Emergency Control in Shipyard Safety Systems*

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Abstract

Large shipyards for gigantic cruise ships require a special attention to safety due to the huge number of workers involved and to the complex structure of spaces. A critical issue of such environments is to keep the environment under control to avoid a disordered evacuation in case of an emergency. After introducing the basic issues related to safety in shipyards, we discuss the design of an information system for checking the shipyard safety status, supporting synthetic information visualization techniques about escape routes and dynamic evacuation plans. We discuss also the problems of communicating with workers in case of evacuation using visual cues to signal the correct escape routes.

1. Introduction

Large shipyards for gigantic cruise ships require a special attention to safety due to the huge number of workers involved, the complex structure of spaces, the large range of activities performed inside, and the spread in people ability to react to adverse situations. One of the most critical problems to be faced in case of an adverse event is the evacuation of workers. Any satisfactory solution to this problem is based on the possibility to drive the evacuation in an ordered way. Conversely, the most critical situation is to face a disordered evacuation, defined as a type of evacuation which adds damages and injuries to people beyond those due to the disaster.

At the Computer Science Department of Ca' Foscari University in Venice, Italy, we have developed a study about shipyard safety systems with Fincantieri SpA, the largest Italian shipbuilding company. The study aimed to design: (a) a comprehensive information system for monitoring the shipyard in normal and emergency situations; (b) a set of visual interfaces helping persons in charge of safety to get a synthesis of the escape routes situation; (c) algorithms for computing dynamic evacuation plans; (d) personal devices and visual cues to drive workers to safe places in case of emergency. From the perspective of the emergency responsible, the main goal of a safety system is to overcome the limits of current practices, based on static evacuation plans and large signboards, whose size and content is defined by a set of official regulations, but that do not adapt well to the shipyard dynamics. During the building of an environment wide and complex like a cruise ship plans must be changed dynamically with the evolution of the environment itself and the degree of completion.

In this paper we focus on the issues related to the design and management of information about the ship status during its building, and to the the visual representation of critical situations that could lead to emergency problems.

2. Regulations about shipyard safety

The prevention of emergency situation is ruled in Italy by Law 626 [1], which has introduced professional roles devoted to safety control and environmental requirements targeted to risk protection. Among the duties of the emergency responsibles, the most important are risk evaluation, the adoption of suitable measures to protect the yard and the people working in it, and the continuous monitoring of the work places. To achieve their goal, emergency responsibles and emergency workers must be supported by information management systems specifically targeted to the yard environment.

In case of emergency, Law 626 defines a number of concepts and procedures targeted to evacuate the workers by driving them through safe escape paths under any adverse condition. To this end, qualitative as well as quantitative parameters are associated to the escape paths and must be monitored to assure a continuous and up-to-date assistance to the workers in danger. The parameters describe features such as the level of risk of the places, the number of different escape routes, the width and capacity of the doors, passages and stairs (called *checkpoints*, their features are discussed in Section 5); they also constrain the presence of oc-

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clusions due to work progress and define the size and shape of the signboards used to signal the escape routes. Such regulations apply during ship building in order to guarantee that suitable escape routes exist from any place, sized on the presence of workers. At the same time, they allow a safety responsible to check if some limit is trespassed, providing the means for restoring a safe configuration.

Law 626 applies to every type of building. As a shipyard presents specific problems due to the pervasive use of metal as building material, and to the high risk of fire caused by fuel operated tools, a set of international regulations also apply, called SOLAS (*Safety Of Life At Sea*) [2]. SOLAS regulations define primarily parameters related to fire resistance, which evolve as a deck environment, initially empty, is progressively populated with halls, cabins, rooms, replacing a large open space with small closed ambients. SOLAS rules therefore progressively overlap the rules defined by Law 626 as building progresses. This situation, if not properly driven, may cause conflicts rather then reinforce safety, also because the risk evaluation made at design time must be continuously compared with the actual work progress.

3. Safety constraints

Besides architectural issues deriving from the frequent changes in the spatial configuration, three classes of constraints are relevant to safety.

Technical constraints. Deploying communication and sensing infrastructures is difficult due to the dynamics of the environment. Large spaces being progressively split into small closed environments, cables and sensors cannot be placed freely; moreover, the large amount of metal used limits radio communication.

Human constraints. Workers in a shipyard are very heterogeneous, coming from many countries, with different base cultures and different skills. As many as 70 different languages have been counted, English being often unknown; emergency messages might be misunderstood, or not understood at all.

Organization constraints. Changes in the environment are recorded with variable delays, thus leading to inconsistency between the ship state known by the persons in charge of safety and the real state, possibly suggesting emergency actions that refer to an outdated ship configuration. The most critical concern is that workers often do not know the real danger level to which they can be exposed, possibly taking wrong decisions in case of emergency.

Figure 1 shows four views of a shipyard illustrating typical cases that can affect safety. The four pictures refer to normal, allowed situations, not to exceptional or incorrect situations. The top left picture shows one of the staircases external to the ship hull, giving access to the decks. The

Figure 1. Views of a shipyard

stairs are not connected to every deck, resulting in more articulated routes to escape on ground. The top right picture shows a deck hosting the passenger cabins before walls' installation: the environment is easy to walk, but lacks precise reference points. The bottom left picture shows the same deck after cabins' mounting: places and routes are clearly identifiable, but the narrow passage can be difficult to traverse in emergency due to partial occlusion caused by carts and building materials. Finally, the bottom right picture shows a staircase passage closed by a safety ribbon, hence not usable.

4. Evacuation management

The main goals of a correct evacuation are to be fast and ordered, to give correct information to people in danger, and to keep control over the environment. They are achieved by a correct mix of prevention and intervention. Prevention mainly requires the analysis of the potential sources of emergency problems, through a network of sensors monitoring the state of the ship [3]. Intervention requires fast delivering of correct information, as well as the limitation of damage propagation with physical and organizational means.

Therefore, an evacuation management system operates in two distinct phases: observation time and emergency time.

Observation time. During the normal work information about the ship state is collected and processed, generating knowledge about the workers flows and the rooms occupation. This phase prepares the system to plan an evacuation in case of emergency.

Emergency time. The system delivers reliable information about how to leave the ship in safety, providing both on-

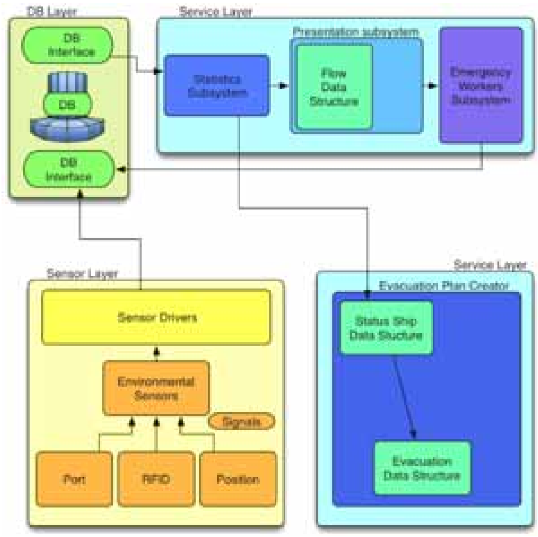

Figure 2. The emergency management system architecture

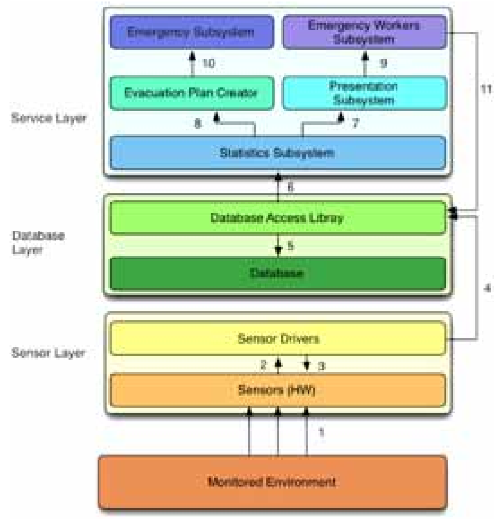

Figure 3. Information flow among the system components

board emergency workers and rescue teams with detailed information on the state of the ship, on the evacuation progress and on the number of saved people.

Both phases rely on the management and the delivery of critical information, hence depend on how the information is presented, since an emergency situation benefits from pre-attentive stimuli and unbiased signals universally interpreted.

5. The emergency management system

A ship is spatially organized in a three level hierarchy [4]: *decks*, which mark a vertical decomposition, *main vertical zones* (MVZ) corresponding to the longitudinal watertight compartments, and *rooms*, like halls and cabins, which are the areas in a MVZ which can be traversed in case of an emergency, if free from temporary occlusions. Locations in a ship are thus identified by three coordinates related to the deck, the longitudinal frame (counted onward and backward from the rudder), and the ship side (left, center, right).

Two other elements are of primary importance for monitoring the environment and guiding the workers in case of emergency: the *checkpoints* and the *well known points*. The simplified concept of communication passage between two environments used in buildings, e.g., a door, is unsuitable in a shipyard, due to the large number of types: doors, openings, stairs, steps, etc.. The concept of checkpoint (CKP) is introduced to define any passage in the environment through which the number of persons crossing at the same time is limited and can be measured. Well known points (WKP) are environments with special architectural and functional clues like theaters, halls, restaurants, lift lobbies, suites, shops, panoramic walks etc., that can easily identified by everyone onboard.

A database is built around such a ship structure. It has a fixed content, describing the ship structure, and a variable content defined by data collected from sensors monitoring the ship areas during building, which change according to the actual ship state.

5.1. The system architecture

The emergency management system architecture is shown in Figure 2. The *sensor layer* manages the hardware and software (drivers) infrastructure needed to store in the database the information on the ship status.

The *statistics subsystem* is part of the *service layer* and manages a data structure containing information about workers occupation and flow through the different ship rooms. Raw data are read from the database and processed to inizialize the statistics subsystem. The *presentation subsystem* uses information from the statistics subsystem and from sensors to create visual maps about the ship and workers situation.

The *evacuation plan creator* computes the best escape ways, storing the information in a data structure that will be used by the *emergency workers subsystem*.

In case of emergency, the emergency workers subsystem uses the data provided by the evacuation plan creator to signal the best escape ways through the environment devices

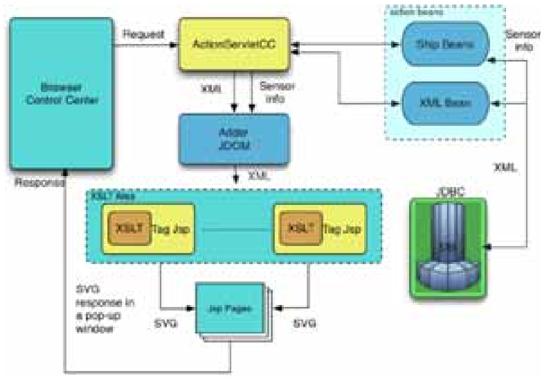

Figure 4. The control center

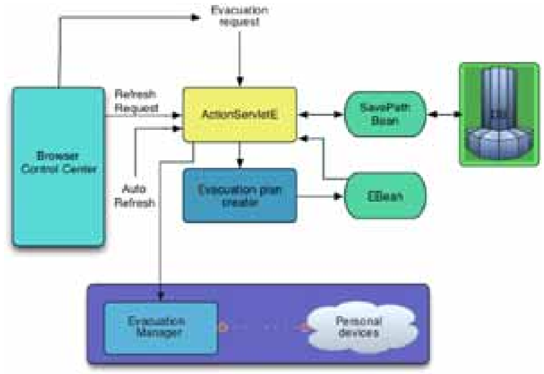

Figure 5. The evacuation plan creation

located in proper places along the escape routes, and possibly through the portable devices worn by the ship workers.

5.2. The information flow

Figure 3 illustrates the information flow between the sensor, database and service layers. The numbers in the following description match the numeric labels on the arcs of the figure. (1) The sensors monitor the workers' location inside the environment. (2) Signals coming from the sensors are processed and converted into usable information; (3) sensors can be configured according to the progression of the building. (4) Sensors send updated information to the database. (5) The database is constantly updated to reflect the current ship situation both in normal situation and in an emergency situation, concerning ship workers, onboard emergency workers and rescue teams involved. (6) The statistics subsystem creates and stores the data structures containing raw information related to people's flow, overcrowding and ship status. (7) The raw statistic data are combined and interpreted to provide meaningful and reliable information to the onboard emergency workers. (8) Collected statistic data are also used to create an evacuation plan, dynamically updated as the workers flow changes. (9) Visual information is presented on the personal devices of the onboard emergency workers. (10) If the ship must be evacuated, visual information about the safe escape routes is sent to the emergency subsystem that manages the emergency panels and the workers personal displays. (11) Feedback is sent to the emergency database in order to identify critical points such as persisting overcrowding, occlusions and changes in the escape routes due to the emergency evolution.

5.3. The emergency control center

Figure 4 shows the control center operations. The emergency responsible queries the system about the status of a specific ship area. A control servlet receives the request and activates two components that manage the occupation indices of the ship areas (*Ship bean* component), as described in Section 6, and the ship planimetry (*XML bean* component) expressed in a XML dialect and stored in the DB. An *Adder* component superimposes the two information by modifying the ship planimetry to add visual information about the current workers occupation and flow [5]. The result is translated to SVG graphics, visualized in a browser window in the control center.

Emergency plans are maintained starting from initial plans defined according to the official safety regulations. They are periodically updated as the ship building proceeds and the occupation of the shipyard areas evolves. Figure 5 shows a fragment of the system devoted to plan update. Information about the current ship status is extracted from the DB and passed to an emergency plan creator, an algorithm that builds a network of connections among nodes representing the locations that can be traversed in emergency. The arcs are labeled with cost values that are function of several variables: the most important are the properties of material as defined by the SOLAS regulations, biased by the knowledge about the current emergency dynamics and the people flow. Due to space limitations we do not elaborate on this algorithm, but it's worth to note that, since it must be fast and it must converge to a solution, euristics are adopted to speed up the computation, even if they do not provide optimal solutions.

6. Checking occupation and people flow

Two synthetic features are able to anticipate critical situations if kept under continuous control: *congestion index* and *flow index*, respectively measuring the ratio between people and environment size and capacity (showing overcrowding), and between people flowing through passages and passage capacity (showing critical situations due to es-

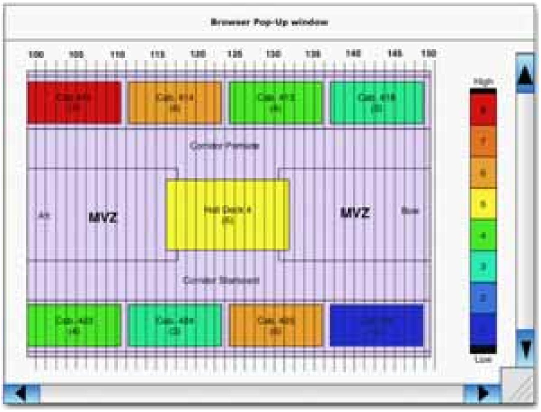

Figure 6. The interface for occupation control

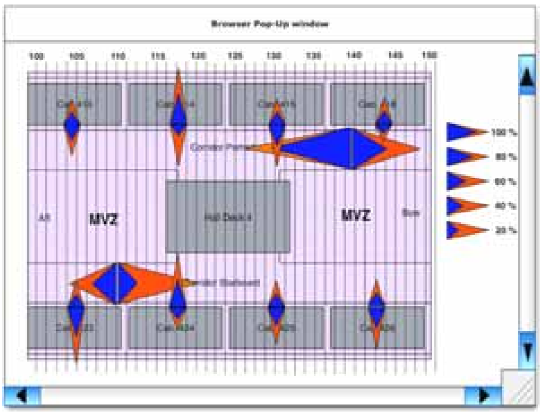

Figure 7. The interface for people flow control

caping persons congestion). In most cases the capacity of environments and passages is fixed by safety regulations, but the presence of temporary occlusions due to building material and the reaction of persons to an emergency situation might reduce the capacity and cause the limits to be surpassed.

To display the ship environment visual information processed by the sensor level is overlapped to the ship map. Visualization is thus linked to the ship structure, and may concern a bridge, a MVZ across all the bridges, a MVZ of a single bridge, or the whole environment of a bridge (least level of granularity).

Information about occupation is represented using colors; each color represents a different level of occupation, as defined by a legend on the right side of the display. Warm colors represent high workers concentration, cold colors represent low workers concentration. In Figure 6 the rooms of a MVZ are colored and every room displays the number of persons inside. In such a way both qualitative and quantitative information is displayed, highlighting the real danger level.

The representation of workers flow is based on the checkpoints. Every checkpoint has a theoretical capacity: the number of persons that can cross it in a unit period of time without danger. Work tools and materials laying in the environment can reduce the checkpoint capacity, so we must know which is the real capacity and how much it is reduced with respect to the theoretical capacity. Both must be displayed to identify situations where the current state of an environment or of a checkpoint could increase the risk level and lessen the evacuation speed. A similar concept is the comparison between the current persons flow and the supported flow as defined by the actual capacity, to identify situations where the dynamics of workers moving could create bottlenecks.

These two pairs of measures are represented using *flames*, two overlapped triangles of different color: blue for the theoretical capacity, red for the real capacity (Figure 7). In a similar way, green and red flames visualize the ratio between the actual flow and the real capacity. Flames are drawn on the ship map, aligned with the checkpoints. The triangle vertex represents the flow direction. The theoretical capacity is represented in the background since it is alway greater or equal to the real capacity, and the overlap between the triangles immediately shows their relationship.

7. Communicating with workers

Most of the information about the ship actual configuration collected during the prevention phase is used to compute and communicate to workers the escape routes in case of emergency. Such information, and the way of presenting it, depends on technical radio communication limits and on some non technical issues.

Workers usually do not know the whole ship but only the part in which they work. Suggesting them a path through unknown ship areas increases the risk; longer escape paths can be safer if they cross only areas to which workers are accustomed, where they can find known visual cues.

Different ship areas are exposed to different risk levels. Normative institutions have issued a classification of danger in different environments. A good escape route crosses areas with decreasing danger level.

Since people work in groups, the evacuation procedure is safer if during the escape the cohesion of the group is maintained. This principle is very important because the ability to help each other is increased by people being used to work together, by speaking the same language, by being used to understand each other, and by being able to integrate their partial knowledge of the environment into a more complete view of the situation.

To signal the escape routes three issues are important: (1) to take care of the changes in the environment due to the building progress, from a skeleton of wide spaces to a complex structure of small rooms, requiring to adapt the granularity and the range of the signals; (2) to differentiate the stimuli used to signal escape routes and wrong paths, using visual signs for positive stimuli and auditory signs for negative stimuli; (3) to avoid the use of text in favor of graphics and symbols independent from specific languages and cultures.

According to these issues, we have proposed two approaches: a weak approach and a strong approach, differentiated by the spatial granularity of signs and information delivery. A strong approach requires positioning a larger number of visual escape signs, and such positioning cannot be done in a highly dynamic and highly incomplete environment. A weak approach is based on fuzzy cues which refer to a few well known locations, easy to identify according to their function. From a general point of view, during the building of a ship the system should evolve from a weak to a strong approach. During a simulation it was evident that due to the little detail present in initial phases of ship building, environments are poorly distinguishable unless they are focal points in the ship (e.g., a hall, which can be easily recognized even if incomplete), or are connection nodes, such as stairs and elevators. Such environments are generally known by all workers, and being a few (with respect to cabins and corridors) are easily identifiable, therefore are marked as well known points.

8. Discussion

The evolution of an event like a fire is not impulsive or instantaneous. It starts in a localized area and may extend potentially to all the ship. But its speed allows people in charge of safety to adopt local strategies and to follow its evolution, starting with the evacuation of a limited number of people close to the fire center, and proceeding to a total evacuation only if the event cannot be controlled. A plausible strategy can be based on three elements: (1) An evacuation signal (visual and/or acoustic) must be forwarded only to people inside the area subject to an immediate risk, through the personal device and the signs in the focal locations. (2) A feedback signal must be received by the people in charge of the emergency management, by monitoring the position of people at risk, checking that they are moving in the right direction. (3) In case the feedback shows immobilized persons, personal devices should be used as beacons to guide the rescue squad.

The work presented here has focused mainly on the design of the information system able to provide timely information for knowing (and managing) the risks due to an emergency, and on the visual aspects of emergency information management. Future work will explore in details the dynamics of emergency and the communication between the control center and the workers. We can anticipate some themes that deserve attention.

Sensor reliability. Sensors measuring the workers presence and flow could be damaged by a fire, creating critical holes in the monitoring of the evacuation process. Damage could prevent data to be read, but could also cause the transmission of altered data. Hence, diagnostic functions must check if the sensors work correctly. Besides using redundancy and transmission channels devoted to check the sensor availability, the shipyard environment is equipped with many types of sensors, among which the fire and smoke detectors are the most reliable due to their primary importance in detecting emergencies. They can be used to circumscribe the areas whose sensing information requires further check in case of a fire.

Signboards, public displays and personal devices. While large electronic displays could be useful for delivering public information during normal operations, their use is not advisable in emergency because they violate two important requirements: (1) since the environment changes continuously, there is a high risk to damage devices devoted to emergency information, whose position must change with the building progress; (2) during an evacuation visual stimuli (and audio stimuli, which are not described here but have been considered in our work) are very simple, e.g., based on colors matching the escape routes, and personalized according the path the worker is following. They are better identified through personal devices and simple color marks, e.g., with laser-like light that can be seen also in presence of smoke.

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