conditions. There is no explicit recommendation but only vague one.
- It contains the evacuation procedure and the maximum evacuation time authorised.

  $$\textit{evacuation time} = \frac{SFP - 7}{3}\ (\text{min})$$

  where $SFP = \textit{structural fire protection time}$ (min)

  The subtraction of 7 minutes corresponds to the initial period for detection and extinguishing action.

3. Existing methods

Various techniques has been implemented yet or appeared challenging enough to be studied to chose the most applicable. Here after we include a quick overview of the major ones.

3.1 Hydrodynamics

The first simulation methods for crowd flows or urban traffic were based on hydraulics analogies which consider the flow as continue with variable density. The main problem is to determine this density by the resolution of a partial derivative equations system.

Hydraulics approach: The most "simple" or at least most used hydrodynamics method consists in considering the flow as a compressible continuum. For example a car line model taking traffic signs into account can be undertaken using a Burger problem [5].

This method is pretty good and realistic for traffic flows with a high density on one line, but it experiences many limitations as the difficulty to introduce des stochastic or statistic drivers'

behaviours or a weakness for defining heterogeneous car profiles. As a Eulerian approach, it does not fit well to analyse individual results as point to point running time for a given car.
The Italian Classification Society RINA has implemented a such approach for passenger evacuation.

Particles methods: The particles methods for solving partial derivative equations have been widely developed in the last ten years. Main applications are dedicated to computer fluid dynamics. For simulating granular continuum, the regularised particles method (SPH - Smooth Particle Hydrodynamics) [6] is used. Nowadays some industrial applications appear as material damage models [7] or fast dynamics [9]. In spite of the "particular" aspect of the method, it relies on a continuum description, and so forth, does not fit very well to evacuation problem. But some algorithms as seeking neighbours may be useful.

3.2 Cellular automata

A cellular automaton works in a dynamical system where space, time and states are discrete. To each point of a Cartesian grid, called cell, is associated a state with a known set of possible values. Local rules allow updating the cell states. At a given time, a cell state is only linked to its own and neighbours' value at the previous time step. All cells of the grid are updated simultaneously, and their state varies upon discrete time steps. Many applications have been done using cellular automata for simulating traffic flows or crowd evacuation. One interesting reference is the various research works done by the University of Duisburg in Germany [10]. In these methods, each individual cell can contain only one actor (person or vehicle). Algorithms are highly parallelizable and very efficient for the geometrical aspect of displacement. But when rules of management for actors' interaction become complex the efficiency decreases quickly.

3.3 Distributed Artificial Intelligence

Traditional Artificial Intelligence (AI) tends to model the intelligent behaviour of one unique agent, Distributed Artificial Intelligence (DAI) focuses on intelligent behaviours resulting from the cooperative activity of many agents [11]. It allows a distribution of expertise on a group of agents which have to be able to work and act into a common environment and to solve possible conflicts. Various implementations exist: Parallel Artificial Intelligence, Distributed Problems Resolution and Multi-Agents Systems. For evacuation problems where individual behaviour may be more important than group behaviour, components must be able to "think". Thus they must be provided with perception and action capabilities and must include a certain autonomy to behave. Multi-Agents Systems appeared as the best solution [12].

4. Multi-Agent Systems

An agent may be defined as an entity (physically or abstractly) able to act on itself and its environment, provided with a partial representation of this environment, able to communicate with other agents and with a behaviour coming from its observations, knowledge and relationship with other agents [13].

Three different kinds of agents exist:
Cognitive agents: They have a comprehensive set of knowledge-based capabilities of thinking, allowing them to solve more or less sophisticated problems and interaction with other agents. Each agent may be compared with an Expert System.

Reactive agents: For supporters of this method, each agent has not to be fully intelligent to simulate a group intelligence. He has just to understand a communication protocol based on a stimuli-action based approach.
Hybrid agents: As far as each of the previous methods are note obvious to implement in a whole, it is often better to use a hybrid method combining local and global views [14].

4.1 Functions of a cognitive agent

Agents are provided with various features (intentionality, rationality, involvement, adaptativity, autonomy, anticipation, emotivity). The structure of an agent is given on

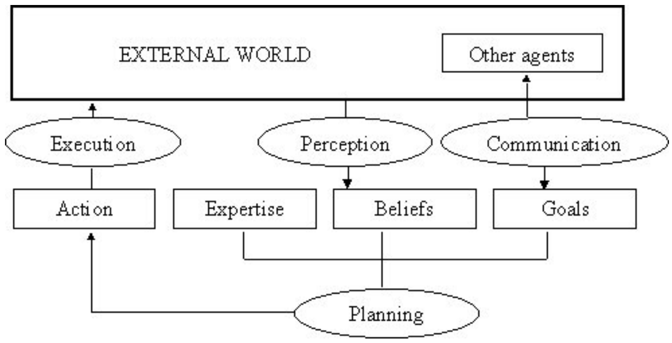

Figure 2: Typical functions of a cognitive agent

An agent may acquire knowledge on external environment (perception). He has also some interaction capabilities with the other agents (communication, negotiation). Relying upon knowledge and beliefs he has and the goals he is aiming to, the agent must build a plan for action. For that, he uses his expertise to decide which first goal to chose and to complete and which action he plans to reach it. Knowledge may come from initial knowledge (I remember my way to enter the room) or from the environment (Where is the next exit sign?). The beliefs represent the way the agent interpret the information, as far as the perception is not always rational (an agent can miss an exit sign). Planning cannot be decided a static way. The agent must take into account the vicinity of other agents and to negotiate with them (communication) before deciding his actions (possibility of collisions or leader followship for instance).

4.2 Agents Society

An agent's society may be defined with three main elements [15]: a set of agents, a set of tasks to achieve and a set of objects related to the environment. An agent may demonstrate his ability to achieve a task and to overtake the responsibility for it. Then he takes a leadership attitude in the group. In a such case to realise a task he/she may have to manipulate objects of the environment or other agents as helping a lost agent or mustering an agents group.

Here are various aspects to include in the agents to maintain the group consistency:
Control and decision mechanism: Control is to be included to define the rules of the society creating a kind of master-slave relationship between agents and a super-agent (supervisor). The decision mechanisms must include for instance all relevant conclusions after a negotiation process.
Cooperation: In one agent's model of the environment, information coming from other agents must be included. For instance an agent may suspend a plan to help another or ask for help when his knowledge is not enough to find a solution by himself. Cooperation needs a coordination that may help in finding a common solution for a group or in solving a conflicting situation. Coordination

may be centralised (supervisor) or decentralised (agents). Cooperation also needs negotiation that includes mechanisms to get the agents coordinated.
Communication: Communication includes mechanisms and protocols to support the negotiation. The protocols must include all relevant "words" of the restraint "language" used by the agents to cooperate. Communication may be done through a shared memory or on a point-to-point basis. The most efficient approach is to let the agents communicate a point-to-point way but using a supervisor as a post office.

5. Communication

Some experiments on communication in case of emergency have been carried out. Interesting results are included here after [16].

Test Experiment 1: The first experiment relates to the concept of agent communication. Rational agents have the ability to give information to other agents to help them to escape more effectively. Rational communicating agents have been used to supply information to uncertain agents. The percentage of irrational agents that escape is measured against the amount of communicators in the room.

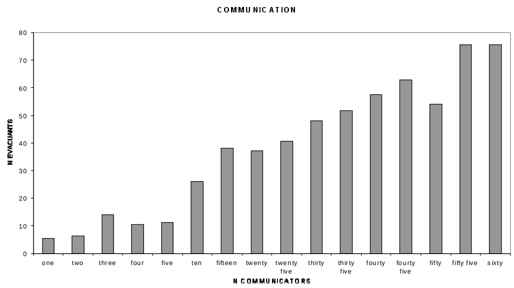

Figure 3: The amount of *Rational* communicators in the room plotted against the amount of evacuated *Irrational* agents

As expected, Figure 3 indicates that an increasing amount of positive communication within the system allows agents with irrational behaviour to escape the room more easily. This result can be interpreted as meaning that if more rational agents help other less capable agents to escape then these less capable agents will stand more chance escaping the room.

Test Experiment 2: Another manner in which agents can receive information is through sensory information relating to exit sign positioning. Exit signs provide localised information relating to the general position of the main exit. More information provided should enable the agents to evacuate a room more effectively. The percentage of evacuants is measured against the number of exit signs positioned at random in the room. Because of the stochastic effects relating to the initial positioning of agents and signs the results are averaged over 25 runs.

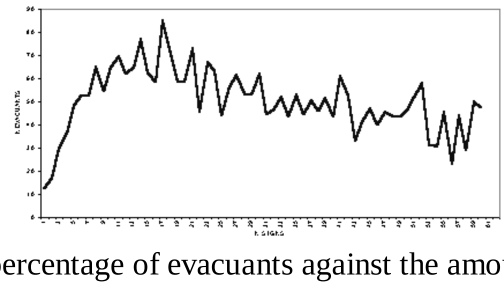

Figure 4: The percentage of evacuants against the amount of exit signs.

Increasing the number of exit signs in the room produces the interesting results of Figure 4. The escape performance of the agents is initially increased, reaching generally high levels between 10 and 25 exit signs, but then performance seems to fall away. The reason for this relates to the nature of agents sensors. These agents will constantly look for exit signs and follow the information until they see an exit to escape from. Beyond a certain amount of exit signs it seems that agents become ‘confused’.

Test Experiment 3: The final experiment shows how the general escape flow of ‘Rational’ agents slows down when their avoidance behaviour increases. This sensitivity is important because it can model the development of bottlenecks in crowds.

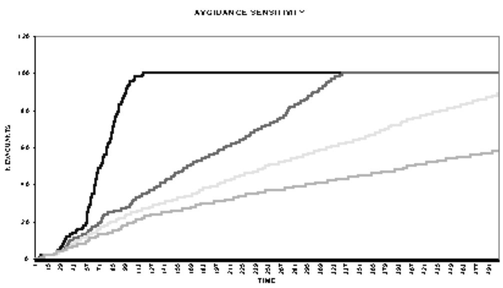

Figure 5: The flow of *Rational* agents through time at various levels of avoidance sensitivity.

If people are sensitive to avoiding other agents the results of Figure 5 indicate that more bottlenecks emerge and this greatly affects general escape speed. These rules have provided a simple and provisional set in order to demonstrate agent movements through space. In order for the current project to accurately model crowd flow through marine vessel architectures the agents need to behave as much like a real collection of people on board a marine vessel. For this to be made possible it is important to ensure firstly that the agent model is sufficiently realistic and secondly that it is executed within an accurate computerised representation of a given marine vessel.

6. Object-oriented model of the simulator

The simulator is based on a time steps basis that complies with the following schema:

- Initialisation (reading of the database or input files)
- Main loop
    - Time management
    - Updating external world (introduction of hazards)
    - Updating agents (realisation of actions, updating goals)
    - Dealing with conflicts from the current goals
    - Possible saving of intermediate or final results

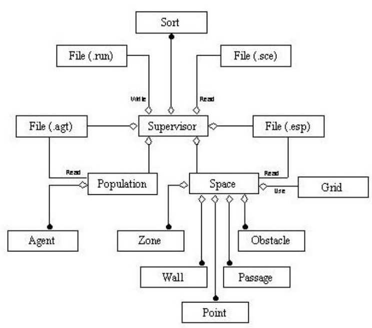

Figure 6: Schema of the relationship between Supervisor, Space and Agents.

The database or input files contains the description of the scenario (time steps to use, initial position and speed of the agents, time of appearance of events such as hazard or initialisation of a specific agent), description of the space (walls, passages, obstacles and zones with their status such as stairs or muster station) and description of the agents (personality such as maximum speed (physical) or maximum level of vexation (intellectual), initial state). Please refer to Figure 6.

6.1 Supervisor

The first supervisor function is to be an interface to SPECS database and input/output files. For instance it is in charge of reading initial data and parameters of the simulation (scenario, space, agents). Then it manages time steps (RunStep method which in turn trig the agents' RunStep method) and appearance of events as initialisation of delayed agents and hazards changing the space state (passage being blocked, fire propagation, ringing alarms). Finally, it is responsible for saving interim or final results from the simulation.
The second supervisor function is to decide for agents unable to deal with a negotiation. Following the same idea it may be mandated to give an oriented perception of the reality to the agents upon the interest of the overall population.
In the first implementation, the supervisor is slightly managerial (reactive agents oriented) but when the agents will get more and more intelligence the supervisor will withdraw in the background letting more initiative to the agents (cognitive agents oriented).

6.2 Agents

For each time step one single agent executes the following tasks: Feeling, Thinking, Acting. The Feeling function is carried out using a perception object communicating with the supervisor to build beliefs of the external world. The Thinking function is carried out using a planning object that builds a plan and select an immediate goal to achieve. Finally a Goal object selected by the planner deals with the Acting function. To do so it runs a set of behaviour rules and combines the resulting actions to modify the internal states. Please see Figure 7.

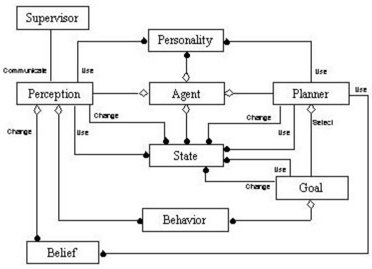

Figure 7: Schema of the relationships for the Agent object

We can highlight some specific aspects of this schema:
Belief: For reacting or decide the agent needs beliefs of the external world which have not to be rational. Beliefs are maintained by the perception. Some beliefs may result from a combination of various pieces of information on le the external world and internal states. Examples of beliefs are: Presence of a passage, vicinity of other agents, obstacles on the way or states of an other agent as "lost", "panicked", "wounded"…
State: A state represent an internal feature of the agent together with its current value. At each time steps a state can be updated by the perception relying upon events. Examples of states are: position, speed, tired, moral, stress or vexation.

Personality: To decide whether an action can be engaged the agent uses its personality. Usually, a personality is linked to a state and represents a reference value (maximum possible level for instance). The population will comprehend agent with various personalities deduced from a typical set of passengers (percentage of old people, of potential leaders…).
Goal: The agents have a stack of goals organised by priority. Some goals are immediate others are long term. For instance the father of a family may have two major goals firstly to remain grouped with his family and secondly to reach the next exit door.

6.3 Space

The Space is an object embedding all geometrical information to be used by supervisor or agents. The top most object used by the space is a Zone. A Zone includes links to other geometrical data as Walls, Passages or Obstacles. A Zone has also a Status (for instance muster station or stair) and States (under fire, non horizontal floor). See Figure 8.

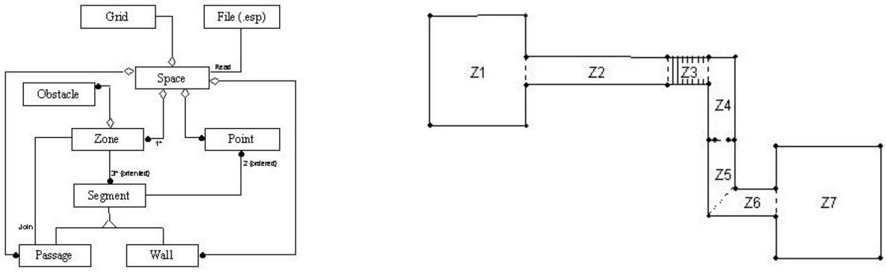

Figure 8: Schema and example of a Zone.

7. Conclusion and perspectives

A first implementation of the SPECS project has been developed yet. The project will run for one more year that will be dedicated to add more intelligence and human behaviour in the agent model. On major aspect of a such development is to validate the model. For that evacuation drills are planned. The two first drills will be carried out on HSC (a 1000 passengers one and a 1200 passengers one). The next drills would be planned on cruise liners. But one must bear in mind that such simulators would give just approximate values (as evacuation time) which must be obtained only with many different populations and scenarios to give average values. An interesting set of results would be the qualitative ones as finding out the bottlenecks or the fluidity of pathways.

For the future it has been planned to enlarge the simulation scope to the movements near the show rooms on board cruise liners or embarkation/disembarkation. The French Navy has also mentioned the interest of a such approach for simulating red alert codes, fire extinguishing and embarkation/disembarkation as well.

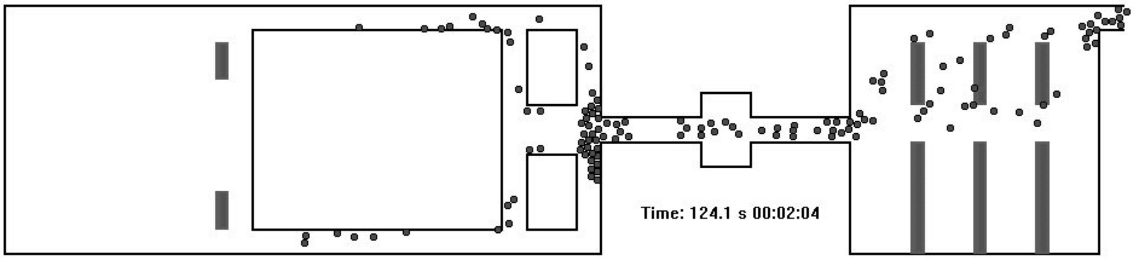

Figure 9: A sample visualisation of the simulator

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