Resilience Management Guidelines

Toolkit

VERSION
Version 1.0

DATE
05-Dec-2017

ABSTRACT
The DARWIN project aims to develop state of the art resilience guidelines and innovative training modules and tools for crisis management. The guidelines, which will evolve to accommodate the changing nature of crises, are developed for those with responsibility of protecting the population or critical infrastructure/services from policy to practice.

The main purpose of this deliverable is to describe two tools associated to the DARWIN Resilience Management Guidelines (DRMG). The DRMG include Concept Cards (CCs) with interventions associated to specific resilience concepts.

This deliverable is composed of the following main items:

1. Simulation environment to support uptake and facilitation of the DRMG
2. DARWIN serious -games based in virtual reality

Readers such as critical infrastructure managers, practitioners and front-line operators may use this document as overview of these tools. The simulation environment can serve as pre- and de-briefing tool for different scales of operation exercises while serious games can be used as introduction to concept cards. The document aims to enhance understanding on resilience management during crisis and everyday situations. Readers from the DARWIN project can use this document during evaluation or workshops associated to the development of resilience management guidelines.

KEYWORDS:
Resilience, Resilience Engineering, Crisis Management, Serious Games, Discrete Event Simulation

DELIVERABLE ID
D3.3

SYGMA ID
D10

DISSEMINATION LEVEL
PU

DELIVERABLE TYPE
R/OTHER
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

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<th>SECURITY BOARD REVIEW REQUIRED?</th>
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The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

**Release history**

<table>
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<th>VERSION DESCRIPTION / MILESTONE DESCRIPTION</th>
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<td>0.1</td>
<td>13-December-2016</td>
<td>PCOS proposed</td>
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<tr>
<td>0.5</td>
<td>23-Nov-2017</td>
<td>Intermediate proposed</td>
</tr>
<tr>
<td>0.6</td>
<td>29-Nov-2017</td>
<td>External revised</td>
</tr>
<tr>
<td>1.0</td>
<td>05-Dec-2017</td>
<td>Released</td>
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*The project uses a multi-stage internal review process, with defined milestones. Milestone names include terms (in bold) as follows:

- **PCOS proposed**: Describes planned content and structure of different sections. Document authors submit for internal review.
- **PCOS revised**: Document authors produce new version in response to internal review comments.
- **PCOS approved**: Internal project reviewers accept the document.

- **Intermediate proposed**: Document is approximately 50% complete – review checkpoint. Document authors submit for internal review.
- **Intermediate revised**: Document authors produce new version in response to internal reviewer comments.
- **Intermediate approved**: Internal project reviewers accept the document.

- **External proposed**: Document is approximately 100% complete – review checkpoint. Document authors submit for internal review.
- **External revised**: Document authors produce new version in response to internal reviewer comments.
- **External approved**: Internal project reviewers accept the document.

- **Released**: Executive Board accepts the document. Coordinator releases the deliverable to the Commission Services.
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

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<tbody>
<tr>
<td>AAA</td>
<td>A triple A game, analogous to a « blockbuster » movie.</td>
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<td>ACC</td>
<td>Area Control Center</td>
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<td>ANSP</td>
<td>Air Navigation Service Provider</td>
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<td>AP</td>
<td>Assembly Points</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>ATM</td>
<td>Air Traffic Management</td>
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<td>CC</td>
<td>Concept Cards</td>
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<td>CPX</td>
<td>Command Post eXercise</td>
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<td>DCoP</td>
<td>DARWIN Community of Practice</td>
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<td>DES</td>
<td>Discrete Event Simulation</td>
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<tr>
<td>DIS</td>
<td>Distributed Interactive Simulation</td>
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<tr>
<td>DoA</td>
<td>Description of Action</td>
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<tr>
<td>DR</td>
<td>DARWIN Requirement</td>
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<td>DARWIN Resilience Management Guidelines</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<td>HAL</td>
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<td>HTTPS</td>
<td>Hypertext Transfer Protocol Secure</td>
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<td>IoT</td>
<td>Internet of Things</td>
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Table 2: List of terms

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<td><strong>MQTT</strong></td>
<td>Message Queue Telemetry Transport</td>
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<td><strong>PA</strong></td>
<td>People Allocation</td>
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<td><strong>RD</strong></td>
<td>Ressource Deployment</td>
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<td><strong>TCP/IP</strong></td>
<td>Transmission Control Protocol / Internet Protocol</td>
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<td><strong>TTX</strong></td>
<td>Tabletop eXercise</td>
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<td><strong>VR</strong></td>
<td>Virtual Reality</td>
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<td><strong>WP</strong></td>
<td>Work Package</td>
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<td><strong>3D</strong></td>
<td>Three Dimension</td>
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**DARWIN DRMG**

**DARWIN Manifesto**

The DARWIN Resilience Management Guidelines (DRMGs) consist of guiding principles to help or advice a certain organisation in the creation, assessment or improvement of its own guidelines. Such principles should help the organisation in developing a critical view on its own crisis management activities (management of resources, procedures, training, etc.) based on resilience management concepts.

It is important to underline that the DRMGs could become complementary to guidelines, procedures and practices already present in a certain organisation, but they are not intended to replace them.

Consistently with this nature, the DRMGs are mainly addressed to policy makers, decision makers and managers at different levels in an organisation. They can only indirectly affect the activities of front line operators or first responders in crisis management, since these actors are users of those guidelines, procedures, practices that may have been redesigned or generated ex novo, after the adoption of the DRMGs by their organisation.

**Minimum Viable Solution**

Also known as minimum viable product (MVP) is the set of minimum set of features required to test or experiment a solution. Its purpose is to get through the “build-measure-learn feedback cycle as quickly and efficiently as possible. The DARWIN project proposed this solution based on interactions with experts (managers and...
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<td>front line operations). This approach contrast the traditional product development of designing, performing preliminary and critical reviews, producing and testing and perfecting the product. The lean start up emphasises interaction with market to minimize efforts that could be wasteful in terms of addressing customer or market assumptions that are incorrect. Using minimum viable solutions, we emphasize on exploitation by proposing realistic solutions from the development phases.</td>
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<tr>
<td>Needs</td>
<td>Represent something that is essential for someone to be able to achieve a certain goal or task. The ultimate goal of resilience could be thought of as ensuring performance, safety and security.</td>
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<tr>
<td>Practices</td>
<td>Represent a solution that has been incorporatedimplemented in a real environment.</td>
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| Resilience         | The term resilience is increasingly popular and has many definitions and understandings. The DARWIN project builds on systematic literature review on journals addressing resilience for crisis management, consortium knowledge and experience in the areas of Resilience Engineering and Community Resilience. DARWIN relates to proven resilience abilities:  
  • Anticipate threats, opportunities and cascade effects. It is not only about identifying single events, but how parts may interact and affect each other.  
  • Monitor in a flexible way means that the system’s own performance and external conditions focus on what it is essential to the operation  
  • Respond and adapt to expected and unexpected crisis in a robust and flexible manner. The system is designed to provide a limited range of responses, there is still a necessity to adjust responses in a flexible way.  
  • Learn and evolve from experience of actual events, successes and failures what to learn and how the learning is reflected in the organization. |
| Resilience Management | Resilience management addresses the enhancement of the abilities of an organisation to sustain adaptability and continue operations as required when facing expected and unexpected events. It includes “everyday operation” as this information is essential to ensure that the organisation functions. This information includes how multiple activities work together to produce successful outcomes for different kinds of systems and organisations at different levels. |
Executive Summary

This deliverable will explain in detail the chosen approach for a simulation environment and the DARWIN serious games. These developments within the DARWIN project will help to facilitate the uptake of the DARWIN Resilience Management Guidelines (DRMG) and the derived Concept Cards (CC).

These developments will contribute to the overall DARWIN project objectives:

- **O2** “To enable use of resilience guidelines in non-crisis situations, for purposes of: 1. Basic learning and familiarisation; 2. Practical training, based on simulation techniques (including “serious gaming”).”
- **O5** “To build on “lessons learned” in the area of resilience by: 1. Identifying criteria that provide indicators of what works well and what does not; 2. Applying these criteria in defining and evolving resilience guidelines.” and
- **O7** “To establish activities that will lead to project results being adapted to, and later adopted by, practitioners in domains other than the two used in the pilots.”.

The main WP3 objectives:

a) **Define the process and provide the tools for easy accessibility of guidelines**

b) **Adapt available simulation and serious gaming tools to support the utilization of the guidelines**

c) **Provide training material for resilience management addressing the needs of different stakeholders**

have been achieved – a) and c) are described within D3.4 while b) is addressed by this document. The prototypes of the tools (simulation and serious games) are now ready to be used to support the utilization of the guidelines and will therefore provide a tremendous part of the DARWIN project outcome.

**About the project:** The DARWIN project aims to develop state of the art resilience guidelines and innovative training modules for crisis management. The guidelines, which will evolve to accommodate the changing nature of crises, are developed for those with the responsibility of protecting population or critical services from policy to practice.

The guidelines address the following resilience capabilities and key areas:

- **Capability to anticipate**
  - Mapping possible interdependencies
  - Build skills to notice patterns using visualisations

- **Capability to monitor**
  - Identify resilience related indicators, addressing potential for cascade
  - Establish indicators that are used and continuously updated

- **Capability to respond and adapt (readiness to respond to the expected and the unexpected)**
  - Conduct a set of pilot studies
  - Investigate successful strategies for resilient responses

- **Capability to learn and evolve**
  - Explore how multiple actors and stakeholders operate in rapidly changing environments
  - Enable cross-domain learning on complex events

- **Key areas:** social media and crisis communication; living and user-centred guidelines; continuous evaluation and serious gaming
1 Introduction

One aim of the newly developed DARWIN Resilience Management Guideline (DRGM) is that they are easy to understand and that their effect can be measured. The DRMG are tested in the pilot trials and afterwards evaluated. The evaluation and the pilot trials are supported by WP3 and the tools that have been generated therein.

1.1 Purpose of the document

This document is the report on DARWIN’s developments regarding simulations and serious games. The simulations were developed by TUBS TU Braunschweig to support the pilot trials, whereas SINTEF focussed on the generation of serious games. This deliverable focuses on the detailed technical description of the simulation modelling and the serious games whereas D3.4 “Resilience Management Concepts and Application Tutorials” will cover the training material package. The tools described in this document can be used during training (serious games) or after action reviews (simulations). Therefore this document serves as a technical reference to the developments of the simulation tool and the DARWIN serious games.

1.2 Authorship and licenses

The two partners involved in this document have equally shared the introductory and summary part of this document. The simulation environment has been developed and described by TUBS while the review and adaption of serious games to the DARWIN approach has been tackled by SINTEF.

The simulation environment will be made available only as part of consultancy projects as the detailed handling and modelling of the needed processes is too complex to provide it on an open source platform. Additionally a MATLAB ® Simulink commercial license is needed as the event driven models are implemented in this software package.

The DARWIN serious games are released under the Creative Commons CC-By 4.0 license. Thus, people using the DARWIN serious games can: share, copy and redistribute the material in any medium or format. Adapt, remix, transform, and build upon the material for any purpose, even commercially. The attribution is that people using the guidelines must give credit to the DARWIN project and EC support. No warrants are given. However, the DARWIN serious games contain assets and software components owned by third-party with different licensing models. These assets and software components are not necessarily released under the Creative Commons CC-By 4.0 and their sources are not released within the DARWIN serious games sources. Compiled versions of the DARWIN serious games contain compiled version of these assets and software components and anyone can share, copy, redistribute, adapt, remix, transform, and use the compiled serious games commercially.

1.3 Intended readership

The main readers of this deliverable are the users of the tools developed in this task. These users might be managers or people from the Research and Academia Community (for the simulation environment) or even a broader target group for the serious games. More details to the discussion on the readership can be found in chapter 4.
1.4 Structure of this document

The structure of this document is straightforward. In chapter 2 the simulation modelling is described followed by chapter 3 on DARWIN serious games. Chapter 4 gives a discussion on the two different approaches. Chapter 5 gives an outlook on further developments and possible usage and chapter 6 will cover the conclusions of the authors.

1.5 Stakeholder involvement

The involvement of end-users and stakeholders is central to achieving the development of the DARWIN Resilience Management Guidelines (DRMG), which is the main objective and core result of the DARWIN project. Their involvement will ensure transnational, cross-sector applicability and long-term relevance, and to secure their input and involvement in the project the DARWIN Community of Practitioners (DCoP) has been established. The DCoP includes relevant stakeholders and end-users representing different domains and critical infrastructures as well as resilience experts. A dedicated workshop with DCoP members is planned for the upcoming DCoP workshop in March 2018. The tool development and its description in this document will not cover the results of this workshop. These results will be presented in the deliverable D4.4.

1.6 Relation to other projects and initiatives

The simulation and serious games can be of interest to other DRS-7 projects to map complementariness and gaps on tools associated to resilience management guidelines (RESOLUTE\(^1\), SMR\(^2\), IMPROVER\(^3\), RESILIENS\(^4\)). Games based on virtual reality and augmented reality are gaining attention thus collaboration and synergies are identified with a Swedish project, project coordinator participates to the DCoP - CCRAAFFFTING (Creating Collaborative Resilience Awareness, Analysis and Action for the Finance, Food and Fuel System in INteractive Games) and IN-PREP new H2020 project invited to the DCoP. The basic idea is projects with longer duration than DARWIN such as CCRAAFFFTING and IN-PREP can benefit from developments documented in this deliverable.

1.7 Relationship with other deliverables

The interdependencies of the tasks of WP3 with the other work packages and tasks.

This document will describe the simulation tool (chapter 2) and the serious games (chapter 3) which are project outcomes as themselves. They will help to facilitate the usage of the DARWIN Resilience Management Guidelines after the project lifetime. Additionally they will support the training material and courses described in D3.4 “Resilience Management Concepts and Application Tutorials” and finally they helped during the project in evaluating (parts of) the guidelines. This evaluation support campaign has been performed after the pilot trial in Sweden. A brief description of this supportive activity can be found in chapter 2.1.4.1. The work described in this document was based on the outcome of WP2 with the DRMG and the respective Concept Cards. Additionally the simulation environment has been used the Swedish Pilot Trial as scenario to demonstrate its possibilities and opportunities.

\(^1\) [http://www.resolute-eu.org/](http://www.resolute-eu.org/)
\(^2\) [http://ciem.usa.no/project/smart-mature-resilience](http://ciem.usa.no/project/smart-mature-resilience)
\(^3\) [http://improverproject.eu/](http://improverproject.eu/)
\(^4\) [www.resiliens.eu](http://www.resiliens.eu)
The work presented in this document received inputs from the following deliverables:

- **D1.3 – Practitioner and academic requirements for Resilience Management Guidelines**: This deliverable provided the various types of requirements for the development and the evaluation of the guidelines.
- **D2.1 – Generic Resilience Management Guidelines**: Resilience concepts to be used for the simulation and serious games.
- **D4.1 – Evaluation Plan**: In this document, the first scenario descriptions are given, but were refined in D4.2.
- **D4.2 – Initial Evaluation of the Guidelines**: This deliverable encompasses the refined scenario descriptions that are necessary as a first step to decide for which scenarios the tools will have to be configured.

The tools presented in this document provided inputs to the following deliverables:

- **D3.4 - Resilience Management Concepts and Application Tutorials**: the tools described in D3.3 will support the training courses and material described in D3.4.
- **D4.4 – Final guidelines evaluation report**: D4.4 is the final evaluation of the guidelines. The simulation environment has been used in the evaluation phase of the Swedish Pilot Trial and will therefore serve as input for this deliverable as well.
- **D6.6 – Presentation of the project**: The tools developed in WP3 and described in D3.3 will support the presentation of the project. The simulation environment will help during DCoP events, for example, to demonstrate the dependencies of different stakeholders from different strategies to approach bottlenecks or other critical process elements. Therefore the simulation environment will strongly support the understanding and facilitation of DARWIN products.
- **D6.8 - Plan for business and exploitation of the results**: The tools will be used by the respective partners after the project duration. The detailed business plans for this usage will be described in D6.8.

### 1.8 Addressing D1.3 requirements

In the first work package of the project, requirements were developed for the DRMG as a whole and for specific aspects like the development process or the evaluation. These requirements are published in D1.3 [4].

In Table 3 those requirements are shown that are applicable to the tools developed for the resilience management guidelines toolkit. The numbering of the requirement follows a scheme that DReq-ID is the “DARWIN Requirement Identification” that is composed of a “DR” and a continuing number. Requirements for specific aspects are numbered additionally with a Requirement-identifier (Req-ID) for these areas. Relevant here are the following:

- Quality Requirements on the Guidelines (GRQ)
- Target Requirements on the Guidelines (GRT)
- Concept Requirements on the Guidelines (GRC)
- Quality Requirements on the Evaluation of the Guidelines (ERQ)
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

The full list of D1.3 requirements is available in Appendix A. The following table presents the requirements that have been identified as relevant for this deliverable, and how they are addressed.

Table 3: Addressing D1.3 requirements

<table>
<thead>
<tr>
<th>Req-ID</th>
<th>Requirement</th>
<th>WPX applicable</th>
<th>Means of compliance / how requirement is addressed in this deliverable</th>
<th>Status*</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRQ-08</td>
<td>The DRMG should contain a training and maintenance package (TMP) that facilitates the introduction of the DRMG.</td>
<td>Y</td>
<td>The virtual reality applications developed in this task are part of the TMP and are being used to help introducing the DRMG.</td>
<td>Achieved</td>
</tr>
<tr>
<td>GRT-05</td>
<td>The DRMG should be adapted to specific domains (health care and ATM), including guidelines for its application.</td>
<td>Y</td>
<td>The tools described in this deliverable were developed with these two domains in mind and will be used to determine the effectiveness of resilience concepts using specific parameters.</td>
<td>Achieved</td>
</tr>
<tr>
<td>GRC-19</td>
<td>The DRMG should support the use of resilience management support systems as a part of everyday practices.</td>
<td>Y</td>
<td>The tools developed here are thought to be included in the training curriculum of the organizations using the DRMG. Thereby, they are meant to be used regularly</td>
<td>Achieved</td>
</tr>
<tr>
<td>GRC-28</td>
<td>The DRMG should specify the need to conduct joint training exercises to ensure efficient collaboration.</td>
<td>Y</td>
<td>The scenarios are designed as joint training exercises on different levels of abstraction.</td>
<td>Achieved</td>
</tr>
<tr>
<td>GRC-31</td>
<td>The DRMG should address different magnitudes of emergencies, disasters and crises in training programs.</td>
<td>Y</td>
<td>The scenarios are designed with varying levels of magnitude.</td>
<td>Achieved</td>
</tr>
<tr>
<td>GRC-32</td>
<td>The DRMG should support design of scenario-based exercises to prepare for worst-case scenarios.</td>
<td>Y</td>
<td>The tools generated in this task are designed to show the effects of worst-case scenarios.</td>
<td>Achieved</td>
</tr>
<tr>
<td>ERQ-03</td>
<td>The evaluation of the DRMG should use scenarios, chosen to stress the resilience ability of the user organizations and to investigate aspects such as the interactions of these organizations with the public and between, to stress risks</td>
<td>Y</td>
<td>The simulation designed in T3.2 detects the bottlenecks and shows the cascading effects in the scenario.</td>
<td>Achieved</td>
</tr>
</tbody>
</table>
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

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<th>Means of compliance / how requirement is addressed in this deliverable</th>
<th>Status*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>identifies and possible cascading effects, and to link to established risk management.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Achieved / Partially achieved / Not achieved
2 Simulation modelling and development

During the evaluation of the resilience management guidelines, simulations are meant to act as a tool to facilitate the assessment of the guidelines (according to the DARWIN DoA). This especially addresses the detection of bottlenecks and subsystem interdependencies. A “What-if” capability of the simulation environment aims to provide an estimation of the implications of particular actions at a given time in order to support the decision making process. When detecting brittleness during the course of the crisis, the simulation is intended to automatically provide appropriate counteractions. Furthermore the simulation will calculate a selected set of system parameters, determined by domain experts, in order to support the assessment of the effectiveness of the applied guidelines. This section describes the definition process for which scenarios simulations will be used and the rationale why an approach of a discrete event simulation was chosen. The modelling approach was derived from the characteristics of the selected scenario and the general requirements as mentioned above.

Furthermore, the modelling will be described and some results of the simulation will be presented.

2.1 Assessment of application in the DARWIN pilot trials

During the course of the project, four scenarios have been defined that will be investigated during pilot trials. The revised scenarios are described in D4.2 “Initial Evaluation of the Guidelines” [6]. In the following, the selection process for which scenarios simulations could have been developed is described.

2.1.1 Scenario 1: Aircraft crashing in urban area close to Rome Fiumicino Airport shortly after taking off

This scenario developed by ENAV, ISS and DBL deals mainly with the coordination of the different stakeholders at the airport of Rome Fiumicino and in the emergency response system, e.g. the airport, the air navigation system provider (ANSP), the aircraft accident investigation board, the fire-department of the airport and the city, police, ambulances and hospitals.

The pilot trial was run as a table-top exercise (TTX) composed of experts of the various stakeholders assessing the situation and describing what actions would be done by the involved personnel.

2.1.1.1 Applicability of simulations in scenario 1

A simulation calculating the arrival times of emergency forces and the distribution of the patients to and the utilisation of the hospitals was discussed. A visualisation is shown in Figure 1.

However, such a simulation was not deemed necessary by the experts executing the pilot trial.
Figure 1: Situational symbolic map of emergency management resources (Map courtesy of GoogleMaps)

2.1.2 Scenario 2: Total loss of radar information at Rome Area Control Centre

The second scenario examines the effects of a total radar blackout in the Rome Area Control Centre (ACC) due to a cyber-attack. Its development was led by ENAV. The pilot trial will be composed of a table-top exercise in which experts play through the communication necessary to manage the air traffic in the concerned area and the actions to get the ACC back online again.

2.1.2.1 Applicability of simulations in scenario 2

In order to have substantial benefit of a simulation tool, a simulation of the airspace on a European scale and the surrounding parts of the world would be necessary. To achieve this, access to international flight plans, the routes of the airspace and its structure would have been necessary. Furthermore, in-depth knowledge of the processes in and between ACCs and other air traffic controllers, e.g. the ones in the towers would have been necessary. Such a simulation would have gone beyond the scope of this work package.

2.1.3 Scenario 3: Disease outbreak during an incoming flight

This scenario deals with the processes that are necessary to keep an evolving epidemic or even a pandemic at bay. It is focussed on the communication between the stakeholders of the Italian and European health system and was devised primarily by ISS.

The connections to the air traffic are of such a way that the so called “patient zero” (the first person with the virus arriving at a certain place) arrived on a plane and that he has passed the virus to other passengers as well.

The pilot trial will be run as a table-top exercise with experts of various health organisations.

2.1.3.1 Applicability of simulations in scenario 3

For such a scenario a simulation of the world-wide air traffic system would have been necessary. Furthermore, the probabilities of transferring the disease and a simulation of passenger transits would have been required. Again, such a simulation would have gone beyond the scope of the project. In addition
such simulations are already available at e.g. the Robert-Koch-Institute [1]. The result of such a simulation can be seen in Figure 2. Therefore such a simulation can be played based on publications without building an own simulation.

![Figure 2: Simulation made by Gomes et al. to show the effects of an Ebola outbreak using an air-traffic model [1]](image)

2.1.4 Scenario 4: Collision between oil Tanker and passenger ferry leaving Gotland islands in severe weather conditions

The fourth scenario was designed by the Swedish partners of FOI and KMC and addresses the issue of handling the collision of two ships in the Baltic Sea with numerous injured people. It was devised as a command post exercise (CPX) that has been run after a number of preparatory lessons and table-top exercises. It focussed on the communication between the involved stakeholders and simulates patient flows and resources used in the crisis response.

In the course of the project the scenario was revised a bit compared to the description in D4.2, but the main topic remained the same. The main differences are that the weather is not severe anymore and that the number of injuries has increased. Furthermore, the ferry moved towards a harbour using its own engines.

Figure 3 shows an overview of the situation during the scenario. The coastal vessels and helicopters moved to the ferry and took the patients depending on their grade of injury to the assembly points (AP) that will have been constructed in the meantime or (by helicopter) directly to a hospital. Throughout the area of South-Eastern Sweden ambulances have been dispatched to the APs and took the injured persons from the APs to the hospitals.

As the ferry moved towards Norrköping harbour, the nearest AP was used for the handover of the patients.
2.1.4.1 Applicability of simulations in scenario 4

A modelling and simulation environment to be used in scenario 4 was deemed valuable by domain experts. In this case, FOI and KMC as organizers of the scenario were involved in that decision. FOI defined the modelling requirements as well as system parameters to be evaluated. The rationale for a predictive simulation to evaluate the guidelines in case of scenario 4 will be explained from the perspective of the involved domain experts afterwards.

The concept of resilience is often related to complex emergency and crisis scenarios. The application of the concept, both for the purposes of education & training and assessment & evaluation in the emergency/crisis management domain, is challenging.

First, the application of the concept is to a large degree context-sensitive, that is, specific for (a) the actual actor (organization) that is applying the concept and its way of operations, (b) the risk/hazard portfolio the actor faces or must handle, as well as (c) the geographical, cultural and political settings in which the actor resides. In other words, there is a number of different ways of how response operations can be managed, how resources can be deployed and used, as well as how needs, goals and risks can be defined and prioritized. This means in turn that “to be resilient” may have different meanings for different actors.

Second, many of the scenarios that the emergency/crisis actors may find relevant have never been handled by the actors. That means that these relevant scenarios might pose new questions concerning resource distribution or operational strategies and goals. Thus, emergency/crisis actors lacking a benchmark or reference for
a) which approaches to manage response operations to such scenarios are actually suitable,
b) how resources should be deployed to achieve best possible use of them, as well as
c) which needs, goals and risks/hazards need to be addressed and with what priority.

Predictive simulations are an important tool in order to address these challenges. They can be used to simulate scenarios that are specific for particular actors in terms of their strategies, resources and risks/hazards. In turn, they can be used to create an understanding of what are the possible outcomes of

a) different priorities and objectives for response operations,
b) different strategies to set up response operations, and
c) different approaches to deploy and use resources.

A simulation environment can be used to generate data of theoretically achievable results in scenarios, that a specific actor has never faced before. These data can be used to support education & training, for example, in table-top exercises. Such environment can also be used to test to what degree an outcome of a response operation is sensitive to how resources are deployed and used. Such a test also serves to identify key elements that need to be in place in a certain kind of response operations in order to succeed. Predictive simulations can be applied to develop routines and procedures to be tested in command-post, functional and full-scale exercises. Another example of how a simulation can be used in the aftermath of a concluded actual response operation, a command-post, or a functional and full-scale exercise, is to identify whether a change in priorities or in the set-up of the response operation, or alternatively, in the resource deployment itself, may significantly change the outcome of the actual operation, or exercise.

Main objectives of this fourth scenario address the evacuation of injured persons to hospitals using a defined set of rescue vessels, helicopters, ambulances in an effective way.

Due to the reasoning of the domain experts and organizers of scenario 4, it was decided to create a simulation for that specific scenario. The simulation aims to support the participants during the debriefing phase of an exercise. By reflecting on the particular crisis management, participants might provide suggestions for improvement of resilient management guidelines related to “adaption relative to events” or “noticing brittleness”.

The latter Concept Card of brittleness deals with the issue of detecting how rapidly the system’s performance decreases when operating close to boundary conditions. D2.1 refers to scenario-based methods in order to “gather various perspectives about brittleness and potential solutions”. Also the collection of information during a crisis for subsequent analysis is addressed. These methods are provided by the simulation. That is to assess the effectiveness of different strategies and to compare actual results of participants (during the trials) with possible achievable solutions of the scenario. Several triggering questions of that Concept Cards are tackled by the simulation such as:

- What were the bottlenecks? For example, how long have rescue ships to wait at the ferry in order to board patients?
- Were we able to adjust resources when needed? For example, are enough ambulances deployed to transport patients from the primary assembly points?
D3.3– Resilience Management Guidelines Toolkit

- Were we able to adjust operations when needed? For example, how effective are different strategies such as transporting patients with helicopters directly to hospitals versus transporting patients to assembly points?

- Were we able to adjust goals and priorities when needed? For example, what strategies are suited best when the reported capacity of particular hospitals suddenly decreases due to local casualties?

- What goal conflicts and trade-offs did we experience? For example, what is the assessment of flight hours of helicopters versus transported patients? Is it reasonable (within the given boundaries of costs) to transport patients of a green triage with a helicopter?

2.1.5 Summary of scenario selection

Even if it would have been desirable to cover more than one scenario a selection had to been made due to the limited resources available. The chosen approach to implement the Swedish scenario (scenario 4) has been discussed on project level as well as on DCoP workshops. The arguments as already laid down in the previous sub-chapters were convincing and were supported by the project team as well as the DCoP members. It has been acknowledged that the basic principles of the simulation environment can be observed and judged based on this scenario. The lessons learned for the other scenarios would have been very beneficial for the project (as feedback for the developed Concept Cards) as well but had to been skipped due to timing and resource issues.

The results of the debriefing phase of the Swedish exercise will be covered in detail in D4.4 as well as an additional exchange with DCoP members during the workshop foreseen in March 2018.

2.2 Modelling approach

To create a modelling and simulation environment that fits the needs of the scenario 4 and the requirements from the DoA, such as detecting brittleness, what-if capabilities or automatic generation of appropriate alternative actions as well, a discrete event approach was chosen which uses the framework of MATLAB/Simulink. That modelling framework provides a drag and drop functionality for convenient evaluation of selected data and a programming environment that enables rapid prototyping. Thus, an adaption of scenario specifications, or the implementation of a different level of detail in selected model parts, on a later stage in the project, can be accomplished with reasonable effort. Discrete event models calculate the system’s state depending on events. Event driven characteristics can be found in process chains systems like traffic or logistic systems.

The Swedish scenario represents such a logistic problem. It has to be noted, the scenario implementation at the current status does not foresee stochastic influences.

Typical discrete event problems such as synchronization, choice, sequence and concurrency of processes and actions can be observed in this scenario. For example, the transportation process of patients can be viewed as an event driven process that is evoked by the end of the boarding procedure of a vehicle and finished when reaching the anticipated target. Generally, in discrete event systems, activities between events will not be depicted and therefore be skipped. It is important to note that during a time step in the
simulation, different system states can occur. This is especially valid with respect to the modeling process since due to the simultaneity of events and therefore states, the sequence of events has to be defined thoroughly.

Figure 4 illustrates the difference between event and time driven systems.

![Diagram](image)

**Figure 4: Differences between TDS and DES**

Generally, the scope of a model is defined by boundaries to other systems, the number of involved actors and their roles, technical system and resources. The level of detail of those elements is also being outlined by the scenario. The so called conceptual model of the scenario aims to represents the relevant operational procedures and resources. The necessary abstraction of the particular elements of the system, to roles and resources, is being carried by the help of domain experts and can be represented by different means such as workflow depictions i.e. flowcharts. This was done in preparation of implementing the model.

The discrete modeling environment embedded in Simulink is called “SimEvents” [3]. “SimEvents” itself provides a variety of discrete event modeling blocks which can be arranged to depict an abstraction of the conceptual model given by the specification of the scenario. Necessary additional functionalities (for example the calculation of the position of the ship, helicopters or rescue vessels) are developed in code and integrated into the model afterwards. The environment allows for a hierarchical modeling and a modular structure of a scenario implementation. Thus, alterations in the level of detail (of specific aspects) can be changed afterwards, or, new modules such as a generic hospital simulation could be added. Currently, hospitals serve as sinks in the model. Although, given the discrete event character of operations at a hospital (flow of patients, treatment at different stations), this part could be intergraded at a later stage as well.

Figure 5 shows a part of the model where the boarding of patients at the ferry is calculated. Here, the particular triage patients are assigned to either helicopters (upper part) or rescue ships (lower part). It illustrates different modelling blocks, subsystems (representing hierarchical modelling) and means of data acquisition. The latter (green and blue blocks for either display or data storage) can be inserted by drag and drop easily at every part in the model which is of interest. Every entity within the model can be observed. For example: for every patient, the different transport legs and the individual transport durations as well
can be witnessed. Since some helicopters and rescue ships are able to board different triage categories simultaneously, the assignment of passengers to the vehicles has to be calculated depending on the underlying strategy.

Figure 5: Example of a model part (boarding of patients at the ferry by helicopters and rescue ships)

The underlying modeling approach applied here is flow based related. So called entities flow as commodities through the system (or network) from one node to another node. For example, a patient at a hospital can be depicted as an entity which is progressing from one station to the next, spending time at a particular place. “SimEvents” uses a transaction based modeling. This depends on events which evoke the advancing of an entity in the network, such as the beginning or the end of a process. In our example, a patient will be kept up at one place until his treatment is finished. This latter event “releases” the patient from that position, or, allows the entity to progress in the model. The movement (or flow) of entities is designed by the arrangement of discrete event blocks, provided by the environment. Thereby an abstraction of the flow of patients or helicopters is created and serves as an intuitive analogy when modeling.
Amongst others, Discrete Event Simulation DES blocks comprises of generators, sinks, servers, gates or queues. Entities can be assigned with attributes. For example, patients who are created at the beginning of the model (at the ferry directly after the accident occurs) are assigned with a specific triage distribution. The patient entities then “wait” at a gate block to be released by an incoming helicopter, in order to be transported to a selected hospital. The process of transportation is modeled by a server. Eventually the patients arrive at a hospital which can be represented as a sink. The patients are transported following the urgency of the triage system to the nearest hospital which has available resources. Different allocation algorithms can be implemented also in the future. Figure 6 and Figure 7 below show exemplary the hierarchical structure of Figure 5 and different modeling blocks such as servers, gates or queues as well. Figure 6 is a subsystem of Figure 5.

Figure 6: Subsystem depiction of the boarding duration of red patients at the particular rescue ship types

Figure 7: Subsystem “Implementation of assigning a given number of patients to a vehicle

A first general modeling example was presented by TUBS at the first DCoP workshop to illustrate the capabilities of the environment and the discrete event approach respectively. Afterwards FOI decided to follow this approach and a first generic and simplified model with assumptions concerning the transport capabilities and number of hospitals was presented by TUBS. Later, a full description of the scenario was given by FOI. This conceptual model was implemented and extended in a first workshop between FOI/KMC and TUBS October this year. Changes were incorporated and a set of system variables, i.e. performance indicators was provided by FOI to be investigated. That is, different combinations of various patient allocation schemes and resource deployment schemes are investigated by means of the simulation.
2.3 Development of the simulation

The discrete event simulation was developed in multiple cycles. First, a coarse set of requirements was devised together with FOI so that a first modelling could be started. After a first example simulation, the set of requirements was refined.

2.3.1 Requirements

The simulation is based on the requirements given in the work package descriptions of the DoA, the results of D1.3 (see above Chapter 1.8) and on the specific condition of the functional model, defined by the domain experts. The latter requirements emerged during meetings and web conferences with FOI as the main scenario planner of the pilot trials. A 15-page document describes the details of the scenario i.e. the functional model which was implemented. It encompasses the locations of different resources, an injured people allocation (PA) scheme and the resource deployment (RD) settings. During a workshop, questions that were raised during the implementation process, such as different transport assignment strategies of particular vehicles, were discussed and are currently implemented.

The main objective of the simulation is to determine, how the patients are distributed to which hospital by which mean of transport as well as the utilization of the transport vehicles respectively.

The scenario and the problem of how to evacuate patients most effectively, tackles the question of optimal resource deployment and patient allocation. The scenario is set up to be deterministic. Resources are comprised of helicopters, rescue vessels, ambulances and buses and have to be assigned to the moving ferry, to different assembly points and to different hospitals as well. Patients are grouped into the triage system, thereby defining their priority during the evacuation process. The different vehicles are described by particular characteristics, such as load capacities (of particular triage patients), cruising speeds (loaded and unloaded), operational times (and ranges) or preparation times.

2.3.2 Modelling

At present, different sets of patient allocations (to particular hospitals) and resources assignments (to particular assembly points or hospital) are defined. The above mentioned criteria are implemented in a generic fashion in order to enable a sensitivity study at a later stage in the project. Other generic parameters involve aspects as the alarm delay of particular vehicles or the velocity of the damaged ferry which is heading to a harbor.

In order to evaluate the performance of a particular course of action, specific indicators, can be defined by the participants and implemented quickly.

Current performance indicators are provided by FOI. Due to the “drag and drop” functionality of the environment, new indicators can be implemented relatively quickly. Implemented indicators address the total time of transportation of patients of particular triage classes to the hospitals or the number of transportation types used during the exercise. For example the number of particular triage patients at the ferry during the course of the scenario were stored, such as displayed in Figure 8 (blue lined blocks). In this
example the utilization of both vehicle classes (helicopter and rescue ship) with respect to the boarding of patients was stored.

The distances and driving durations given in this document, have been calculated using online route planner. It has been assumed that emergency vehicles are able to use the roads as if normal traffic occurs. Furthermore, the routes of the coastal vessels and the ferry use slightly simplified trajectories compared to the sea lanes of the ragged Swedish coast.

The entities of helicopters, ships, ambulances and patients are treated as sources in the simulation, whereas the hospitals are the sinks, as shown in Figure 8.

The patients are divided into four categories:

- Green: lightly injured,
- Yellow: moderately injured,
- Red: seriously injured,
- Black: deceased.

In agreement with FOI, the deterioration of the status of the patients if they are not treated is neglected, but it can be installed in a future version of the simulation if the necessary prerequisites for such deteriorations are provided.

The vessels as well as the helicopters feature realistic parameters about their technical specifications like preparation times after the alert, fuel capacity and consumption, unloaded and load velocities and patient capacity of the particular triage, operational times and ranges.

Currently, 6 different types of rescue ships and 3 different types of helicopters are implemented, as well as ambulances and buses.

![Figure 8: Coarse block diagram of the modelling for the simulation](image)

In the current model, the transport durations of ships and helicopters are calculated by applying great circle distances and the specific characteristics of each vehicle with respect to load capacity, operational range and cruise speeds etc. Since no further information is available, all vehicles (also ambulances and buses) travel with constant speed.
To calculate the duration of rescue vessels and helicopters heading towards the ship, a simple iterative
algorithm was implemented to calculate the best assumption of an interception point. For the sake of
simplicity and calculation speed the simulation step size was set to one minute.

Figure 9 illustrate the interception points during the course of the ship, depicted as white crossed squares.

The environment allows for an easy “drag and drop” data extraction, to be introduced at different parts of
the model. Also, the modeling blocks provide statistic information, such as the length of a queue or the
average duration entities spend in a server. This contributes to a faster data analysis. Errors (such as delays
or malfunctions) could be introduced in the model at different positions too, but are neglected at this
point.

2.3.3 Description of the simulation

The model can be run at different simulations speeds (which include fast time) that can be changed during
the simulation. A configurable map that shows the position of all facilities (such as assembly points,
hospitals, harbors, helicopter bases etc.), as well as of the ferry and all transport vehicles, contributes to
the monitoring of the simulation when seen necessary by the actors.

A further configuration panel allows creating initial conditions for different patient allocation and resource
deployment schemes, which cover all variables introduced above. A next panel allows selecting different
system variables in order to perform parameter studies as well as to define the performance parameters.
Future options could address the access to the allocation and deployments schemes during the simulation
run and the search for an optimum of a specific performance indicator investigating a set of selected
system variables.
Figure 10: GUI of the simulation tool

Besides the motivation for a predictive simulation, to be used in scenario 4, (mainly to investigate

a) different priorities and objectives for response operations,

b) different strategies to set up response operations, and

c) different approaches to deploy and use resources),

another application with regard to the training tool TORC was developed in coordination with SINTEF. Here, the simulation could be used during the game itself to anticipate the outcome of a current course of action and to assess the effectiveness of specific measures, taken by the group of experts during the cycle of TORC. Since the simulation is able to run at different speeds and to provide runtime analysis of selected system variables, participants of TORC could use it during the phase of anticipation and the monitoring of the effects of the collaborative decision making process. Concerning the latter aspect, the simulation would be stopped at a given time step and selected system variables would be adjusted. For example, this could encompass the course of transport vehicles, the number of vehicles, or the capacity of hospitals.
Figure 11: Chronological sequence of red labelled triage patients

Figure 12: Chronological sequence of yellow labelled triage patients
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

Figure 13: Chronological sequence of green labelled triage patients

Figure 11, Figure 12 and Figure 13 above represent a first overview of the course of possibly system variables during a specific patient allocation and resource deployment setting. It has to be mentioned, that due to security issues, results published in this report are based on a slightly altered scenario. Here, mainly resource distributions are changed.

As mention in the example of Figure 5 the number of patients at the ferry is of interest. For example. Figure 11 depicts the number of red patients at the ferry over time. Compared to the yellow and green labelled triage patients shown in Figure 12 and Figure 13 as expected, red patients are evacuated faster. Yellow patients (Figure 12) are transported when no red patients are available anymore (see minute 300). The same applies for green patients with respect to yellow ones (Figure 13).

As mentioned above, it might be of interest how efficient rescue ships and helicopters could use the ferry to evacuate, meaning that any form of queue at the ferry should be avoided. Queues before the very indicate bottlenecks. Figure 14 and Figure 15 illustrate the utilization of helicopters and rescue ships respectively. Utilization is calculated by 1/n times the time average of the number of helicopters/rescue ships staying at the ferry.
The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.

Figure 14: Utilization of helicopters at the ferry

Figure 15: Utilization of rescue ships at the ferry
2.4 Advantages, limitations and next steps of the simulation

The simulation environment was developed with respect to the specific requirements of the scenario 4. The environment is based on the discrete event simulation language of MATLAB/Simulink/SimEvents. For the specific needs, new, specifically tailored, functionalities were introduced, using the MATLAB domain. This domain also serves for the development of the visualization and automatic evaluation functionalities.

The simulation supports the domain expert in assessing a particular strategy of resource deployment or the implications of a particular set of initial conditions. Distinct system variables were prescribed by the experts and serve to evaluate the system’s performance. For example, bottlenecks of patients or vehicle flows are detected automatically by the simulation, thus relating to the aspects of brittleness as described in D2.1 [5]. Chapter 2.1.4.1 gives an example of how the simulation supports domain experts with respect to brittleness. For example, aspects such as the operation strategy or the ability to distribute resource at a given time are associated with brittleness. This can be tested with the simulation.

Due to the generic character of the simulation, a variety of initials conditions can be played out in (fast time) What-if simulations and new systems variables can be introduced to investigate different aspects of the system. Furthermore, the disruption of processes can be depicted by establishing stochastic influences. For example, the probability of failure rates or the duration of a disruption can be displayed by probability density functions, which are part of the simulation language. Currently, the simulation is deterministic and different state spaces are calculated which depend on different patient allocation schemes and resource deployment scenarios and strategies.

The modular character of the simulation allows incorporating further modelling aspects, such a depiction of the operational procedures within a hospital, which defines the particular capacity. Currently the capacity is fixed and hospitals serve as a sink.

The hierarchical nature of the simulation environment enables it to apply different levels of detail on distinct parts of the model. Thus, aspects of the model which are of interest to the domain experts can be altered afterwards. For example, currently, every patient and every vehicle within the system are equipped with individual attributes or (properties) that can be changed during the course of the scenario. Furthermore additional attributes which affect the state of a patient can be introduced at a later stage.

The development and the adaption of the simulation tool to this specific pilot case (scenario 4) took longer as originally anticipated. This was caused by the complexity of the scenario. Because of this, the tool has not been used during the Swedish pilot trial but has been used in an after-trial workshop. During this workshop specific questions were formulated by FOI to be investigated by the simulation. This addressed different resource deployment strategies and patient allocation schemes. A variety of system variables were defined to be examined. With the help of the simulation, bottlenecks of the flow of patients or different types of vehicles can be detected automatically and further statistical analysis, such as throughput, mean response time, or utilization of a particular resource can be performed as well. Furthermore, a sensitivity analysis, based on specific variables, could be applied in order to evaluate the efficiency and trade-offs of different initial conditions. As the evaluation is still an on-going task a detailed description of this after-trial workshop and the particular results will be given in D4.4 “Final Guidelines Evaluation Report".
In this context, the applied flow based approach of entities is used outside DARWIN in the Air Traffic Management domain as well. For instance, the operational procedures of an aircraft on the ground are simulated for different airports. Currently effects of new aircraft designs on ground processes are investigated using the method.

Further options of the simulation environment are a MySQL functionality to provide a data exchange interface to other simulation tools and time synchronization in case a wider simulation framework is being set up.

On the other hand, the simulation is intended to be used mainly by managers. The functionalities for front line operators are limited to What-if probings of the implemented model.
3 The DARWIN Serious Game
This section presents the serious game developed by SINTEF within the DARWIN project. It is an ambitious game innovating in various domains. It offers a unique game design, an innovative collaboration between players, a cutting-edge virtual environment while having a serious goal.

3.1 Rationale for the use of a serious game
The DARWIN project developed this serious game to improve human responses to expected and unexpected crisis, such as natural disasters and man-made disasters. Its purpose is to be used to teach and to train any person involved in real crisis.

In the game, players conduct exercises to improve their understanding of the DARWIN concepts and guidelines, and to have memorable experiences that are hopefully beneficial in real crises. These exercises are not necessarily all related to the specific player's roles in real crises, but they should present the main concepts, constraints, and guidelines so everyone involved in a large crisis has a better understanding and behaviour.

The serious game is also used as a communication and dissemination tool. Moreover, it is aimed to be an entertaining medium to introduce anyone to the DARWIN guidelines.
3.2 Review of serious gaming tools

We reviewed various tools for the DARWIN serious game. The review was conducted using our experience from previous projects, the recommendations we published in the paper "A foray into the use of serious games in controlled research on crisis management" [4], and tests and benchmarks at the beginning of the work package.

Table 3 presents the tools we reviewed. The main criteria we used during the review were the license, the possibility to modify the tool from the source code, our previous experience, and the virtual reality support. You will find more details about virtual reality in the section 4.1.3. The review has been conducted at the beginning of the work package and the situation has changed since. We did not conduct a new review but when writing this document, we noticed that a few more tools now support virtual reality, or have in all likelihood improved. All the reviewed tools did not offer a bespoke simulation for DARWIN, and required many modifications.

Table 4: Comparison of the reviewed tools for serious gaming in DARWIN

<table>
<thead>
<tr>
<th>Tool</th>
<th>Type</th>
<th>License</th>
<th>Source code available and modifiable</th>
<th>Virtual Reality Support</th>
<th>Our previous experience with the tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Battlespace Simulator 3</td>
<td>Military Serious Gaming Framework</td>
<td>Proprietary</td>
<td>No</td>
<td>No</td>
<td>Mixed</td>
</tr>
<tr>
<td>Arma 3</td>
<td>Military Video Game</td>
<td>Proprietary</td>
<td>No</td>
<td>No</td>
<td>Bad</td>
</tr>
<tr>
<td>XVR</td>
<td>Serious Gaming Platform</td>
<td>Proprietary</td>
<td>Unknown</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Godot</td>
<td>Game Engine</td>
<td>Open-Source MIT</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>CryEngine</td>
<td>Game Engine</td>
<td>Restricted for serious gaming and simulations</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Unity 3D</td>
<td>Game Engine</td>
<td>Proprietary</td>
<td>No</td>
<td>Yes</td>
<td>Good</td>
</tr>
<tr>
<td>Unreal Engine</td>
<td>Game Engine</td>
<td>Proprietary</td>
<td>Yes</td>
<td>Yes</td>
<td>Good</td>
</tr>
</tbody>
</table>

The framework Virtual Battlespace Simulator (VBS) was not selected despite all its qualities and features because it provided very classic human-computer interactions, and because it was also focused too much on battles and not enough on rescue operations. Most of its tools were powerful but quite difficult to use or understand in our opinion. Its scripting programming language was particularly impracticable compared to the competition. Arma 3 was a video game based on the same framework. It has simpler interactions and good default content, but it also suffers from the same issues. Both VBS and Arma did not support...
virtual reality. XVR was looking very promising but it did not support virtual reality so we did not take the
time to evaluate it despite that. We evaluated game engines because they offer a lot higher flexibility, and
since we had to build our own simulation, game engines were very competitive. They especially had high-
quality tools to had new content. CryEngine’s license did not allow serious gaming and simulations, so we
quickly rejected it. Godot was a very promising open source game engine, but it did not support virtual
reality and it lacked many features we found in Unreal Engine or Unity. Unreal Engine allowed modification
of its source code for everyone and not only major game studios like Unity. Unreal Engine also provided
more features we found useful for our serious game, compared to Unity which required additional modules
by third-parties. Both Unreal Engine and Unity supported virtual reality very well.

3.3 The Gameplay
The DARWIN serious game offers a unique gameplay for the project needs. We created a new genre in
which a large number of players play together as a team to solve a set of exercises related to emergency
situations or large crisis.

In terms of game design, this is a multi-player puzzle game. By puzzle, we mean that each session is a
situation, or a puzzle, that needs to be resolved. The game also offers concepts from real-time strategy
games and sandbox games. The players can define their unique strategy and define unique workflows and
solutions. Unlike many serious games, the gameplay does not use a game master, a human controlling the
game, it is fully automated.

The game consists of a set of exercises with dynamic scenarios, which focus each on a few concepts from
the DARWIN Concept Cards. These exercises range from small situations such as road traffic accident or
light floods to large scale situation with thousands of victims to manage. Overall, the exercises are focused
on resources management, coordination, victims support, and resilience thinking. During an exercise,
dynamic events may occur to train the user to think about what could happen, what are the pitfalls, what
could be the sources of brittleness, or other concepts introduced by the scenario.

Players have an important liberty to solve each exercise. There is not a single good solution, but an infinity
of solutions. A team cannot really lose, but it may score very low if it does not manage the crisis correctly.
The score is based on the team’s performances, for example how many victims are saved, how many
resources are used efficiently, and the timeframe. The goal is not to obtain a high score, but to solve the
situation properly and to obtain experience and knowledge.

3.4 The Medium
The DARWIN serious game is split into two main components: a virtual reality game with one player, and a
mobile game for all the other players. As everyone plays together on the same team, the virtual reality
game and the mobile games are linked together.

We decided to use this mixed configuration, because it allows using the benefits of virtual reality, which will
be presented in the next section, and because it also provides a realistic experience for the other players
using the mobile game. In real situations, people often only carry a smartphone or a radio. Moreover,
having a virtual reality multiplayer game with many participants was not realistic in terms of logistics and budget in this project.

![Figure 17: The DARWIN Video Game being tested by a student](image)

### 3.4.1 The Virtual Reality Game

When we started to define the DARWIN serious game, we wanted to deliver a different experience compared to common serious gaming tools used in crisis management. At the same time, augmented reality and virtual reality technologies became popular and available for consumers and we saw an immense potential in these. After a few trials, we decided to develop the DARWIN serious games as a Room-Scale virtual reality game because it provided the best environment for our needs.

#### 3.4.1.1 Which are Augmented Reality, Virtual Reality, and Mixed Reality?

Augmented reality (AR) is the augmentation of a real-world environment with computer-generated content, such as graphics and videos. Notable examples are the Google Glass device displaying graphics on top right corner of the user field of view, or the Pokémon GO game displaying fictional creatures in the real-world environment through GPS localization and through an indirect view on smartphones.

On the other hand, virtual reality (VR) moves the user to a completely virtual environment. This is a mature technology, but the latest generation of VR systems has reached the general consumer market. The technology is affordable and the quality is acceptable. Many devices are today available, such as the HTC Vive, the SONY Playstation VR, the
Facebook Oculus Rift, or the Samsung Gear VR. The commercial success of the latest generation is debatable compared to the tremendous investments made by many actors, but the technology has been well received by the early adopters.

Mixed Reality is the mix of a virtual environment in a real-world environment. It could be described as AR, but the interactions are more similar to VR interactions. Today’s examples are the possibility to play videogames such as killing giant robots in an office open-space, playing Minecraft on the coffee table, or to transform an apartment into a Windows computer with virtual icons on the furniture and Microsoft software on the walls. The technology is very promising but is also less mature. The main device is the Microsoft Hololens development kit.

3.4.1.2 The Choice of a Room-Scale virtual reality Game

The DARWIN serious game uses virtual reality, because we think it is the most mature environment for research and development on advanced user interactions in 3D space, compared to Mixed reality and augmented reality. However, most of the concepts and interactions are designed to also work in mixed and augmented reality. The game could likely be ported to mixed reality when this technology will become ready.

The DARWIN serious game is room-scale, it means the user can freely walk around in the virtual environment with the same motions than her/his real-life movements. The user can also see the position of her/his hands in the virtual environment. This kind of interactions improves the immersion and the user experience. Instead of pushing buttons or manipulating joysticks, the user can simply walk and manipulate objects as it is in the real-world.

The presence, the feeling to be in a different world, is high in room-scale VR and we wanted to test whether this could help situation awareness. We also wanted to see whether 3D map based visualizations in 3D spaces are an acceptable solution. Allowing the user to control the user interface with her/his hands and physical virtual objects is a new paradigm that triggers many research questions and engineering challenges we are interested in.

Lastly, serious gaming is fundamentally gaming and while virtual reality cannot transform a dull game into a fun and enjoyable game, we think it does improve participation and involvement of our players.

3.4.2 The Mobile Game

The mobile game is the second component of the game, which is used by the players who are not in the virtual environment. Interestingly, the mobile game has a serious look and feel and it simulates mobile applications that are not games, such as messaging applications. It is a smaller component compared to the virtual reality component, and it is used mainly as a communication tool between the players and the virtual environment.

The mobile game supports most common modern devices, such as smartphones, tablets, or laptops. It requires an internet connection to be loaded and connected to a game session.
The players using the mobile game are not expected to spend all their time on the application. They need to discuss between each other, and they may use any kind of other tools such as the resilience guidelines documentation or a drawing board.

![Screenshot of the DARWIN mobile serious game](image)

**Figure 19: Screenshot of the DARWIN mobile serious game**

### 3.5 Scenario Description

The DARWIN work package four defined pilot exercises with advanced scenarios. One scenario about a ship collision between a cruise ship and oil tanker outside the Swedish east coast, one disease outbreak during an incoming flight, one air accident nearby Fiumicino Airport, and one blackout at Rome’s Air Control Centre. Because these scenarios were already high-quality, defined and refined by experts, we wanted to design the serious game for them. However, we considered the resources we had for the serious game and we decided to implement a single scenario which is described in this section. It would have been a too large effort to implement each scenario. We also implemented a few very simple scenarios, which could be considered as training serious games for the larger scenario.

The scenario about the collision between the cruise ship and the oil tanker was the most interesting kind of scenario because it included many aspects of the DARWIN project we wanted to use. You may find a full description of the scenario in the work package four. It involved air traffic management, first rescue, large-scale evacuations, health-care management, bad weather... However, we concluded after preliminarily tests that many aspects of the scenario were not suitable for the serious game in virtual reality. The scenario was mainly too long and too complex. It was definitely possible to build the game for this scenario, but we were not sure about the quality of the gameplay. Therefore, we decided to reuse concepts from this
 scenario and to implement a different simpler scenario which, we believe, is a more interesting and useful for our players within the setting of serious gaming.

![Figure 20: Sketch of the scenario map](image)

The scenario takes place in a remote area separated in half by a river. It contains two fictional cities, with one small city named Barjols which is crossed by the river, and a second bigger one named Tulle further away in a plain. A small road-network is connecting the two cities together and to the external world. The river is crossed by two bridges, one in the city Barjols, and a second one in the north.

Tulle benefits from a small hospital, a fire station, a police station, and a school with a gymnasium. Tulle also has a small regional airport nearby that accept light to medium aircrafts. Being a smaller city, Barjols doesn't contain any interesting infrastructure except a small hospital specialized in critical health-care for elderly people. A third hospital is also present close to the airport, but on the other side of the river.

This scenario trigger event is a flash flood followed by heavy rains that cause flooding in Barjols. A few houses must be evacuated, and a few police cars and fire trucks are already on scene when the player starts. As time goes, the situation does not improve and players will encounter unexpected events. More houses must be evacuated as water rise. Barjols lose its electrical power connection. The hospital electricity backup generator is flooded and therefore, it must be evacuated. The bridge crossing the river in Barjols will appear to be flooded and unsafe to cross, forcing the evacuation to use the second bridge far away or helicopters. Positive events may also happen, such as newly available rescue resources coming from other places.
The scenario is designed to last around five minutes, and it could be played a few times by different players with some variation. We decided to have a short scenario to focus on resilience concepts, instead of having a realistic time progression.

### 3.6 The Players Roles

Each player has a specific role during the session. The player in virtual reality has a "resilience manager" role, a role consisting of monitoring the situation, interacting with the data, and helping all the participants to conduct the exercise. Other players have an agency manager role and play using the mobile application and any kind of other equipment or documentation. The agencies are government agencies such as police, hospital, ambulance, maritime rescue, etc.

![Figure 21: Schema of a session with participants using their smartphones around a display showing the situation, and the resilience manager inside the virtual environment](image)

To succeed, players must communicate and take decisions together. It's preferable to have all the players around a table in the same room. The resilience manager being isolated in virtual reality, communication with her/him is possible through voice and video. The situation is displayed on a screen to the agencies managers, and them resilience manager can see the through a webcam if she/he wants to.

#### 3.6.1.1 The Resilience Manager Role

Our hypothesis is that compared to users monitoring a situation using classic tools such as flat interactive maps, paper-based documentation, and other flat software tools, the resilience of a large-scale event will improve if an user, called the resilience manager, is monitoring and contributing to the decision process using a virtual reality environment. Based on this hypothesis, we therefore introduced the resilience manager role. This role does not exist outside of the DARWIN serious game, and its usefulness will be tested for the first time in this serious gaming context.

The resilience manager has access to advanced visualisation in three dimensions, with innovative interactions. We spent a lot of energy and thinking into making this experience something memorable and useful. All interactions have to feel natural and easy for the player, who can focus on the exercise.
A session must have one resilience manager. The current implementation does not support more than one resilience manager, due to time and budget constraint, but supporting more resilience managers could be an improvement done in the future.

### 3.6.1.2 The Agency Manager Role

The agency managers are played by the other participants of a session. Each player impersonates an agency manager. An agency could be real or fictional, its name and purpose are up to its managers.

The agency managers may use all the tools they have access to, in addition to the game mobile application. This application is used to define the agency, to monitor its resources, and to control its resources. To simplify the game, an agency manager manages only one building. For example, it means that if two fire-stations are on the map, they are two separated agencies with two separated players controlling them.

A simple training scenario may require no agency managers, but a classic scenario will have up to ten agency managers. The technology could realistically support up to fifty agency managers before the visualisations become too busy.

### 3.7 Timeline of the Main Scenario

The timeline of the main scenario is described here. Because the scenario is dynamic and not scripted, we could not describe all the possible events during the crisis.

![Figure 22: Timeline of the Main Scenario](image)

- **Initialisation and connection**
  - The resilience manager puts the virtual reality equipment and start the game.
  - Agencies managers start the game on their smartphones.
  - The resilience manager is waiting in a virtual room. She/He sees a session number to communicate to other players, and see the list of connected players.
  - Other players can specify the session number in the game and connect.
  - Once everyone has connected, the resilience manager will start the game by pushing a large "start the game".

- **Before crisis: Discovering the map and attribution of the agencies**
The resilience manager can now see and discover the game map. At this point, the emergency has not happened yet. Some information about the cities and the risk may be displayed.

Agencies managers can see a new screen in their app, showing the list of available agencies. Each player will have to select the agency they want to play. The list is empty at the beginning.

The resilience manager will see the agencies building in the map and she/he has to enable them by grabbing them. When an agency becomes enabled, its building change colour and it will immediately become visible in the list of available agencies. Agency managers can then select it, and the first to select it will get it. The map may have more agencies than players but players may want to select the same agency and some speed competition could happen. A good steam strategy could be to wait for all agencies to be enabled, and to select them strategically.

Once a player has selected an agency, she/he may specify a name and a logo to her/his agency. This doesn’t serve any purpose for the game, but it helps the player to appropriate the agency and to play more conscientiously.

The next step is to buy the resources for her/his agency. The resources are randomized and cost points to buy. Players can buy resources as long as they have points left. A player may buy many resources leaving no points for other agencies, as the points are shared between everyone. Buying too many resources will reduce the final score and buying too few may make the scenario difficult or impossible to succeed. Therefore, players are advised to communicate and elaborate a strategy before buying resources as fast as possible.

When every agency manager has selected and agency, bought the resources she/he thinks are needed, that the discussion about the resilience before crisis finished, the resilience manager can finally start the next step by pushing a large "start the crisis" button.

During the crisis

Now that the crisis has started, agency managers may receive messages from civilians or other services on their smartphones. They can decide to keep the information for them, or to share it.

Agency managers can discuss with the leader of each resource they own. The communication is happening through the smartphone, using text messaging, and the leader is simulated by an artificial intelligence. The communication can be used to get more information about the environment, and to give instructions to the leaders.

Agency managers must supervise the operations and give instructions to their resources leaders. These instructions are related to the kind of agency they operate.

Meanwhile, the resilience manager sees an updated situation on the map, but does not see all the data from agency managers. Its role is to maintain the common operational picture, to inform everyone of what is important, and to keep an eye on the resilience issue they may be facing.

Unexpected events triggered by the scenario may happen and both the resilience manager and agency managers must react.

- A bridge collapsed due to the floods, forcing the ground vehicles to find another road.
- An hospital must be evacuated because it could not satisfy the security of its patients.
- More resources from other countries become available.
- A new group of victims is discovered.
The weather worsens and prevents helicopters from flying.

After the crisis
- The crisis stops when all the risks are treated and no more unexpected events are planned by the scenario.
- The crisis may also stop after a delay specified in the scenario. The delay should leave more than time to manage the crisis, and it is used to stop the game if the players are stuck or very badly managing the situation.
- Players have a debriefing about the crisis management, and they may discuss resilience and what could have been done better.

3.8 How to setup the serious game?

To setup a game session, the organizer needs the following:

- A large enough meeting room to host the participants
- An area with free space
  - A minimum 2x2 meters surface, 3x3 meters or more recommended
  - Not many reflective surfaces such as mirrors or glass walls
  - The area may be located in a different room from the other participants
- A HTC Vive set consisting of:
  - HTC Vive Headset
  - Two motion controllers
  - Two lighthouses base stations
  - HTC Vive hub
  - The HTC Vive cable, the HDMI cable, the USB cable
  - 5 power adapters: one for the hub, one for each base station, one for each motion controller
- A VR computer:
  - CPU: Tested with Intel i7 6700K and i7 7700HQ. A similar or better CPU is recommended
  - GPU: Tested with a desktop and a MaxQ Nvidia GTX 1080. A similar or better GPU is recommended.
  - RAM: Tested with a minimum of 16GB.
  - It could be a laptop, but if so its power adapter must be connected during the session.
- A device for each agency manager player
  - Each device may be a smartphone, a tablet, or a laptop. We recommend using smartphones or tablets.
  - They must run a web browser released after 2013, and an updated web browser is recommended.
  - We recommend using the devices owned by the participants, but the organizer should bring a few spare devices for the potential participants without devices.
- Stands or foots for the lighthouses
  - We recommend using photography light-stands or tripods.
- Two extension cords, and a power strip.
- An internet connection for each device.
  - The devices do not need to be on the same network, they only have to access internet.
High speed and low latency are not required.

Setting up the HTC-Vive is explained in the SteamVR documentation [https://support.steampowered.com/steamvr/HTC_Vive/](https://support.steampowered.com/steamvr/HTC_Vive/) Follow the instructions for a room-scale configuration. We recommend to avoid areas with reflective surfaces as the

We recommend to make sure the installation is correctly functioning by running the game in VR, and by connecting at least one device to it.

### 3.9 Gamification and Realism

The DARWIN VR video game does not try to simulate a crisis in a perfectly realistic fashion, but aims to be an effective training material. Most of the situations presented to the user are highly simplified, to let her focus on the important concepts presented by the scenario.

What is not necessary to be simulated precisely in the scenario is not. For example, while time is a very important variable in a crisis, the game takes some flexibility. Simulating time correctly is interesting but tedious in our tests and therefore time can be accelerated, which makes the rescue vehicles a lot faster, the actions quicker, and the events happen sooner. That allows scenarios that are hours or days long to be played in a few minutes.

![Mock-up of a simple search and rescue scenario](image)

**Figure 23: Mock-up of a simple search and rescue scenario**

### 3.10 Technical Information about the Virtual Reality Game

#### 3.10.1 A game made with Unreal Engine

At the beginning of the project, we had to select a technical platform to run the DARWIN serious game. It was a critical decision to take because once we committed, it was impossible to change the platform. We reviewed various tools, as described in section 2.2 of this document.
We evaluated the possibility to use existing serious gaming simulation platforms such as VBS from Bohemia Interactive. Based on our previous experience, we thought that for our specific usages, they were difficult to use and also lacked flexibility. Especially in regards to virtual reality interactions, or simulations to rescue victims.

Therefore, we decided to develop the DARWIN serious game directly on top of a state-of-the-art game engine from the industry. Using a game engine required us to integrate a simulation into our game, instead of reusing an already made solution, but the simulations were bespoke to our needs. We didn’t foresee major differences to build our maps scenarios, but we noted that using a game engine offered more flexibility and opportunities for the user interactions.

Many game engines were available at this time, as the game industry was evolving to a new model with more openly available game engines. Unity 3D, Unreal Engine, or CryEngine were competition to attract new developers and projects. We also considered free and open-source such as Godot. After experimenting and benchmarking a few engines, we eventually selected Unreal Engine.

Unreal Engine is a professional game engine supported by Epic Games that originated from the video game Unreal released in 1998. It has been used over the years in many video games from various genres running on many platforms.

The license of Unreal Engine allows developers to use the engine in exchange for 5% royalty on gross revenue for commercial products. The DARWIN serious-game not being a commercial product, Epic Games allows us to freely use the engine. The source code is accessible for free, and it is allowed to read, use and change it, as long as it is not used to make a different game engine. This implies that Unreal Engine is far from being free and open-source, as usually defined by organisations such as the Free Software Foundation. But in the context of the DARWIN project, we can use it for free and we can read and edit its source code.

Figure 24: The DARWIN game inside the Unreal Engine editor
We selected this engine for the quality of the tools and algorithms it included. The graphics using the default settings were also high quality, allowing us to focus on more important tasks for the serious game during the development. The networking was also a key feature, as every Unreal Engine game is a multiplayer game by default. We also appreciated the multi-platform support. It notably supported room-scale virtual reality. Unreal Engine includes a high-quality three-dimensional physics engine based on PhysX by Nvidia. Finally, the visual programming language Blueprint has shown to be a very powerful language that is perfect for quick prototyping and work on user interactions.

At the end of the development, we were still satisfied with our choice. Needless to say, not everything was perfect. The virtual reality support required a few more releases to be stable and high quality for example. But we would probably use the same engine again if we had to make a new serious-game.

3.10.2 Graphics and 3D models

Although we seek a visually pleasing and great sounding game, the graphics quality was not the priority. We opted for a cartoon/low-polygons art style because the models are fast to render, this kind of assets from different artists mix well together, and it looks good without requiring too much work on details. The majority of assets are bought from various marketplaces such as the Unity Store, the Unreal Marketplace, or TurboSquid. Various assets were distributed freely under a permissive licence such as a Creative Commons CC-By, and a few assets were created inside the project.

![Figure 25: Examples of 3D assets in the Virtual Reality Game](image)

The 3D models were fixed, improved, or customized using Blender. The textures were made using Unreal Engine and the software Gimp. We also used the virtual reality application Blocks to model simple objects and the environment.
3.10.3 Audio and Sound Design

Audio is an important component of the DARWIN video game. Following the same concepts than the graphics, we didn't put too much effort into the sound samples we bought assets from various marketplaces and made a few “low-fi” sounds using the software sfxr, bfxr, and a synthesiser.

The game has no music, to focus on situation awareness and notification sounds, but each environment has a soundscape so the world does not feel empty. Each interactive object emits sound in a 3D binaural configuration. This significantly improves the presence and the situation awareness. For example, a new victim could be discovered in the back of the player, and even though it is not in her/his field of view, the notification sound happening behind the user will notify her about the victim.
3.10.4 Manipulating virtual objects in virtual reality

Manipulating virtual objects is the main interaction the player does in the DARWIN serious game. She/He must be able to move, add and/or remove objects very easily and quickly. We wanted to make sure that these interactions feel natural.

Virtual reality with tracking of the players' hands enables new way of interacting with objects. In traditional software user interface, the user may click or select element using their finger or a mouse, pointing at elements on a flat surface. The software just has to find the object pointed by the user, often by exploring a tree of two-dimensional surfaces. The DARWIN serious game implements something fundamentally different, using the three-dimensional physics engine.

Objects have a visual appearance but also a physical shape. The physical shape can be exactly the same than the visual shape, but simpler shapes such as spheres, cubes, or simplified mesh are often used for performances reasons. Interaction events are triggered by the physics engine when the player's hand collides with the physical shape for example.

Collisions and physical reactions were defined accordingly to every kind of object and their states. The player body doesn't have any collision nor physical reaction, meaning the player can freely walk into objects without any effect. This not realistic, but the alternative had major issues with the player hitting objects without noticing it, due to the lack of tactile feedback from the virtual reality technology. The hands do not collide with objects, but events are triggered when they are touching objects. This allows the possibility to display more information when a hand is hovering an object.

Figure 27: Spectrograms of a few sounds made for the DARWIN serious game.
During the development, we implemented and tested two solutions for manipulating objects. We finally decided to use the method that is more natural to use, but they are both worth explanations and we could do more research on this topic in future work.

The first method we use is very simple: when the player grabs an object with her/his hand, the object is fixed to the hand until she/he releases it. To rotate or move the object, the user can move or rotate her hand. To find which object is grabbed, an algorithm search for the closest grabbable object in a 15cm perimeter around the player’s hand.

The second method we implemented but decided to not support allows the player to manipulate objects without touching them. She/He can point at an object and press a button to capture it and release the button to release it. The object keeps the same relative distance to the hand, but can be moved by moving and rotating the hand. This is a very similar behaviour to the invisible “force” in the popular Star Wars movies. To help the player to control the objects and point the objects, a small line consisting of blue lightning connects the hand to the object or the pointed direction. We use a raytracing algorithm to identify which object is pointed at.

Figure 28: The player grabbing a helicopter

The research leading to these results has received funding from Horizon 2020, the European Union’s Framework Programme for Research and Innovation (H2020/2014-2020) under grant agreement n° 653289.
Manipulating objects requires some software communication with the objects, they must know that they are being manipulated. Moving vehicles will stop moving when grabbed. Objects affected by gravity will disable gravity when grabbed and enable it again when released. Waypoints object will update their status when released. Altogether, these simple interactions took a substantial development time.

3.10.4.1 Adding and removing objects: The serving tray metaphor

Objects inside the virtual environment may appear or disappear automatically based on the scenario, the simulation, and the player’s interactions. Sometimes, the game master may want to add or remove additional objects. To do that, we use a metaphoric serving tray. The tray can appear in one of the player's hand by pressing a physical button on the controller, or doing a specific gesture with hand tracking equipment. It contains small objects and the player can grab them using her second hand. When the object is moved away from the tray, a new object automatically appears on it. The player may release the grabbed object everywhere inside the virtual environment.

To remove an object, the player needs to grab the object and release it on the serving tray. The object will then disappear in a small cloud of dust.

We wanted to make the serving plate interaction a straightforward but efficient experience. Behind its apparent simplicity, the tray has a complex functioning, with many physics interaction using the physics engine, animations, force feedback effects, sound effects, visual effects, transitions, and states management. This component has been made in a generic way, to be easily reused and extended in future work.
3.10.5 Displaying information

The DARWIN serious game displays information to the user through different channels. The position and the kind of an object can easily be displayed in 3 dimensions using a symbolic model placed inside the virtual environment. However, an object often has more information to communicate to the players. The game can change the material of the object, changing its colour or opacity for example. A not enabled hospital may use a grey material, update to white when enabled, and finally update to the player's agency colour once selected by a player.

An object may also emit sound. The sound is used to inform the resilience manager in virtual reality its location, using binaural audio, and its state. A moving road vehicle will for example emit a different sound than a static road vehicle waiting for instructions.

An object may also have a beacon light representing its state using a simple colour code. An empty helicopter flying towards destination will blink using a different colour than an helicopter transporting patients to an hospital. The used colours code in the game are not described to the players, but should be simple enough to let them figure them.

Finally, an object may need to display a lot more information to the user if necessary. We decided to implement this as a flat information screen standing above the object, as displayed on Figure 32.

3.10.5.1 Flat information panels

Information panels may be displayed above objects. These information panels are flat and use classic graphical user interface widgets to display the information. This allowed a quicker development process, and also made the virtual environment less busy visually.
Some objects always display the information panel, while some other display it when the player is hovering the object with her/his hand. In this case, objects have a sphere of influence and display or hide the panel based on the presence of a player hand in its sphere of influence.

Information panels must always be visible and readable by the player. They must rotate on pitch and yaw to always be facing the player’s eyes. In our tests, having rotating information panels was quite unsettling for the user. It made the virtual environment very artificial and strange. To prevent this behaviour, we first reduced the rotation speed. We also made rotation by steps, instead of always facing the player’s eyes with the exact angle, panels rotate by steps of 30 degrees for example. If the player slightly moves her/his head, the panel will not rotate. But if they player walks far, the panel will still rotate.
3.10.6 Video Cameras between Reality and Virtuality

We explored possibilities to improve the collaboration between the virtual environment and the real-world environment. We implemented a virtual video camera that could be manipulated by the player in virtual reality. Its video feed is displayed on a computer screen for the other players in the real environment. In reverse, we implemented a real video stream that can be displayed inside the virtual environment.

The virtual video camera has a heavy performance cost, as the computer must render the 3D environment for both the player and the camera. To counteract the performance cost, we reduced its quality to an acceptable level, waiting for more powerful hardware.

![Figure 33: The Video Camera and the virtual tablet displaying video feeds](image)

3.11 Real-time path-finding algorithms

The gameplay involves resources management; how to dispatch resources, when, and where. We decided to automate the path-finding instead of asking the player to draw paths. Drawing path is a gameplay element used in various games, but we thought to have an automatic path-finding was more realistic. A helicopter pilot will take initiatives in a real-world situation; not waiting for a resilience manager to tell him is detailed flight path. An automatic path-finding would also give more time to the resilience manager to focus more on the resilience problems.

However, this decision made the automatic path-finding algorithm one of the most important and critical algorithms of the gameplay. We definitely wanted to have something realistic for the quality of the simulation, and also because we didn’t want the player to complain about potentially questionable paths used by any resources.
3.11.1 Land and water path-finding

Fast path-finding is a solved problem and we used the standard A* algorithm implementation from Unreal Engine whenever possible. We used a path-finding map for land resources, and a path-finding map for water resources. These maps are only used for the path-finding algorithm and are not visible by the player. We made multiple maps because the engine doesn't allow different categories of path-finding and it was easier to use multiple maps than adding this feature to the engine.

Inland resources path-finding map, we defined areas with various travelling cost. The roads had path-finding areas with a cheaper travelling cost, to invite land vehicles to use roads instead of cutting across fields. Water areas had an infinite travelling cost. As opposite, the water path-finding map had an infinite travelling cost for land surfaces and every water area had the same travelling cost. It is illustrated in figure Figure 35.

The altitude can be easily computed for land and water path-finding. In water areas, the altitude is always the water level, we didn't implement submarines. But the helicopter path-finding algorithm described later could be adapted if necessary. For ground vehicles, the altitude is simply the ground level altitude.
3.11.2 Air path-finding

Air path-finding is another problem. We experimented the A* algorithm in three dimensions, but it made artificial and unrealistic flight paths. Our implementation was quite slow as well, so we tried something different. We wanted to have air resources flying similarly to real-life resources.

3.11.2.1 Helicopter path-finding

We started with the helicopter path-finding because a helicopter can go up and down without having to move forward, simplifying the problem. We also decided to always use a straight trajectory towards the destination. Therefore, a helicopter could only avoid obstacles by flying above them. For example, a high tower between the departure point and the destination point would require the helicopter to fly above it while a real-life pilot could avoid it by its left or right side. But we think this kind of issue is very unlikely in the DARWIN game, and we preferred to keep a simple and fast algorithm.

The algorithm itself could be summarized like this: the helicopter looks towards the destination. If it can see the destination, the helicopter flies in a straight line towards the destination. If not, it means that an obstacle is present between the helicopter and the destination. The helicopter will scan the obstacle by looking at near-by surfaces repeatedly, from the bottom to the top. Once it doesn't see the obstacle anymore, it has detected an area above it. It will then fly towards it and restart the algorithm. This algorithm is costly because scanning a surface involves many raytracing operations, the path is therefore updated at a 2Hz frequency.

3.11.2.2 Planes path-finding

Plane path-finding consist of flying from point departure to destination as fast as possible. With one major constraint: planes have a maximum rate of climb and a maximum rate of descent. These rates are specific to each plane model, but we decided to use yet realistic, higher rates compared to what is normally used in the civil aviation, to make shorter and easier to understand routes.
The first step of the algorithm is to determine the right flight level. In this algorithm, the flight levels are based on the real flight levels used in Europe. They are also different depending on whether the route is clockwise or counter clockwise from the north. For simplicity, we decided that planes will use only one flight level for a specific route. They will first climb to reach it, fly the longest possible at this flight level, and descend to the destination.

The flight level is determined by the distance to travel, the rate of climbing, and the rate of descent of the plane. Schematically, the higher the distance is, the higher the flight level will be. The algorithm will finally scan the route to detect potential obstacles at the flight level. If one obstacle is detected, higher flight levels are successively tested until no obstacles are detected.

The second step is to find a route to reach the flight level. The plane will attempt to reach the flight-level using its maximum rate of climbing. It starts by flying towards the destination, and when a near obstacle is detected, it will check whether it should turn left or right by scanning the obstacles around. It will always try to turn the less possible, try to turn in the same direction compared to the previous decisions, and try to fly towards the destination. The algorithm eventually builds a spiral trajectory from the departure to a position at the correct flight-level. The top position is not necessarily between the departure and the destination points, but usually not far away.

The third step is to find the trajectory for descending to the destination based on the maximum rate of descent. We decided to use the same algorithm than the second step, by just using it in the opposite direction and with the rate of descent instead of the rate of climbing.

This plane path-finding algorithm may be unrealistic in real-world situations, planes do not always fly in a straight line, routes may have more than one flight level, the spirals it makes are not always optimal (or very safe), but we think it should not be a major issue in our scenarios. The algorithm could also be improved in extreme cases, for example when the angle of descent or attack require a longer travelling distance than the Euclidean distance due to a very wide and high obstacle, but we think these cases are unlikely to happen. Similarly to the helicopter path-finding algorithm, scanning obstacles is a costly operation consisting of many ray-tracing operations, and the update frequency of the path is limited to 2Hz.

3.12 Technical Information about the Mobile Game
Players having an agency manager role play the DARWIN serious game using a specifically developed mobile application.
The mobile application has been developed using web technologies and it may run on smartphones, tablets, and computers. We decided to use web technologies because it is multi-platform, and also because it can be maintained on the long-term it. We selected state-of-the-art but solid web technologies, namely React, Mobx, Babel, and MaterialUI. This was not a risky choice technologies, and we hope these technologies will be maintained on a long-term basis. The application was developed using the JavaScript programming language in its latest version. The application also follows Google's Material Design guidelines.

The important features of the mobile application are presented in the following sections.

3.12.1 Chatting with Virtual Resources

![Figure 38: The interaction with the virtual resources is done by a messaging like application and chatbot technologies](image)

The communication with the different resources controlled by an agency is done by the respective agency manager players. Instead of using classic graphical user interfaces, we decided to go for a more realistic approach with a simulation of communication between humans in the agency using chatbot technologies. The player, for example, discusses with a helicopter pilot or an ambulance driver to retrieve information about their status, or to be notified when something unexpected happens.

SINTEF has experience using chatbots technologies and for the DARWIN serious game, we selected a third-party online API named DialogFlow, which allows to convert a voice or text input to any kind of intent, given a specific context.
This kind of interactions requires an artificial intelligence with cognitive features, to understand what the player is telling to the virtual resource, and to provide the appropriate answer or to take the correct decision. The current state-of-the-art requires to write down as many sentences as possible, to train the artificial intelligence. This task is time consuming and therefore, we decided to support a limited number of sentences in the DARWIN project.

Messages form virtual resources, such as answers to questions or notifications to unexpected events, must be written by humans and we didn’t use any kind of machine learning for this purpose. This allowed a better control of the answers, and simplified the development.

3.12.2 Swiping Cards

While the web application uses very common technologies and graphical user interfaces, we wanted to have some interesting game interactions in it. One of them is the swiping cards mechanism, inspired by the Tinder dating application, where players can match resources for their agencies. This interaction was developed as an alternative to a list of resources as a comical component.
So the player faces a stack of cards representing resources, and can swipe cards one by one. If she swipes left, the resource is permanently discarded. On the contrary, if she swipes right the resource is matched and added her agency resources. The player doesn't know what will come after she swipes a resource, but knows that available resources are not infinite. She might have to match a not so interesting resource to mitigate the risk to never find the dreamed resource for her agency.

3.12.3 Networking

Like many multi-player video games, the DARWIN serious game needs to exchange data between the different instances of the game. Unreal Engine provides a framework to implement this easily, but it is limited to software developed using Unreal Engine. We preferred to use a technology more open and more flexible.

We did not have the same constraint than classic multi-player video games, we required a high quality of service without a low latency nor high messages rate. We didn't need to have trust or anti-cheating measures in our architecture, as players are working in a team and not competing against each other.

We selected an inventive network architecture inspired by the internet of things (IoT). We use the publish-subscribe pattern, where clients may subscribe to a topic, and publish messages to a topic. When a message is pushed to a topic, it is broadcasted to all clients subscribed to the topic.

Clients connect to an online message broker, which manages the subscriptions, the messages, and the quality of service. We use the MQTT messaging protocol to communicate, which can run above TCP/IP or WebSockets. MQTT provides three quality of services levels to send or receive messages, respectively "at most once", "at least once", or "exactly once". A higher quality of service is slower and not always needed so we use the various quality of services wisely. MQTT also provide a "will feature" that allows to send a message when the connection is closed, providing support for detecting disconnected players.

Many hosting providers provide message brokers as a service, but we preferred to have more flexibility and to deploy our own message broker on a low-power server with a good internet bandwidth. The deployment uses Docker software containers, which allow us to quickly deploy the system everywhere. Because we use
the MQTT standard, it is possible to easily change the message broker platform without having to re-implement the clients. During the development of the game and other projects, we tested the message brokers EMQTT, VerneMQ, RabbitMQ, Emitter, and Mosquitto. No major differences were noticed, as the game has a light usage of a message broker. We wanted to provide a secure connection to the message broker, using TLS, and we deployed a reverse proxy providing a secure websocket connection using certificates provided by Let's Encrypt certificate authority.

3.12.4 The session number

Players are connected together using a session number. This mechanism is inspired by the quiz application Kahoot. The number is randomly generated by the resilience manager player, in virtual reality. The last digit is however a checksum computed with the Damm algorithm, to detect common transcription errors such as altering one single digit or transposing two adjacent digits. A player may not join the game if the checksum is invalid. In the unlikely case where the checksum is valid while the session number is not, she will join an empty session and will be prompted to check the number again.

![Game Session Number](image)

**Figure 42 The game session number input graphical user interface**

3.12.5 Reactive programming and live synchronisation between players

We needed to synchronize the web application between players in live, and for that we decided to use reactive programming. In terms of technologies, this is supported by the tools we selected, such as React, Mobx and MQTT. However, having such a reactive application made the development more complex compared to classic smartphones applications. It involves many potential race conditions that we must mitigate, and it makes everything more difficult to test.

3.12.6 Deployment and Installation of the Mobile Game

The mobile game is deployed as a web application, from the same server that is running the MQTT Message Broker. It uses a secured web server using a certificate provided by Let’s Encrypt certificate authority, similarly to the message broker.

To install the game and start playing, the participants only need to open a HTTPS webpage. They could play it inside their web browser, or install it using features from their respective platforms (supporting Android, Windows, and iOS).
3.13 Essentials for DARWIN serious games in practice

The value of the DARWIN serious games is the increase understanding of resilience management guidelines.

Object of the play

We propose to conduct the serious games as experiments. Experiments are about possibilities and taking things into a high level of abstraction. The DARWIN serious game aim to enhance situation understanding and engagement on DARWIN Management Guidelines and their associated building block “Concept Cards”.

We have carefully selected the scenarios thus the current version of the game has the potential to be related to the following concepts associated to specific themes:

Support coordination and synchronisation of distributed operations
- CC: Understanding goals and responsibilities
- CC: Promoting common ground in cross-organizational collaboration

Managing adaptive capacity
- CC: Enhancing the capacity to adapt to both expected and unexpected situations
- CC: Adaption relative to procedures

Assessing resilience
- CC: Noticing brittleness
- CC: Identifying sources of resilience

Ingredients

Players Up to 10
Facilitator 1
Duration Maximum 1.5 hours
DRMG handouts for the facilitator (available in the DARWIN Wiki)

Preparation

Before the game the facilitator send the DRMG Wiki link to the participants as preliminary information on resilience concepts.

Execution

1. To set up the game the facilitator prepares the game as explained in 3.8. The he/she explains the technicalities on how to use the controls and play the serious game as well how to play through the application
2. Run the scenario as specified in section 3.7. The player “resilience manager” plays the VR serious game; other participants (agency managers) support their game using their computers or their mobile devices using the game session number.

3. After the VR game is played, participants are asked to reflect on the scenario. The facilitator might use the hand-outs to ask questions and relate to resilience concepts.

4. While the discussion is going the resilience concepts identified by the participants are identified in terms of resilience concepts described in the DRMG.

5. The participants jointly select which concept they will like to discuss further. The participants dig further in a specific Concept Cards. (It might be possible to divide in groups)

6. Summary – lessons learned, the participants make a presentation summarizing key aspects they learned, what do they like, what are they missing, what works well and what they want more.

3.14 Advantages, limitations and next steps

The DARWIN serious game targets to provide a fun and enjoyable experience while keeping its serious objectives. It is an innovative solution, with unique concepts such as combining virtual reality with its great immersion and involving many players playing with their mobile devices. It is also an evolutive framework, ready to support various new features.

In its current state, however, it suffers from a few noticeable limitations. The simulation is modest and it cannot integrate data from other simulation platforms. A useful and realistically achievable improvement would be to support simulation data from other platforms, using standard protocols such as DIS and HLA. On the contrary, building a state-of-the-art simulation would require an immense effort and it might not be what the game needs.

The scenarios cannot use world maps supporting GIS data. This feature is technically possible and is also a requirement for many scenarios. We started to build components for that and we would like to finish implementing and testing them.

The scenarios must be built for the DARWIN serious game, using the Unreal Engine editor which is not user-friendly for this usage. The scenarios also have to be short to be enjoyable by the users, and they have to be relatively simple. We could continue with our approach to have simple and short scenarios, and then we would need to implement a user-friendly scenario editor. We could also focus on existing simulation platforms and use their scenario editors.

With the current game architecture, only one player can be inside the virtual environment. Multiplayer video games in Virtual Reality are very time-consuming to develop and test, and we decided to focus on a simpler technical solution. However, having more than one player in virtual reality would improve the immersion and the collaboration even more.

Finally, and the most important critic we have about the DARWIN serious game, is that we have not scientifically tested and proved the benefits of such a game. Conducting scientific experiments to test the game and verify our assumptions (i.e. to improve the gameplay) is mandatory and our priority.
4 Discussion comparing tools

As described in this document so far, the two approaches (namely Discrete Event Simulation and Serious Games) have different focal points in the facilitation of the DRMG to stakeholders. Saying this, a detailed comparison of the tools is hardly possible as they have completely different scopes and levels of details. The short chapter will give an overview on the applications performed within DARWIN and the strengths and weaknesses of the two approaches. In the final table (Table 6) the target user groups of the tools (as given in deliverable DARWIN D6.3 “Dissemination, exploitation and external collaborations strategy”) are given.

Table 5: DARWIN Typology of tools – who and when

<table>
<thead>
<tr>
<th>Training</th>
<th>Description</th>
<th>Resources</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
<td>Discrete event simulation environment for rapid prototyping based on MATLAB/Simulink. Allows for generic configuration, fast time simulation and hierarchical modelling. Able to reveal bottlenecks and to evaluate different resource deployment and operational strategies for particular defined system variables (given by the domain expert)</td>
<td>MATLAB/Simulink/SimEvents Licence</td>
<td>• Easy access to system variables for evaluation purposes, • modular structure allows for detailed modelling of particular aspects (different levels of detail possible) • entity based approach allows for unlimited amount of elements and assigned attributes in the model (that is patients, vehicles and assigned properties)</td>
<td>.not suited for public use, very detailed due to specific requirements of the scenario, not suited for front line operators • Supports only the CC detecting of brittleness and training</td>
</tr>
<tr>
<td>Serious Game</td>
<td>A multiplayer videogame to teach and train any person involved in real crisis.</td>
<td>Serious Game software, SteamVR</td>
<td>• Innovative and fun gameplay. • Introduction to serious concepts for the DARWIN project. • The game is executed with DRMG CCs as training. In this way it supports the uptake of the DRMG and associated Concept Cards</td>
<td>Not connected in real-time to external simulation platforms. • The simple embedded simulations are not suitable for all kind of scenarios. • Complex to setup due to the required VR equipment.</td>
</tr>
</tbody>
</table>
Table 6: Mapping of target groups and tools

<table>
<thead>
<tr>
<th>Target groups</th>
<th>Managers</th>
<th>Front-line operators</th>
<th>Research and Academy Community</th>
<th>Multipliers / Influencers</th>
<th>Public / Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
<td>Yes</td>
<td>Partly</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Detailed What-if scenarios can support the decision process on management level</td>
<td>The simulation is not useful for daily operations but for preparation and debriefing of (small and large scale) exercises</td>
<td>The simulation environment can be used for multiple future scenario evaluations</td>
<td>Most probably the tool is too complex</td>
<td>The simulation environment itself is too complex to be used by everybody; results of the simulation can be used in publications</td>
</tr>
<tr>
<td>Serious Game</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes.</td>
</tr>
<tr>
<td></td>
<td>The game provides different levels of complexity. It can therefore be tailored for all identified target groups. Even a simple scenario can be provided to be used for public presentations.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1 Simulation

The simulation has been used in a post exercise session of the Swedish pilot trial in Linköping, Sweden. In order to determine if the results of the simulation are realistic, a comparison with actual results from the exercise has been performed. During the exercise, participants used the commercial tool MASA Sword which is a simulation for command post staff training and analysis and used for military as well as emergency training worldwide.

4.2 The DARWIN Serious Game

The development timeline of the DARWIN serious game, unfortunately, did not coincide with the planning and the pilot trials, and therefore it has not been possible to evaluate the game during the DARWIN pilot trials. Therefore, the evaluation will take place after the delivery of this document on the basis of expert and other stakeholders’ knowledge.
5 Outlook

This chapter will present an outlook on how the prototypes of the simulation tool as well as the serious games can be used (and further enhanced) within the DARWIN project as well as outside (after the lifetime) of the project.

5.1 Simulation

After the completion of T3.2 specifically and WP 3 in general, the tool simulation tool developed here will be used during the DCoP workshop planned for March 2018. There, feedback of the participating stakeholders will be collected and reflected. A description will be given in deliverable D4.4 afterwards as well.

The simulation that has been tailor-made for the pilot trial in Sweden has shown the capabilities and possibilities of this framework. The basic simulation tool can be adapted to multiple scenarios. That is, other scenarios which display similar characteristics, with respect to logistic research questions, such as the transport of patients by different means of transportation, can be implemented easily. The generic and modular nature of the simulation environment supports the investigation of such problems. The discrete event methodology is suited to approach a wide variety of research issues which show elements of synchronization, choice, sequence and concurrency of processes and actions, so not only projects with focus on resilience questions can be served. The transaction based approach, which employs so called entities that can be assigned with attributes and which move through a model, can also be applied on questions of the Air Traffic Management system. An example of using an event based approach in ATM is represented by the ground handling processes of an aircraft. This so-call turn around process of aircraft on an airport is currently topic of research work where the simulation tool is also used.

The character of the simulation environment also qualifies for implementing particular workflows of organizations. The abstraction of the relation between processes, actors, roles and resources (for example by the means of activity diagrams), can be used to transfer organizational procedures into the simulation. This would support the domain expert to automatically detect subsystem interdependencies in parts of operational procedures of an organization. That might be useful in case a wider scope in the cross-linking of organizations is envisaged to be subject of investigation. TUBS will continue to use the simulation environment in further research projects.

5.2 The DARWIN Serious Game

The DARWIN Serious Game has been developed in a reusable way. It produced generic components that could be used in various virtual reality games and applications. We worked to make an enjoyable and user-friendly experience, with features and ideas that could be published and reused in future applications. Some components in the game are very well refined, while some other components are still proof of concepts. We would like to continue improving the game in future projects. The game could also be used as a basis for new serious games or other applications in virtual reality and augmented reality. We foresee a strong potential in virtual reality visualisations and chatbot interactions, and this serious game already supports that.

Different experiments on this tool are foreseen involving end-users within and outside the consortium. An experiment is foreseen during the DARWIN Community of Crisis and Resilience Practitioners (DCoP...
workshop planned for March 2018. Section 3.3 describes an initial template on how to conduct the DARWIN serious game has been created associating the game to CCs. This template follows same information as for other innovation games (e.g. D3.4). The template will be improved based on experienced gathered from experiments.

After the completion of this deliverable, the game will be used within the DARWIN project as a dissemination and training tool associated to Resilience Management and DRMG CCs. Interactions are planned with other H2020 project addressing virtual reality to explore synergies and complementaries. The development and experiences from the DARWIN Serious Game will also be used in future research papers.
6 Conclusions

The document has described the two different approaches of supporting tools which will help to uptake and facilitate the usage of the DARWIN Resilience Management Guidelines. Even if the development took longer than expected and therefore the tools weren’t ready to be used during the pilot trials the simulation environment already proofed its usefulness in an after-trial debriefing workshop with the involved DARWIN partners FOI and KMC. D3.3 has described the details of the serious games and the simulation environment. The tools have reached a maturity level which allows the statement that the WP3 objective “adapt available simulation and serious gaming tools to support the utilization of the guidelines” has been achieved. The tools also contribute to the overall project objectives O2 “To enable use of resilience guidelines in non-crisis situations, for purposes of: 1. Basic learning and familiarisation; 2. Practical training, based on simulation techniques (including “serious gaming”).”, O5 “To build on “lessons learned” in the area of resilience by: 1. Identifying criteria that provide indicators of what works well and what does not; 2. Applying these criteria in defining and evolving resilience guidelines.” and O7 “To establish activities that will lead to project results being adapted to, and later adopted by, practitioners in domains other than the two used in the pilots.”.

Even with WP3 ending by end of November 2017 it is planned to use the tools in a dedicated workshop session within the upcoming DCoP workshop which is planned in March 2018. The results of this workshop including the than collected feedback will be incorporated into the D4.4 “Final Guidelines Evaluation Report”. The simulation tool was focused on the Swedish pilot trial (scenario 4) as the modeling of scenarios is a very detailed and time consuming task. But even with this limited setup the principle approach to implement the DARWIN Resilience Management Guidelines can be shown and proven. Both tools are ready now to support the implementation of the DRMG. They are able to be used in different domains as long as enough data parameters for a detailed model description (especially for the simulation environment) are available.

The usage of the simulation environment during the after-trial exercise showed clearly that such a tool will be helpful before as well as after an exercise. With this result a powerful predictive simulation environment has been developed and adopted for preparation and de-briefing actions of stakeholders in different areas of critical infrastructures.

At SINTEF, the DARWIN serious game was a very ambitious task that we are proud to complete. During its development, we explored many fields in human-computer interactions, which are our research domain. We developed new interactions such as live data manipulation on virtual environments. Based on our experience, literature review and virtual games developed on on-going security projects e.g. AUGMED and TARGET, our opinion is that the DARWIN serious game is an unique gameplay in the form of serious games that do not require a lot of resources. We think this is very useful for DARWIN. All the new technics would be further explored and published. Its development will very likely continue after the conclusion of the DARWIN project.
7 References


