



Driving Innovation in Crisis Management
for European Resilience



D923.22 SECOND RELEASE OF THE TEST-BED REFERENCE IMPLEMENTATION

SP92 - TEST-BED

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Table of Contents

[About](#)

[Executive summary](#)

[1. Introduction](#)

[2. Test-bed for Trial owners](#)

[3. Test-bed description](#)

[4. Test-bed for developers & sysops](#)

[Abbreviations](#)

[Annex 1. Terminology](#)

[Annex 2. Change history](#)

[Annex 3. Test-bed design](#)

[List of Figures](#)

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The DRIVER+ project

Current and future challenges due to increasingly severe consequences of natural disasters and terrorist threats require the development and uptake of innovative solutions that are addressing the operational needs of practitioners dealing with Crisis Management. DRIVER+ (Driving Innovation in Crisis Management for European Resilience) is a FP7 Crisis Management demonstration project aiming at improving the way capability development and innovation management is tackled. DRIVER+ has three main objectives:

1. Develop a pan-European Test-bed for Crisis Management capability development:
 - Develop a common guidance methodology and tool (supporting Trials and the gathering of lessons learned).
 - Develop an infrastructure to create relevant environments, for enabling the trialling of new solutions and to explore and share Crisis Management capabilities.
 - Run Trials in order to assess the value of solutions addressing specific needs using guidance and infrastructure.
 - Ensure the sustainability of the pan-European Test-bed.
2. Develop a well-balanced comprehensive Portfolio of Crisis Management Solutions:
 - Facilitate the usage of the Portfolio of Solutions.
 - Ensure the sustainability of the Portfolio of Solutions.
3. Facilitate a shared understanding of Crisis Management across Europe:
 - Establish a common background.
 - Cooperate with external partners in joint Trials.
 - Disseminate project results.

To achieve these objectives, five Subprojects (SPs) have been established. **SP91 Project Management** is devoted to consortium level project management, and it is also in charge of the alignment of DRIVER+ with external initiatives on crisis management for the benefit of DRIVER+ and its stakeholders. In DRIVER+, all activities related to societal impact assessment (from the former SP8 and SP9) are part of SP91 as well. **SP92 Test-bed** will deliver a guidance methodology and guidance tool supporting the design, conduct and analysis of Trials and will develop a reference implementation of the Test-bed. It will also create the scenario simulation capability to support execution of the Trials. **SP93 Solutions** will deliver the Portfolio of Solutions which is a database driven web site that documents all the available DRIVER+ solutions, as well as solutions from external organisations. Adapting solutions to fit the needs addressed in Trials will be done in SP93. **SP94 Trials** will organize four series of Trials as well as the final demo. **SP95 Impact, Engagement and Sustainability**, oversees communication and dissemination, and also addresses issues related to improving sustainability, market aspects of solutions, and standardization.

The DRIVER+ Trials and the Final Demonstration will benefit from the DRIVER+ Test-bed, providing the technological infrastructure, the necessary supporting methodology and adequate support tools to prepare, conduct and evaluate the Trials. All results from the Trials will be stored and made available in the Portfolio of Solutions, being a central platform to present innovative solutions from consortium partners and third parties and to share experiences and best practices with respect to their application. In order to enhance the current European cooperation framework within the Crisis Management domain and to facilitate a shared understanding of Crisis Management across Europe, DRIVER+ will carry out a wide range of activities, whose most important will be to build and structure a dedicated community of practice in crisis management, thereby connecting and fostering the exchange on lessons learnt and best practices between Crisis Management practitioners as well as technological solution providers.

Executive Summary

The Test-bed reference implementation lies at the heart of the Trialling environment of the [DRIVER+ project](#) (see Figure 1 or visit the animation online at <https://vimeo.com/299680658>). It provides an open source technical backbone to perform Trials or exercises in a methodical and structured way by offering Crisis Management practitioners a suite of free *software* tools. This document discusses the Test-bed's usage and design from the perspective of a practitioner. The later chapters, however, are aimed at developers and system administrators, and therefore assume that the reader has at least some technical background. In DRIVER+ deliverable [D923.11](#) "Functional specification of the Test-bed", the requirements of the Test-bed are documented. These requirements serve as basis for the design of the first release of the DRIVER+ Test-bed reference implementation as described in deliverable [D923.21](#).

The current version of this document discusses the **second version** of the Test-bed reference implementation. Therefore, all returning readers are advised to read the [change history](#) carefully, as many parts of this document did not change.

The [trial](#)-oriented environment developed in sub-project 92 (Test-bed) of DRIVER+ is conceived and designed to allow systematic testing of solutions in realistic but non-operational contexts (namely, in Trials) to help practitioners in assessing solutions that can drive innovation (changes) before adopting them. See also deliverable [D922.21](#), "[Trial guidance methodology and guidance tool specifications \(version 1\)](#)".

The purpose of conducting Trials in DRIVER+ is to find out if and how some innovative solutions can help resolve the needs of Crisis Management practitioners.

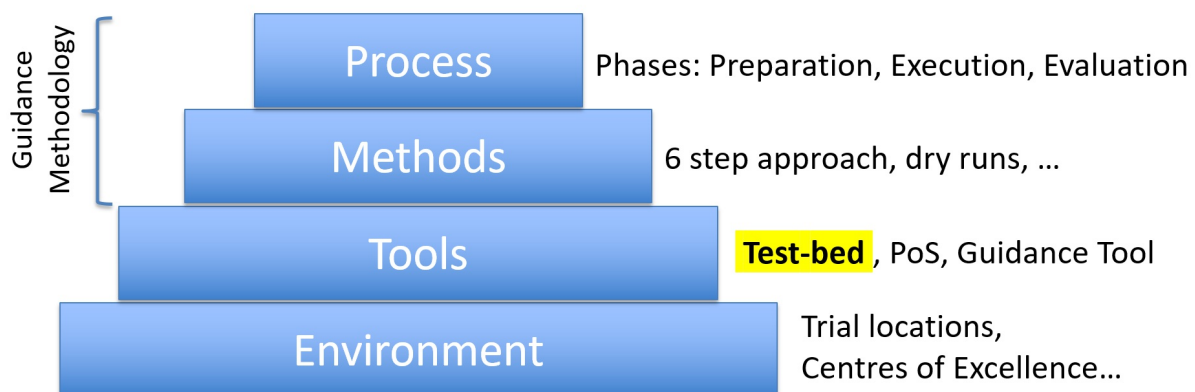


Figure 1. Process-Methods-Tools-Environment (PMTE) paradigm applied to DRIVER+.

The basic problem that the Test-bed reference implementation tries to solve is how to connect different solutions, which solve a particular Crisis Management ([CM](#)) gap, to:

- **Each other**: since no single application can solve all [CM](#) gaps, they need to work together by sharing information.
- **One or more simulators**: since during a [Trial](#), you cannot start a real incident, there needs to be a way to *simulate* a realistic incident.

The main design decision is to connect solutions to a so-called Common Information Space ([CIS](#)), simulators to a Common Simulation Space ([CSS](#)), and to have gateway services in between that selectively allow some information to pass between the two spaces (see Figure 2). These spaces can be public or private, and allow applications to write messages to a topic of interest, or read those messages. Although both spaces are comparable in that they share well structured messages (using Apache [AVRO](#)) over a popular open source distributed messaging system, Apache Kafka, the separation allows for a better control of the message flow, and for replacing parts with an alternative implementation if needed.

In addition, several adapters are created to connect solutions and simulators to the [CIS](#) and [CSS](#): besides allowing users of the Test-bed to choose an adapter in their favourite programming language, and share messages, it also provides a common interface for configuration, heartbeat messages, and security. Currently, adapters in Java, C#, JavaScript/TypeScript, Python and [REST](#) are available.

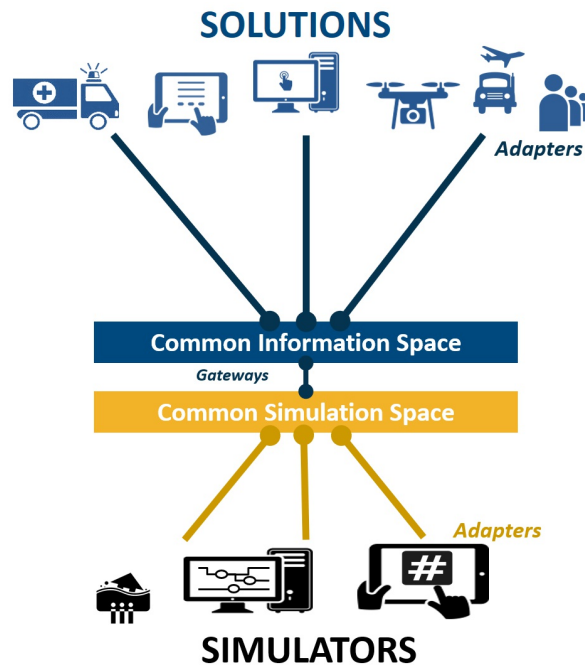


Figure 2. The Common Information and Simulation Space allow the exchange of well-structured, informative messages.

Around this core functionality, additional tools are developed that facilitate the usage of this environment (see Figure 3):

- **Administrative tools**: Is everyone up-and-running, secure, and connected to the right information topics?
- **Evaluation tools**: What did we observe during the [Trial](#), and what implications does this have during the After-Action Review.
- **Scenario tools**: To create an interesting scenario that triggers the participants and solutions in the right way.
- **Support tools**: For testing and debugging, for creating your personalized Test-bed environment, but also to share common data such as map layers or census data.

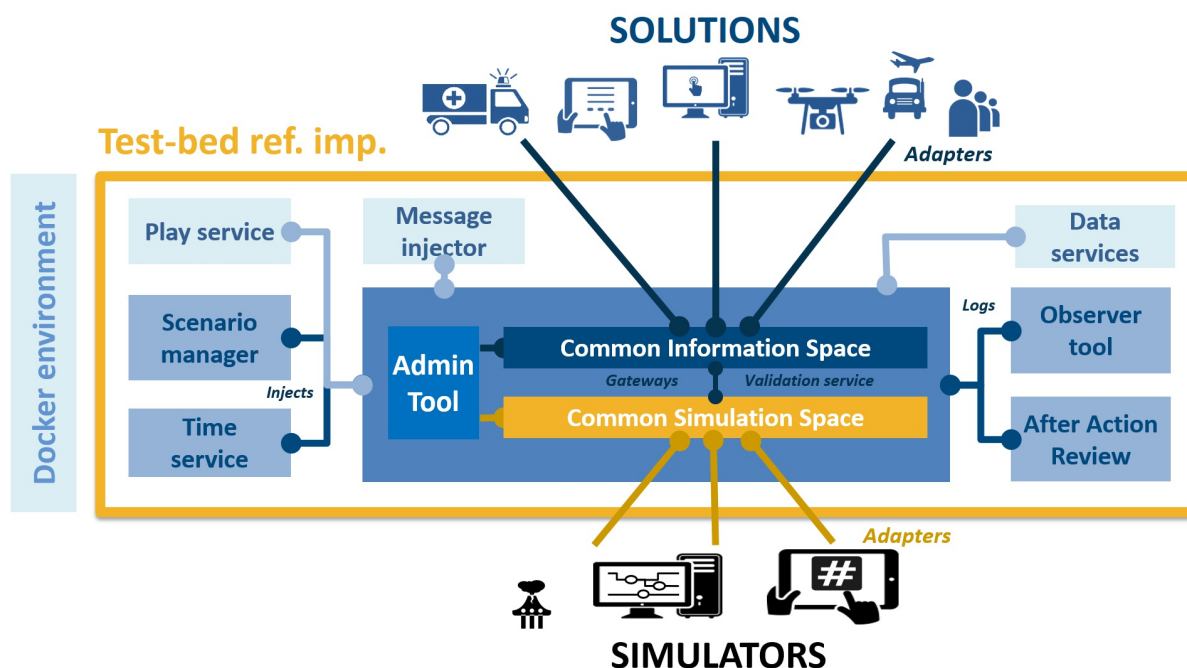


Figure 3. Test-bed reference implementation: the components inside the yellow rectangle are being developed as open source tools in the DRIVER+ project.

The Test-bed will be delivered in 3 versions. Version 1 is intended for use in Trials 1 and 2, and consists of a limited number of components (i.e. [Scenario Manager Tool \(SMT\)](#) and [After-Action-Review \(AAR\)](#) tool are not included and other components in first prototype quality). Version 2 (*current version*) is to be used in Trials 3 and 4 and the Final Demo and comes with all components with a quality level surpassing that of a first prototype. It will contain data-sets and basic scenarios that can be used for effectively implementing and testing the Test-bed. The final version, Version 3, should have an even better quality based on experiences gathered from the use of the Test-bed in the executed Trials.

All versions are already available open-source (under a liberal MIT license) on github.com/DRIVER-EU. The subsequent updated Test-bed reference implementations are documented in D923.21, D923.22 (this document) and D923.23 - Reference Implementations of the Test-bed (versions 1/2/3 resp.).

This document is a living document, and the latest version is available online at <https://driver-eu.github.io/test-bed-design> or can be downloaded as [PDF](#), [epub](#) or [mobi](#) eBook¹.

¹. Since the printed version is automatically generated from the online book, the template is slightly different from a Word-based version. It starts at a high-level with a description of the main components of the Test-bed reference implementation. Next, chapters are dedicated to the main users of this environment, practitioners and developers/ICT administrators. And it concludes with a brief explanation of the main design decisions. ↩

1. Introduction

In the Crisis Management (CM) domain, practitioners need to be prepared for the unexpected: based on past experience and the local incidents they had to deal with, they develop a feeling for the things that did not go so well. As with most incidents many lives are involved, they are continuously looking for solutions to improve their response and preparedness. Their aim is to be more efficient and effective, save more lives, against fewer costs. Some of the ways to achieve this are to improve existing CM procedures, like media communication. Other possibilities are to introduce new software applications or hardware to remedy current shortcomings, such as introducing a Common Operational Picture application when the situational awareness is insufficient. But how does one really know that such a solution improves things? By trying them out in a Trial, a well-controlled experiment carried out under observation.

The DRIVER+ project aims at helping CM practitioners by providing them with the 'tools' to properly evaluate new solutions during a Trial:

- The Portfolio of Solutions (PoS), an online web application where the CM practitioner can find out about existing solutions, and user experiences.
- A Lessons Learned Framework (LLF), an online web application to share experiences among practitioners.
- The Trial Guidance Methodology (TGM, deliverable D922.21 - Trial guidance methodology and guidance tool specifications (version 1)) and Trial Guidance Tool (TGT), a step-by-step approach that guides CM practitioners through all the steps needed to prepare and run a Trial.
- The Test-bed infrastructure, a suite of software tools and services that support practitioners preparing and executing a Trial or training exercise

This document is all about the latter, the Test-bed infrastructure, but since it strongly relates to the TGM, a brief summary of the TGM is presented first.

Within the DRIVER+ project, a Trial Guidance Methodology (TGM, deliverable D922.21 - Trial guidance methodology and guidance tool specifications (version 1)) and tools are developed to help resolve the needs of practitioners through a systematic and pragmatic approach. The Test-bed infrastructure is a suite of software tools and services that enables solutions and simulators in the Crisis Management (CM) domain to easily exchange information (see Figure 3). This allows end-users in the CM domain to Trial solutions, and see if they address their gaps. Additionally, it can be used to support training exercises as well.

The simplified DRIVER+ TGM process to Trial solutions is like this:

1. PREPARATION PHASE:

- The operational issues practitioners experience are matched with one or more of the well-known crisis management gaps, as experienced by many of their colleagues, e.g. *How to get a real-time and dynamic overview of the position of all personnel?*
- These gaps, in turn, are still too generic to address, and are made more specific, leading to so-called 'research questions', e.g. *Which Situational Awareness-increasing solution fits best with our mode of operation?*
- Existing solutions are reviewed and selected. Some solutions can even be tried out standalone using the Test-bed and an existing mini-scenario.
- Based on the selected solutions, gaps and research questions, a data collection plan is developed: what kind of data does the Trial need to generate to enable a valid evaluation at the end of the Trial.
- A scenario is developed that puts these solutions to the test. This includes selecting and connecting simulators of a fictive incident, e.g. a flooding simulator, and other simulators to create a realistic environment, e.g. a traffic simulator.
- Selected solutions and existing legacy systems are connected to the Test-bed, so they can receive input from the simulators as well as each other.

2. EXECUTION PHASE:

The Test-bed is setup, all simulators and solutions are connected, data collection is in place, and a scenario can be run (executed). Before the actual Trial, several dry runs are performed, partially for testing the setup, and partially for training the participants in using the solutions. This phase ends when the Trial is executed and observed.

3. EVALUATION PHASE:

Based on the recorded observations and collected data (screenshots of running applications, messages sent, actions and decisions taken) during the [Trial](#), the solutions are evaluated with the participants, leading to a good appreciation of how the selected solutions have contributed to solving the problems.

1.1 Aim of this Document

This document aims at providing the [CM](#) practitioners with a clear understanding of what the Test-bed is, and what it can do for his or her organisation. Especially chapter 1 and 2 will be of interest to them, and for the more technical oriented [CM](#) practitioner, also chapter 3. Chapter 3 and 4 are concerned with the technical setup, and are directed at developers or system administrators that need to connect new solutions or setup and maintain a Test-bed.

1.2 Scope of the document

This document limits its scope to the core Test-bed design, more specifically, the design of the Test-bed's reference implementation, which is an implementation of the [Test-bed specification](#) (see Figure 3): it thereby provides an overview of the most important components of the Test-bed, how they work together, and how they can be used by different stakeholders.

The [CM](#) solutions and simulators that supplement the Test-bed, however, are *not* part of the Test-bed. The simulators' function is to simulate an incident, and the reactions that may occur in a real world, since we cannot unleash incidents like a flooding and earthquakes on the real world. The solutions are the actual tools that are trialled and evaluated, and measured whether they actually do solve a [CM](#) gap. These solutions are fed with the simulator's output, and perhaps the output of other solutions, so end users can observe and evaluate their contribution during a fictive incident.

1.3 Organisation of the Document

This is a live document, and the latest version can always be found online at <https://driver-eu.github.io/test-bed-design>. It is organised as follows:

For **reviewers**, please refer to [Annex 2 Change history](#) to see what has changed since the previous version. In order to quickly understand the Test-bed, have a look at the [5 minutes animation](https://vimeo.com/299680658) at <https://vimeo.com/299680658>.

The chapter, [Test-bed for Trial owners](#), is specifically aimed at [Trial owners and practitioners](#), and discusses the functionality the Test-bed offers to them. And also, what it does not offer.

The [Test-bed description](#) provides a general overview of the Test-bed reference implementation and its building blocks. It is a more technical chapter aimed at Test-bed users with a (limited) technical background.

In the chapter, [Test-bed for developers and sysops](#), the technical side of the Test-bed is explained in more detail. Specifically: how to manage a Test-bed as a sysop, or how to connect a new Solution or simulator as a developer. To learn more about the design principles underlying the Test-bed, the reader is referred to [Annex 3 Test-bed design](#).

1.4 What's new

Version 1 (2018-03-31)

This is deliverable D923.21, describing the first version of the Test-bed reference implementation. It matches the release version of the software applications as available on GitHub: github.com/DRIVER-EU. Two future releases of this document are planned, v2 and v3, and the major changes between the different documents will be described here. In the mean time, this online documentation is continuously updated, so it matches the current state of the Test-bed.

Version 2 (2018-11-30)

This is deliverable D923.22, describing the second version of the Test-bed reference implementation v1. All changes with respect to the previous version are documented in [Annex 2 Change history](#).

2. A Test-bed for Crisis Management Practitioners

This Chapter discusses the **future** Test-bed functionality that could benefit a practitioner, so although most functionality can already be realized today, not everything is in place yet.

Trial owners will interact with the Test-bed when they want to **Trial** one or more solutions. Since Trials vary in complexity and scope, not all **TGM** steps may be required for every **Trial**. On the one side of the spectrum, the **Trial** may be more like a simple and inexpensive software **test**, in which a **Trial** Owner can verify that a Solution has useful features, is user-friendly, looks good, and does not crash. Typically, this would be done with only a few people. For a **CM** Solution, such a **Trial** also requires (some components of) the Test-bed, together with a test-scenario. The test-scenario allows you to test the solution in a relevant context.

For example, if one would test a **COP** tool as is, it would probably not have any map layers, basically showing an empty map. Using a test-scenario, the **COP** tool can be tested in the context of a simple incident, perhaps a flooding, have some ambulances driving around, and map layers showing population information, locations of critical infrastructure, etc.

On the other side of the spectrum, a **Trial** could involve multiple Solutions, many participants and observers, in a more realistic, operational-like scenario, with proper data collection and evaluation along all dimensions in place. In this case, the full **TGM** should be applied to perform a proper **assessment** and funded conclusions can be drawn. As the latter requires a serious investment in time, people and budget, a **Trial** Owner may consider to combine the **Trial** with a planned **exercise** to reduce the costs of preparing, executing and evaluating a **Trial**.

For simple as well as complex cases, the Test-bed supports practitioners by providing an environment in which they can easily **Trial** new solutions and run exercises:

- **Preparation support:** When preparing a **Trial**, practitioners can use the **Scenario Manager** tool to create one or more scenarios for the **Trial**. In addition, they can already document the observations they wish to see using the Observer Support Tool. As part of the preparation, the Test-bed also offers:
 - **Simulation support:** Due to the nature of the crisis management domain, most solutions cannot be properly tested outside an actual crisis situation. As starting a flooding or burning a forest is clearly not an option to test the solutions, the crisis incident needs to be faked or simulated. The same applies to expected reactions of the environment: people panicking, traffic jams, etc. must be simulated too. As most **CM** simulators cannot simulate realistically all types of incident and reactions, the Test-bed supports multiple simulators so they can collaborate and create the desired fictitious incident.
 - **Solution support:** The new and shiny **COP** tool or other solution that is being evaluated never acts standalone in a void. Normally, solutions need to exchange information with other (legacy) solutions too, which is also supported by the Test-bed.
 - **Development support:** To connect new solutions and simulators to the Test-bed, the Test-bed provides adapters in several popular languages and several debugging tools and services. Also, to check whether everything is up-and-running smoothly, developers and system operators can use the Admin tool.
- **Execution support:** Scenarios created during the preparation phase can be 'executed', or played, in order to control the **Trial**. And the scenario time is controllable too.
- **Evaluation support:** As we are testing and evaluating new solutions, the Test-bed provides the After-Action Review tool for capturing and reviewing sent messages and the Observer Support tool to capture observations. In addition, the exchanged information can be logged and processed for further evaluation after the **Trial**.

In the following sections, a use case (storyline) description of each is provided. The main actor in each story is Monica, a regional crisis manager with a professional background in fire-fighting. One of the challenges she is facing is that she does not always have a good overview of where her people and trucks are during a large-scale fire, and she is looking for a solution. Please also have a look at the animation, which is available online at <https://vimeo.com/299680658>.

2.1 Use Case: Evaluating a solution standalone

Monica has heard about an interesting [COP](#) solution via the DRIVER+ Portfolio of Solutions. She considers using it to address her problems in fighting fires. After defining the gaps and specifying the requirements, according to the [TGM](#), she continues in an iterative way:

1. Monica, perhaps supported by an IT professional, visits the Test-bed's [composer website](#) (see Figure 4). *It allows her, or anyone else, to specify the technical components that should make up the Test-bed. It can be compared to buying a car: do you select an air conditioner, cruise control, and a solar screen, or can you live without them.*
2. She opens the solution's tab and sees that the [COP](#) tool is available for evaluation. *In the future, available solutions could be linked to the Portfolio of Solutions.*
3. She selects it in the menu (see Figure 5).
4. She understands that it is difficult to test a solution without any data / scenario, so she visits the data tab and selects a fire-fighting data set situated in the South of France: *It involves a large-scale forest fire, which is rapidly spreading. Ambulances and fire trucks are deployed and driving around. She can also look at census data of the area and a weather report.*

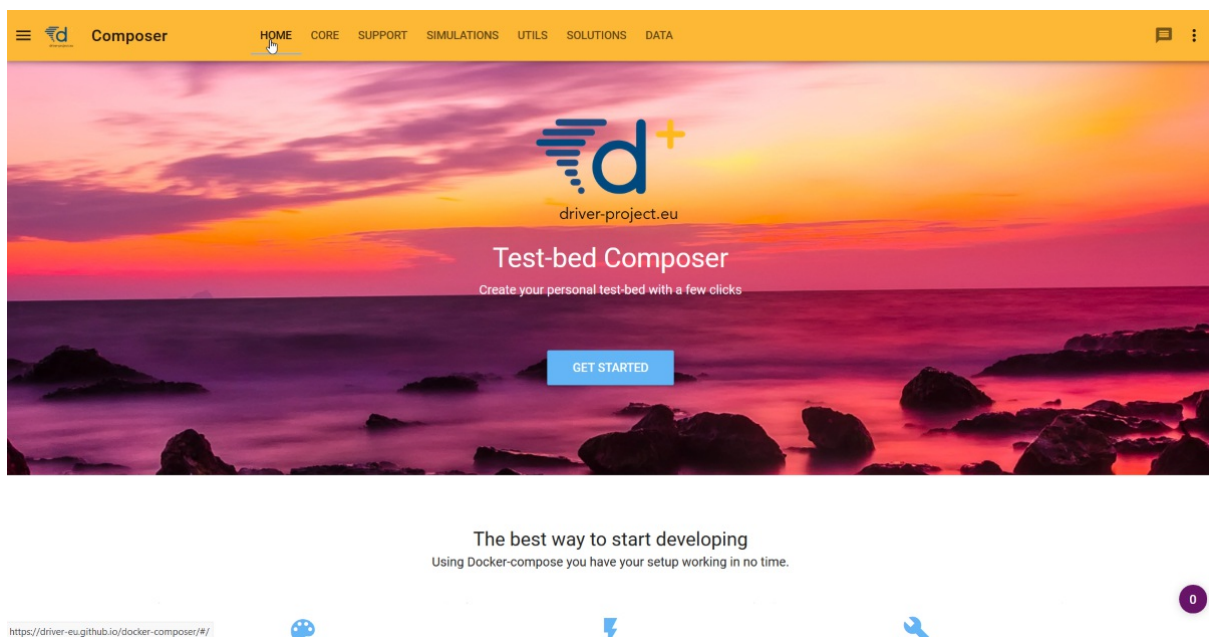


Figure 4. Test-bed composer's home page.

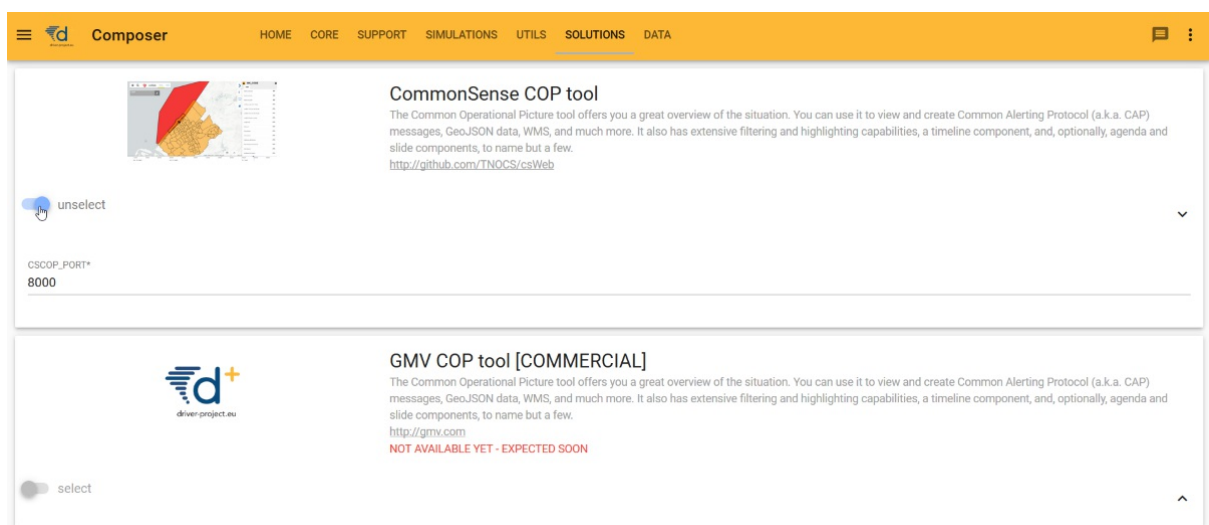


Figure 5. Test-bed composer: Selecting a solution.

From here on forwards, two alternatives are presented. The first one represents the desired situation. The second alternative is already in place.

Alternative 1: Cloud scenario

1. As she currently is not interested in other solutions, she opens the menu and clicks on the DEPLOY button. A dialog opens and informs her to wait while her selected Test-bed is started in the cloud.
2. After a brief moment, the Test-bed is running and she gets her own unique link. She visits this website, and is presented with a simple menu: she can start (pause | stop) the fire fighting scenario, and open the website of the [COP](#) tool. In its layer menu, she can turn on the layer which shows the ambulances and fire trucks. There are also options to turn on the fire fighting layer to show the location of vehicles and staff, etc.

Alternative 2: Local scenario

1. As she currently is not interested in other solutions, she opens the menu and clicks on the BUILD button. A dialog opens and she can download the [Docker-compose](#) file to her PC (see Figure 6).
2. Running a simple command, the Test-bed is downloaded and started on her own PC, and she can interact with the Test-bed as described above.

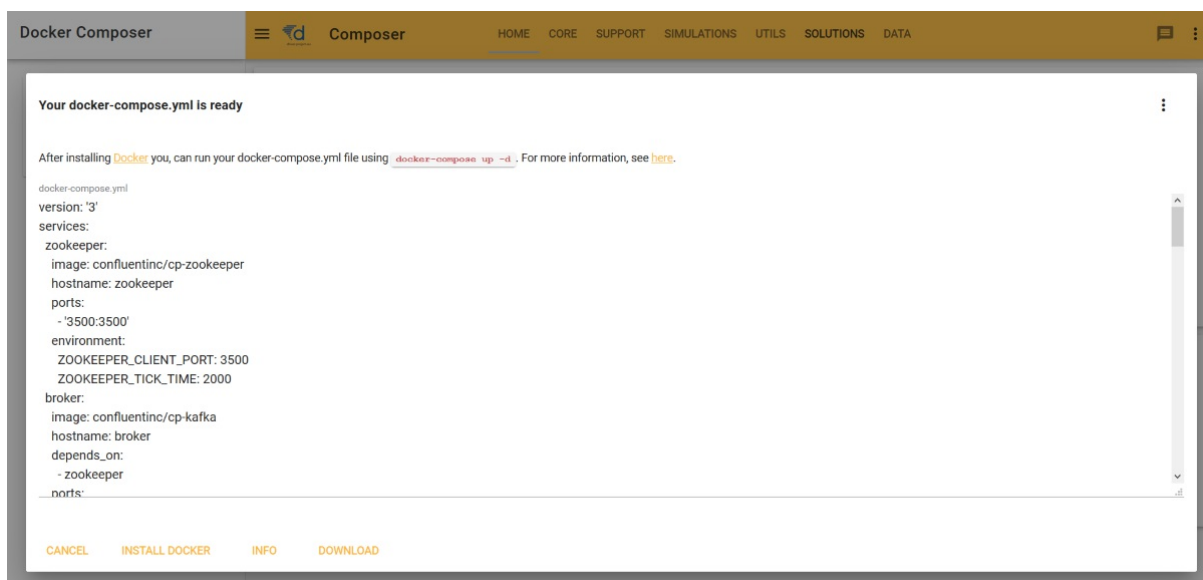


Figure 6. Test-bed composer: Downloading the [docker-compose.yml](#) file.

2.2 Use Case: Assessing solutions using a Trial

In order to run a [Trial](#), a similar process as described above could be followed. The main difference is that more services and solutions will be added, and more people are involved. In addition, the Test-bed is needed already well-before the final [Trial](#) date, since:

- The scenario is created iteratively.
- Not all solutions or simulators are already able to connect to the Test-bed. So even before the first dry-runs, solutions and simulators should be able to test their connection and integration.

In this case, Monica is supported by the local [CM](#) expertise centre, which could also be offered via a consultant, a simulator owner, or otherwise, which helps her in setting up the required infrastructure.

1. She contacts one of the local [CM](#) expertise centres, and request a Test-bed in the cloud. It is created for her instantly.
2. She contacts the solution provider, and informs him of her Test-bed. This solution owner can contact the [CM](#) expertise centre, and with help of its IT staff, are able to connect to Monica's Test-bed, so Monica can have a first look. This connection to the Test-bed is needed, so the Solution can receive information about an fictitious incident, or from other solutions in a more complex [Trial](#).
3. As part of the online Test-bed, she now has access to the [Scenario Manager](#) Tool (SMT, see ??? *under development*), which allows her or one of her [CM](#) colleagues, to create the outlines of several wildfire scenarios by recording the main flow of events during an incident. The scenario is key in that it translates specific objectives to a storyline so the solutions or people can be put to the test:
4. As the SMT does not create the actual incident itself, she realizes that she needs some simulators to simulate a wildfire, traffic and evacuating civilians. In DRIVER+'s Portfolio of Solutions, she finds several simulators that are compatible with the Test-bed and contacts their owners. The simulation providers, like the solutions provider, are able to connect to Monica's Test-bed too. Alternatively, it may be offered by the [CM](#) expertise centre too. Using the Test-bed connection, the simulators can send incident information to the connected Solution, which it can display. In addition, simulators can share information too, so simulated people do not walk happily through the fire!
5. Monica asks one of her colleagues to detail the questions for the observers, which he can document in the Observer Support Tool.
6. During a [Trial](#), Monica can start the scenario. The [Scenario Manager](#) Tool instructs everyone when to perform their planned act. For example, the SMT instructs the Observer Support Tool to send the first set of questions to the observers. Monica can also control the scenario time, for example by freezing the time during a break. In case the users of a Solution missed an important test moment, she can also invoke optional storylines or acts, so the Solution and its users get another chance to prove itself.

3. Test-bed description

The Test-bed supports practitioners by providing an environment in which they can easily [Trial](#) new solutions and run exercises. In this chapter, the main components of the Test-bed are explained (see [Figure 3](#)) and is aimed at a fairly technical audience.

3.1 Core

The Test-bed must support the exchange of information between solutions, simulators and tools. Information such as the location of an incident, alert messages, or the locations of vehicles. Comparable to people exchanging information via email, chat or twitter, the Test-bed exchanges information using the open-source messaging system [Apache Kafka](#) from the [Apache organisation](#).

Since all DRIVER+ solutions are software systems, the Test-bed's support for non-software systems, such as a new process, is limited: Clearly, the Observer Support tool and After-Action Review tool could be used. However, the Test-bed can also provide a suitable environment for exercising a new process, since it offers facilities to create a realistic incident environment. For example, the open source SUMO tool could be used to simulate traffic, and the open source csCOP tool could be used to offer the participants a realistic common operational picture during their [Trial](#). Do note that in this case, the data capturing and analysis would be more primitive compared to technical solutions, in that it would mainly depend on the observations.

Adapters

Adapters are used to connect solutions and simulators to the Test-bed in order to exchange information. As the Test-bed is based on Apache Kafka, which is used worldwide, there are connectors for most programming languages, so software applications can easily connect to it. While connected to the Test-bed, an application can send and/or receive messages. When you want to *receive* a message, you subscribe to a topic of interest: thereafter, you get all the messages that are published until you end your subscription. Optionally, you can even receive messages that were published in the past, or while you were offline, as Kafka logs all messages for a pre-set time. This is especially useful for mobile clients that are not always connected to a network. To *publish* a message, you just need to send it to a topic of interest and every interested application that has subscribed to this topic receives it instantly.

For example, to publish a CAP (Common Alerting Protocol) message to all interested parties, you use an adapter to send your CAP message to the 'cap' topic. Every tool that has subscribed to the 'cap' topic will get it right away.

The default Kafka connectors are lacking certain features that are useful in a Test-bed environment, so several existing connectors have been extended. These extended connectors are called **adapters**, which extend regular Kafka connectors with:

- **Heartbeat signals:** Before you can start a [Trial](#), every solution, simulator and tool needs to be up-and-running. Therefore every adapter transmits a heartbeat signal every 5 seconds to inform others it is online. This is monitored in the [Admin Tool](#).
- **Logging:** Besides being online, it is also important to know that each connected service is running as expected, so each adapter offers the option to log warnings/errors to the Test-bed as well. The logs are displayed in the [Admin Tool](#).
- **Configuration options:** The adapter can be instructed via the Admin tool to subscribe and publish to certain topics, and vice versa, the adapters inform the Admin tool. In addition, this can be configured too externally.
- **Trial Time:** A [Trial](#) scenario typically will not run at real-time, so the adapter needs to share the fictive simulation time. In addition, it shares the simulation speed, as we may be running slower or faster than real-time, as well as the simulation state (paused/playing/stopped).
- **Large files:** Although most messages that are shared between applications are small (< 1Mb), some are not. For example, to describe the flooding in an area, or when capturing drone imagery, file sizes may easily exceed 1Gb. For that reason, the Test-bed runs a service to share large files, and adapters facilitate using this service: the large file is uploaded to the service, and the adapter either sends a message when ready, or informs the application. Other applications can subsequently use the returned (URL) address to access the file.
- **Security:** By default, all topics are accessible to all connected adapters, which is fine in most cases. However, sometimes a less liberal access is required, e.g. when sharing the locations of critical infrastructure or network configurations. The latest versions of all adapters, therefore, include a security component which prevents unauthorized users from accessing specified topics.

The Test-bed currently maintains the following adapters: [Java](#), [C#](#), [JavaScript/TypeScript/Node.js](#), [Python](#), and a [REST](#) adapter, which allows any application to publish and receive messages using basic internet commands.

Messages

As software applications need to understand the messages they receive, the Test-bed has to assure that every message that is sent complies with the expected format (syntax). For example, when a solution wants to share the location of a vehicle or the value of a sensor, you probably need to capture the vehicle's or sensor's location, as well as its type, speed or sensor value. Then it is important to know that the type will be one out of a list of possibilities, that the location is specified using two numbers, and that the speed or sensor value is a number too.

To capture this information, the common solution is to specify it in a so-called schema. The Test-bed enforces this too, and it uses the open [Apache AVRO](#) schema format. All Test-bed schema's are shared publicly in the [DRIVER+ AVRO schema repository](#).

Dealing with standards: In the [CM](#) domain, several standards exist, such as CAP, EDXL or EMSI. They are represented using XML, a textual representation of a message that is easily readable by computers. A recurring problem with all standards, however, is that they rarely represent all the information you would like to share. This often leads to adding new fields, or, even worse, *re-purposing* existing fields. Additionally, not every organisation uses it in the same way. For Trialling new solutions, the Test-bed needs to be flexible and exact, and that's why the Test-bed does support these standards, but converted to the [AVRO](#) format. In that way, every connected solution or simulator will exactly know what to expect when reading a message, as new fields can be easily added in a robust way.

CIS and CSS

The Test-bed distinguishes between a Common Information Space ([CIS](#)) and a Common Simulation Space ([CSS](#)). The [CIS](#) is where *solutions* exchange information, typically based on current emergency standards such as the Common Alerting Protocol (CAP) messages, or Emergency Data Exchange Language (EDXL) messages. The [CSS](#) is for *simulators* to exchange information. Typically, the [CIS](#) will exchange far fewer messages during a [Trial](#), and time synchronisation is simple. In the [CSS](#), however, many more messages are generated, e.g. the location of all vehicles may be updated every second. Simulators often need to be in tight synchronization with each other, e.g. when a flooding simulator floods an area, the traffic simulator should divert its traffic, and in the crowd simulator, people may be drowning.

For simple Trials, the [CSS](#) and [CIS](#) will run in the same Test-bed. In case performance suffers, it may be necessary to split the [CSS](#) and [CIS](#) over two Test-beds that are interconnected, a feature that Apache Kafka supports out-of-the-box.

Note, though, that the [adapters](#) can be used to connect to the [CIS](#) as well as the [CSS](#), so there is no difference between them.

In rare cases, the [CSS](#) may be replaced, or extended, by one of the existing simulation standards such as [HLA](#) or [DIS](#), that are especially popular in the Defence sector. Please refer to [Chapter 4](#) to learn more about this.

Gateways and Validation Services

Even when using well defined messages based on [Apache AVRO](#), it is certain that not all solutions and simulators speak each other's 'language'. As in Europe, where not everyone is speaking Esperanto or English, there is a need for translators, in the Test-bed we need *gateways* to translate one topic's message to another. Examples are not only translating one message format to another, but for example to translate:

- A message from a simulator sharing the location of all vehicles in the [CSS](#), to a [COP](#) tool message in the [CIS](#) that only contains the location of its own resources.
- An EDXL Resource Management request from a [COP](#) tool in the [CIS](#) to a simulator message in the [CSS](#), which in turn sends out an ambulance to the required location.

In order to facilitate Solutions to obtain the needed information from the simulated world, the [CSS](#) needs to be connected with the [CIS](#) by means of translator applications, residing in the [CIS-CSS Gateway](#) (see Figure 7). These translator applications form the bridge between the simulated *truth*, where everything is known in the [CSS](#), and the *perceived truth* in the [CIS](#) by translating relevant changes from the simulated world to messages globally understood in the [CIS](#).

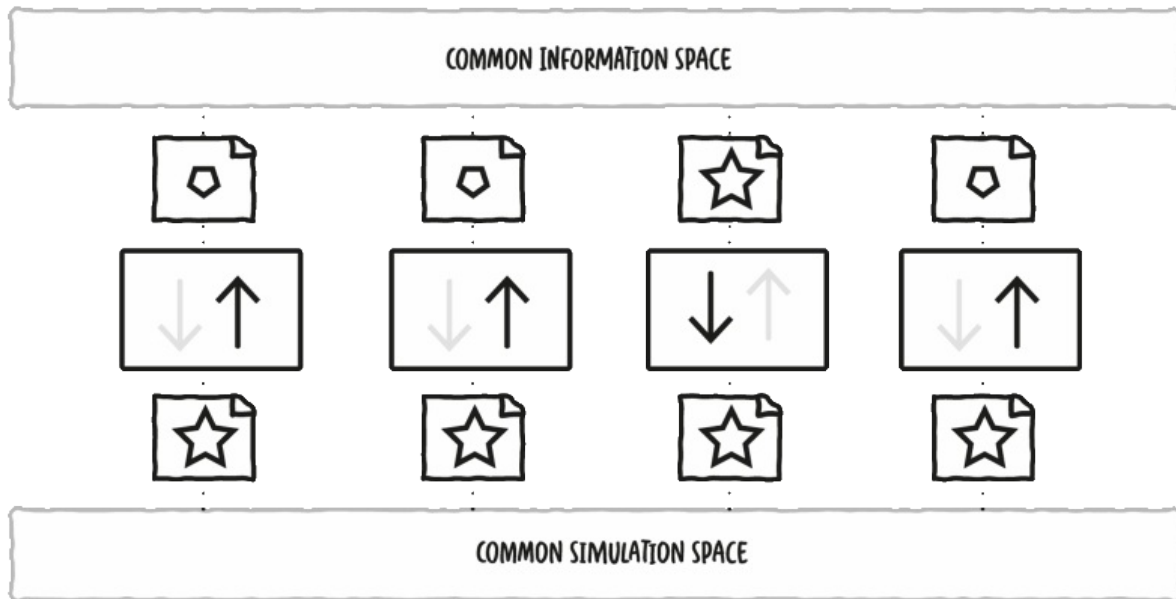


Figure 7. Conceptual diagram of gateways translating messages back and forth between CIS and CSS.

An example of this would be the simulation of a flooding. Imagine a river that has rising water levels due to an increase of rain water. At the river bank, there are several sensors that measure the actual water level. An application is created and connected to current operational systems to send CAP messages regarding the water level in clear categories ranging from LOW to DANGEROUSLY HIGH. A possible solution is assessed on improving decision-making based on the messages outputted by the created sensor application.

In this example, the water level is calculated in a flooding simulator, which connects to the CSS. The gateway listens to the calculated water levels in the CSS, uses it to compute the water levels at the exact sensor locations, and sends out the expected messages to the CIS, similar to the operational application. The decision-support tool, which is connected to the CIS, listens to these formatted messages of the gateway as if it was connected to the actual operational application. This also provides Trial owners the option to experiment with sensor failures, more or fewer sensors, etc.

There are also Solutions that send messages which serve as commands or requests to change the simulated world. Again, a gateway would be used to bridge the CIS and CSS spaces.

For example, a new dispatch centre Solution allows users to send out emergency services from their dispatch towards the incident location. The Solution would send out a standard resource management message via the CIS. The gateway service picks up the message and translates it to a request for changing the simulation space. The responsible simulator would receive this request via the CSS and simulate an ambulance driving through the simulated world towards the incident location.

Validation Services are specific gateways that, as the name suggests, validate a message in more detail, before it is passed on to other systems. For example, if application A is publishing a CAP (Common Alerting Protocol) message for application B, i.e. A → CAP topic → B, the Test-bed will make sure that it complies with the appropriate schema before passing it on. However, there may still be certain aspects in the message that are not completely correct, e.g. the alerting area that is represented as a polygon may not have the same starting and ending point (i.e. it is not *closed*), or the incident location that is represented by two numbers (x, y), may actually be published as (y, x). So during testing, the validation service can 'intercept' messages between A and B and validate them in detail. Only valid messages are passed on, i.e. A → CAP validation topic → CAP topic → B.

3.2 Test-bed administration tool

The Test-bed is a collection of services, simulators and solutions running in a distributed network environment, so it is often difficult to understand what is going on exactly. At the same time, the Test-bed needs to be prepared before the Trial can take place. You can compare it to a theatre play, where the stage needs to be prepared, the actors and musicians must be ready, as well as the light

and sound engineers. The Test-bed admin tool (see Figure 8) helps you set the stage, monitors both the [CIS](#) and the [CSS](#) to better understand the status of all services, simulators and Solutions. In particular, it allows you to:

- Publish all [AVRO](#) schemas that will be used during a [Trial](#).
- Determine whether all services are up and ready (via the adapter's heartbeat message).
- Make sure that all adapters connect to the expected topics.
- Check the distributed error log to see if any adapter is experiencing problems.
- Setup security, if required.

If all checks are passed, it sends out an 'all-clear' message, and the [Trial](#) can start.

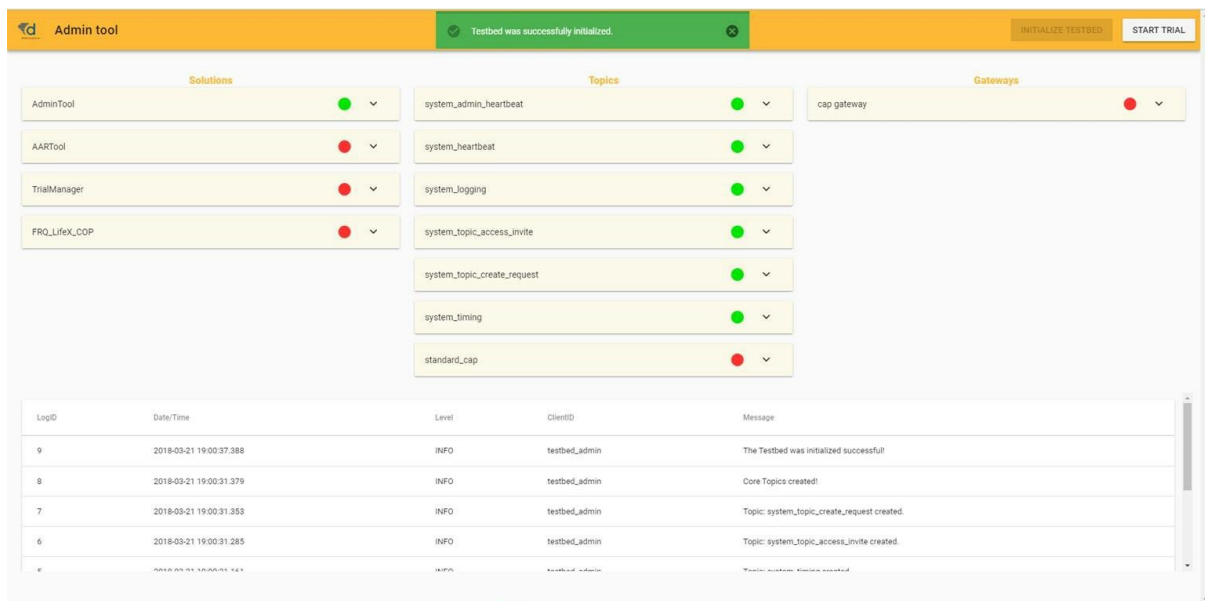


Figure 8. Admin tool.

Detailed information:

- [Functional specification](#)
- [Website](#)

3.3 Trialling, Exercising and Scenario Management

Whether designing a [Trial](#) to evaluate solutions, or an [exercise](#) to train people, a scenario and, optionally, simulations, are needed to immerge the training audience and to give them the feeling that they are dealing with an actual crisis.

For an [exercise](#), one starts by defining the *training objectives*, *What does the training audience need to learn?*. Next, an appropriate *Mission / Main scenario* is formulated in which these training objectives can be tested and exercised. The mission is further broken down into *storylines*. A Storyline describes a developing situation that will set conditions and provide the Training Audience an opportunity to achieve a specific Training Objective and optional secondary Training Objectives. It often targets a subset of the training audience, e.g. only the fire fighters, and consists of timed events, or so called *injects*. Think of an email to the commander, a 'start flooding' message to a flooding simulator, or instructions to a role-playing actor.

In a [Trial](#), although the primary objective is not to train people, but to test and evaluate solutions, a similar procedure is followed. In that case, the *training objectives* are replaced by *research questions*, but the other steps remain the same. More details about the methodology to setup a proper [Trial](#) can be found in the [Trial Guidance Methodology](#)'s public reports.

Existing software

The process described above is the typical approach taken by the NATO's Joint [Exercise Management Module \(JEMM\)](#) (see Figure 9). It is a tool to support live exercises as well as table top exercises, from a few people to battalions. It puts a lot of emphasis on authorization management (*who can do what?*) during the creation of a scenario, and has a limited level of automation. For example, JEMM can connect to Outlook / Exchange Server to automatically create or receive email messages. Sending, though, is still a manual process.

JEMM is only available free of charge to military NATO members, i.e. to use it in a [Trial](#), a military presence is required.

Joint Exercise Management Module (JEMM)
DEMO (DEVELOPMENT)
UNCLASSIFIED

27 APR 2012 21:55 Z D+3

Documents Map Key Processes Training Objectives MEL/ML **Exercise Script** Reports EBT RFC OPCAR Administration

Found 19 entries that meet the selected criteria:

Log	Reference	Subject	Sender / Owner	Receivers	Means	Date & Time	State
		STARTEX				25 APR 2012 00:00 Z	
	01.01.A02	VAS defector	SITFOR - LAP			25 APR 2012 01:00 Z	Ongoing
	01.01.A03	Water mine located close to Mindelo	SITFOR - LAP			25 APR 2012 ± 02:00 Z	Scheduled
	01.01.I03	NRF Rescue Operation	WC - INT MEDIA	DJTF COM	E-MAIL	25 APR 2012 02:43 Z	Injected
	01.01.I01	Contact report from LAP Police to local NRF LCC forces	SITFOR - LAP	LCC G2	PHONE	25 APR 2012 03:00 Z	Injected
	01.01.A04	Maggie May movement	SITFOR - LAP			25 APR 2012 05:00 Z	Completed
	01.01.R01	SITREP	LCC G2	HICON - INTEL		25 APR 2012 ± 07:23 Z	Awaiting
	01.01.I08	PRAIA hospital response	SITFOR - CPV	DJTF MED4D	FAX	25 APR 2012 ± 10:25 Z	On Hold
	01.01.R02	Reception NRF INTSUM of day 2	LCC G2	HICON - INTEL		25 APR 2012 ± 14:51 Z	Draft
		AAR Level 3				25 APR 2012 17:00 Z	
	01.01.I04	Cargo A/C escorted by Two VAS Fighters	LOCON - ACC	ACC AOC	PHONE	26 APR 2012 ± 08:00 Z	Scheduled
		EXCON Meeting, building 37				27 APR 2012 10:00 Z	
	01.01.I07	HUMINTREP	HICON - INTEL	ACC A2, ACC AOC	NS MAIL	27 APR 2012 ± 19:38 Z	To be Modified
	01.01.I05	Refugee Vessel Starts Sinking	LOCON - MCC SURF	MCC JOC	NS MAIL	28 APR 2012 ± 16:12 Z	Draft
	01.01.I06	INTREP - Possible Terrorist ISR at Mindelbo, CPV	SITFOR - CPV	LCC G2	PHONE	29 APR 2012 ± 13:47 Z	Cancelled
	STOR01	test				14 MAY 2012 15:00 Z	
	01.01.A01	ICRC Members trapped	SITFOR - LAP			15 MAY 2012 09:46 Z	Completed
	01.01.I02	UN Informs DJTF trapped U.N. Field Workers	WC - INGOID	DJTF J9	E-MAIL	15 MAY 2012 ± 15:10 Z	Approved
		ENDEX				20 MAY 2012 12:00 Z	

Go to Administration - Scenario - Exercise to change this text

Figure 9. JEMM exercise script example.

Alternative commercial solutions exist too, such as [Exonaut](#) (see Figure 10). They also aim at a military audience, and follow a similar approach.

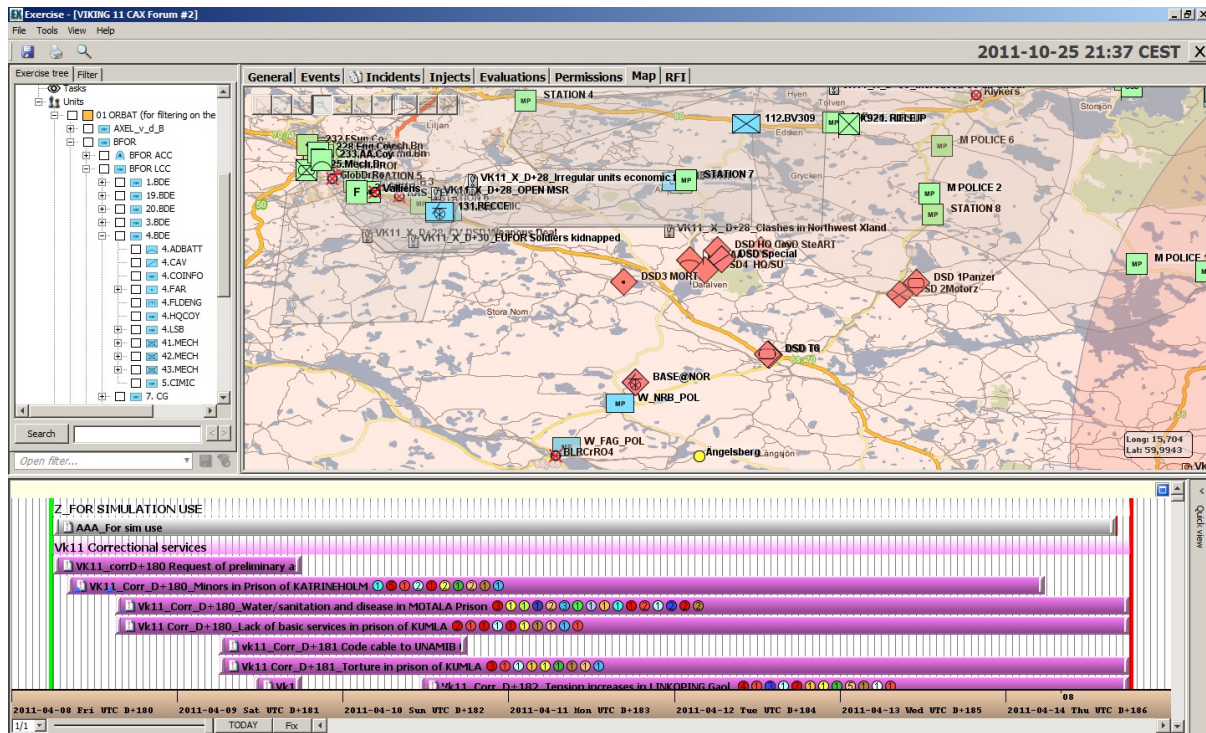


Figure 10. Exonaut timeline example.

Scenario Manager Tool (under active development)

A [Scenario Manager](#) is an integral part of the Test-bed reference implementation too, since it is not possible to use JEMM or Exonaut directly, as:

- JEMM is only available to NATO members, and can only be used in an [exercise](#) when military personnel requests it. This will not always be the case.
- JEMM and Exonaut are aimed at the military community, and the fit with the Crisis Management domain is not optimal.
- JEMM and Exonaut are closed source, so a strong integration with the Test-bed is not possible, as the applications cannot be modified.

The Test-bed's [Scenario Manager](#), then, acts as the *composer* and *conductor* of a classical performance:

- As the *composer*, it defines what each role has to play. For example, what do the simulators or role-players need to do in order to provide a realistic incident and background to the [Trial](#), or it could include sending direct messages to solutions.
- As the *conductor*, it controls *when* each role starts and stops.

It thereby offers its users the following functionality:

- Define the objectives of the [Trial](#).
- Describe an overall scenario that can put these objectives to the test.
- Specific storylines are created to stress the solutions.
- Within each storyline, different acts are created, for example to:
 - Instruct a simulator to start the fire or other incident, or send out social media messages.
 - Send a message to the Observer Support Tool, to switch the set of questions.
 - Inform a role player to conduct a telephone call.

Detailed information:

- [Functional specification](#)
- [Website](#)

3.4 Evaluation

Evaluation is needed to verify that the [Trial](#) objectives have been achieved. The Test-bed provides two services for this: an Online Observer Support tool and an After-Action Review tool.

Online Observer Support tool

Based on the specified objectives of the [Trial](#), an observer expects to observe different kinds of behaviour. At the same time, there is little time during a [Trial](#) to record behaviour, as the [Trial](#) runs on, and that's why the [observer tool](#) provides [Trial](#)-specific pre-made forms (templates) to quickly create a new observation. For example, *Did you observe role X do Y? Yes/No*. These [trial](#)-specific forms are created before the [Trial](#) by the observation team manager in the administration panel based on the data collection plan (as described in the [Trial](#) Guidance Methodology). Using this panel, specific forms can be assigned to specific observers. The observer can use a tablet, phone or desktop application for his work.

Although the [observer tool](#) (see Figure 11) can run standalone, outside of the Test-bed context, there are several benefits when it is connected, since this allows:

- To share observations with [Trial](#) staff: they can use this information to steer the [Trial](#) in a particular direction.
- The After-Action Review tool can use the observations during the analysis and evaluation.
- The [Scenario Manager](#) can inform the observers of major events that are about to occur: so they are warned ahead of time.
- Observation forms can be created dynamically and transmitted to selected observers.

Although the [observer tool](#) enables the collection of personal data, research ethics is outside the scope of this technically-oriented document, and is being described in more detail in [D923.21 - Trial guidance methodology and guidance tool specifications \(version 1\)](#).

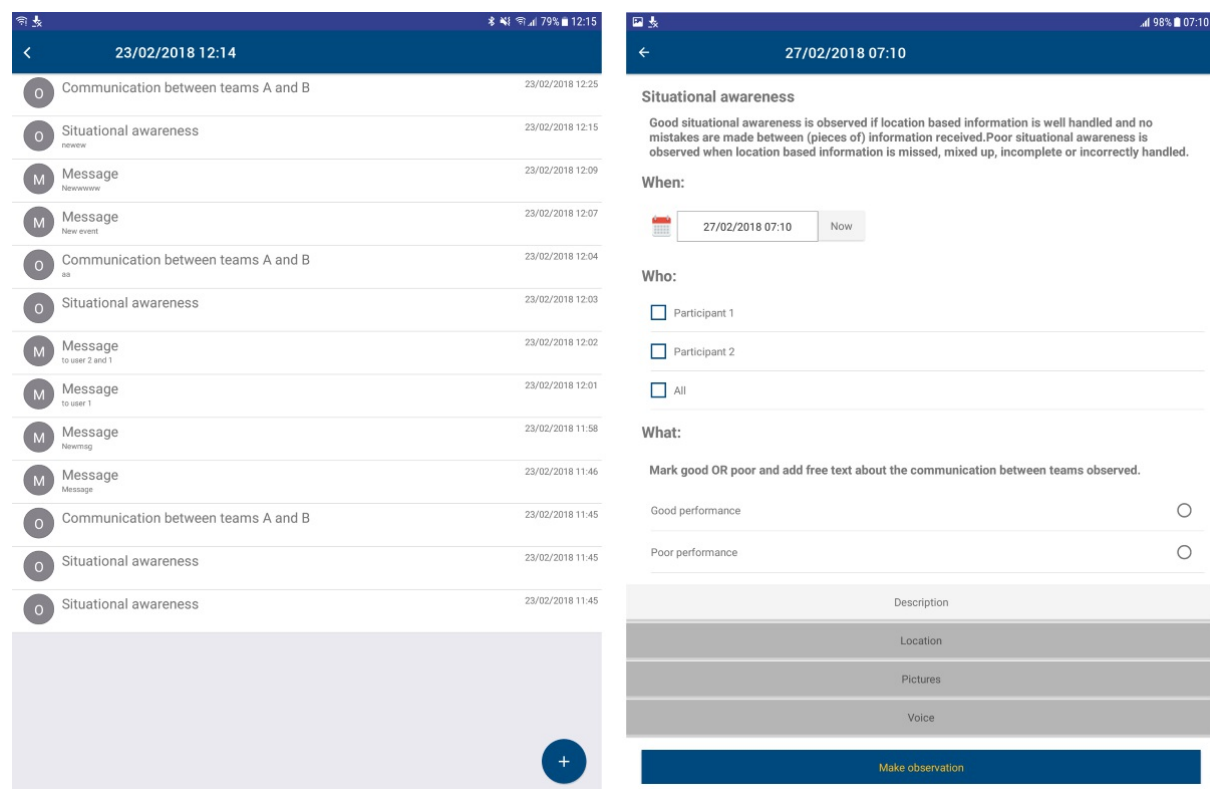


Figure 11. Observer Support Tool: Left, an overview of available observation templates. Right, one of the observation templates is selected.

Detailed information:

- [Functional specification](#)
- [Website](#)
- [Documentation](#)

After-Action Review tool (*under active development*)

The After-Action Review ([AAR](#)) tool collects data during a [Trial](#): messages exchanged during the [Trial](#), observation reports, and screenshots of the solutions during the [Trial](#). Its main purpose is to facilitate the evaluation of the trialled solutions against the predefined objectives, and to help the participants determine how well they functioned. Using a timeline displaying the collected messages, the whole [Trial](#) can be analysed visually, and one can quickly jump to a specific point in time in order to inspect a specific message, observation or see the active screenshot.

Detailed information:

- [Functional specification](#)
- [Website](#)

3.5 Simulation

Much can be said on the subject of simulation, but for the purpose of this chapter, it suffices to provide a brief overview of the Test-bed's relation to simulation.

In the Test-bed, the goal of simulation is to provide a realistic, immersive background for the [Trial](#). Typically, this requires:

- A **simulation of the incident** e.g. a flooding, earthquake or explosion, etc. simulation
- A **simulation of the reactions** to the incident, e.g. people running away or drowning, buildings collapsing, road jams or traffic accidents, etc.
- A **simulation of the perceived world**, i.e. painting a picture of the world to solutions of what they are reasonably expected to see, not what is actually happening. For example, when an area is flooded in the simulation, all simulators know the exact location of the water. So if people are standing knee-deep in the water, or a road is inaccessible due to water, that can be shown and used. However, a [COP](#) tool or other solution does not have such a perfect view of what is happening in the world. It does not know where everyone is, nor the exact location of the water level. As long as it has no sensors, cameras, drones, or people informing it, it may well believe that the flooding is in an entirely different location or not happening at all. For example, during a [CM exercise](#), it took the participants quite some time to figure out that the water was actually threatening their own location, and they had not taken the necessary precautions. A well-designed [Trial](#), therefore, needs to think about how they are going to present the simulated world within the [Trial](#).

The Test-bed, therefore, offers support to simulators for creating this realistic and immersive background, by:

- Providing a [time-service and GUI](#) (see Figure 12): i.e. each adapter knows the scenario time, so simulators and solutions can use this in their user interface and calculations. Think of a clock display, but also when sending an email or CAP message, making sure it uses the correct timestamps.
- The [Scenario Manager](#), as discussed above.

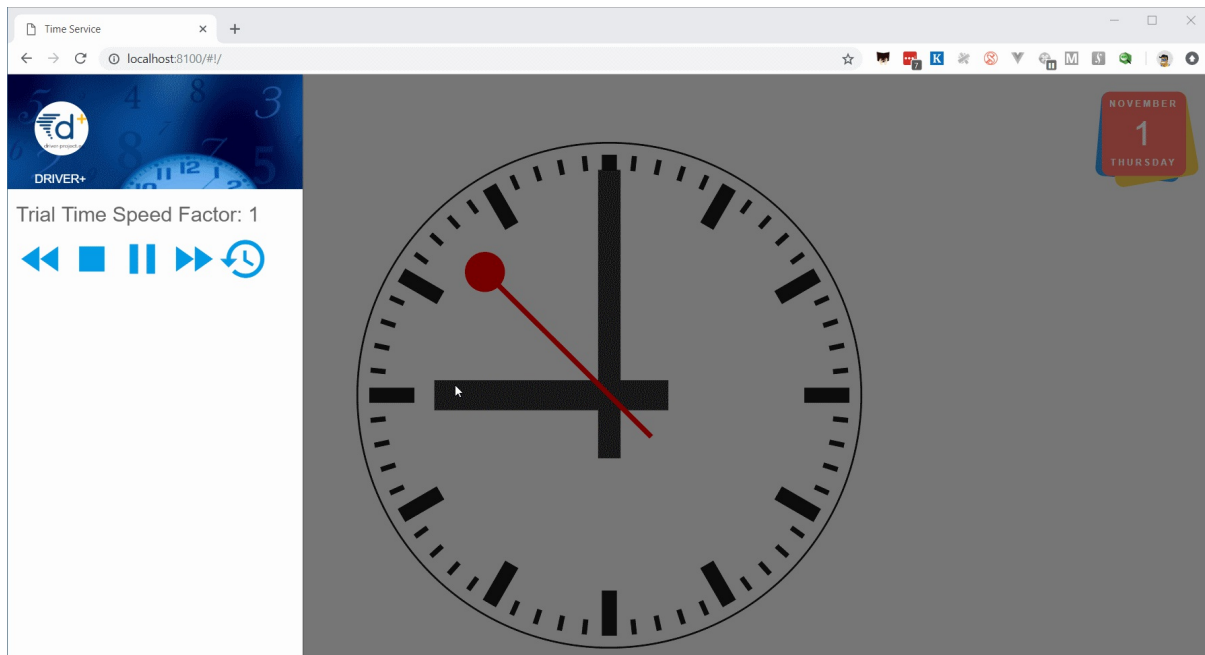


Figure 12. The Test-bed time-service GUI can be used to start/stop/pause a [Trial](#), as well as set the simulation speed.

It does not, however, provide these simulators as an integral part of the Test-bed. They are, and shall always remain, external. And even though some simulators will be connected during the project, they are not bound by the open source requirements that the Test-bed has to adhere too. For example:

- XVR connects their 3D crisis management environment, Crisis Media and Resource Manager to the Test-bed, thereby offering their (commercial) services to other parties too.
- DLR connects their open source SUMO (Simulation of Urban Mobility) traffic simulator to the Test-bed, which provides realistic traffic during an incident
- Thales connects their commercial Crowd Simulator SE-STAR to the Test-bed, e.g. providing a realistic simulation of people in need during a crisis.
- TNO connects their critical infrastructure and chain effects simulator to the Test-bed, providing insights into the cascading effects of failing infrastructure.

A note about Simulators

All simulators have their own data model of how they represent the simulated world. The [CSS](#) allows these simulators to agree on a communication form that the simulators understand to create and maintain a jointly simulated world.

The simulators only need to be concerned with maintaining the current state of a given location (including entities and processes present at that location), and do not have to deal with the different kinds of communication types for tools and users to depict that current state.

The [CSS](#) allows simulators to only focus on maintaining the current state of the simulated world (i.e. the simulated truth of the incident and the world around it). In order to communicate state changes with other simulators inside the [CSS](#), self-created communication messages are allowed inside this space.

4. The Test-bed for developers and system administrators

A system administrator, in the current context, is responsible for installing the Test-bed on their local network, and making sure that all the solution and simulation providers can get access to this network as well. This task is discussed in the use case 'Installing the Test-bed'.

A developer would be tasked with connecting an existing Solution or simulator to the Test-bed. Besides the direct coupling, allowing their tools to receive and publish messages, it most likely also involves translating existing messages to their own format. Finally, in case you are connecting a simulator, you also need more detailed information about the time management in the Test-bed.

Watch the following animation to get a better understanding of what is going on.

4.1 Use case: Installing the Test-bed

The previous chapter already explained how to setup the Test-bed. More detailed information about how to run the [Docker](#)-compose environment can be found [here](#). Alternatively, use the [GUI](#) to build your own Test-bed environment in [Docker](#).

System administrators are also responsible for setting up the local network, such that all solution and simulator providers have access to the local intranet as well as extranet.

In particular, it should be considered that some providers make heavy use of the network, e.g. to download maps, stream video, or access external computer clusters. If that is the case, consider using a throttling service in your network, so one provider does not claim all the network traffic.

More directly related to the Test-bed, however, is the connection of all solutions and simulators: are they connected correctly to the Test-bed, do they run without errors, are they subscribed to the correct topics, and do they publish to the expected topics, are some of the questions that the admin tool can answer for you. In addition, the admin tool makes sure that all message schemas are available. And when everything is in place, the actual [Trial](#) can start. Finally, the admin tool offers a convenient interface to all the other technical Test-bed services, such as the [REST](#) services, Topics UI, Schema Registry, Kafka Connect, etc.

From then on, the system administrator only needs to check whether the Test-bed does not experience any issues, like disconnected applications.

4.2 Use case: Integration process for a single solution or simulator

Within DRIVER+, a dedicated integration process *for solutions* is described in a separate document, D934.21, [Solution testing procedure](#). This section describes how a developer can proceed to integrate a solution or simulator with the Test-bed reference implementation.

This use-case is executed during the integration of a single solution or simulator into the Test-bed. It does not apply to the testing of multiple applications, and should already have been successfully performed before the application is tested in a larger context with multiple solutions and simulators.

1. Developer starts up the Test-bed and the Admin Tool, or uses a Test-bed available online.
2. Developer selects one of the existing adapters, integrates it into his application, and connects to the Test-bed. Adapters are available in multiple languages, each adapter is published separately as a library or package, and has an example project on GitHub explaining how to use it: [Java](#), [C#](#), [JavaScript/TypeScript/Node.js](#), [Python](#) and [REST](#). The Admin Tool shows whether the connection is established successfully.
3. Developer defines the input/output [AVRO](#) message schemas and topics based on the running test-bed. Many popular schemas for CAP, EMSI, MLP, GeoJSON etc. have already been defined in our [AVRO-schemas repository](#) and should be re-used if applicable.
 - i. In case your message format is not available, the developer needs to create a new one and register it with the Test-bed's schema registry. You can do that manually, or alternatively, the adapter will do this for you. The registration procedure is

a bit different for each adapter. Please consult the adapter's documentation.

- ii. In case your information is available, but in a format that the application does not support, you can create a gateway service to translate messages in one topic, e.g. MLP, to another message format, e.g. GeoJSON, and consume the latter. See the paragraph on the [Gateway service](#) below.

4. To receive messages, the developer starts up the [Kafka replay-service](#) to send messages one-by-one or replay a logged sequence of messages. For more detailed information, see the [Replay service section](#) below. To log the messages in a topic, you can use the [Kafka-topics-logger](#) or the [Kafka topics UI](#), which is a default part of the Test-bed, to save them. This is, for example, useful when you need to integrate with an application that does not run locally, e.g. when your [COP](#) tool needs to consume messages from a simulator that you do not have running locally.

In the next version of the Test-bed reference implementation, there will also be a message injector application, comparable to [Swagger](#) or [Postman](#), in which you will be able to create your own messages using a friendly user interface. It will use the [AVRO](#) schema to automatically create a form for defining your messages.

5. In case the integrated application also sends messages, Developer can use the [Kafka topics UI](#) in Figure 12 to verify that they were created and published to the Test-bed successfully.
6. When your message uses time, the developer needs to query the adapter to get the local [Trial](#) time. The Test-bed's [time-service](#) manages the [Trial](#) time, and you can read more about it below.

Message Topics UI

The Test-bed includes Landoop's [Kafka topics UI](#) service (see Figure 13) to inspect all the message topics that exist (default location <http://localhost:3600>). It can be used to inspect whether you have been successful in sending your messages to the Test-bed.

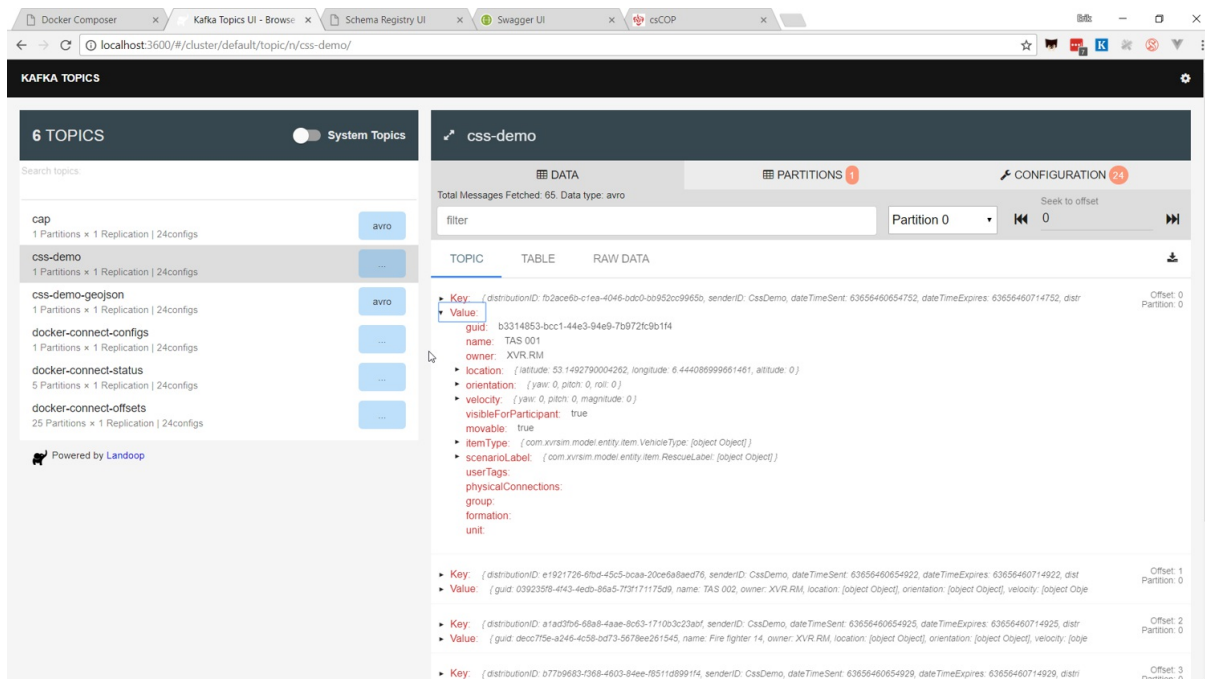


Figure 13. Screenshot of Landoop's Kafka topics UI, which is part of our test-bed.

Schema Registry

The Test-bed also includes Landoop's [AVRO schema registry](#) service (see Figure 14) to inspect all the available schema's (default location <http://localhost:3601>). As each message topic only has one schema, every message send to a topic needs to comply with that schema too. Also, in case a developer is creating new messages, these schemas must first be added to the schema registry, either manually or via one of the existing adapters.

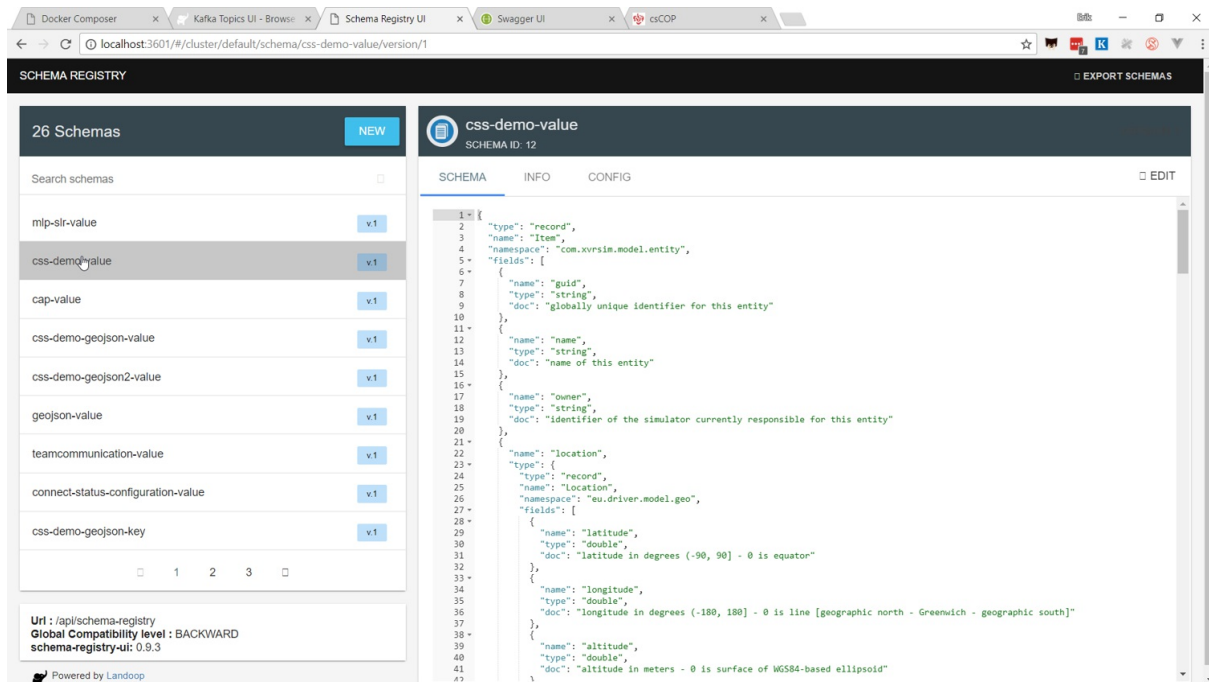


Figure 14. Screenshot of Landoop's **AVRO** schema registry, which is part of our test-bed.

REST service

The Test-bed contains a **REST** service: in case a (legacy) solution is not adaptable, or the solution is developed in a programming language that is not currently supported, it may be necessary to interact with the Test-bed via the **REST service**. In that case, the **REST** interface would be installed and run locally, so the solution that connects to it is still clearly visible in the admin tool as a separate client.

Replay service

Connecting to the Test-bed is needed to share information that you produce, or to consume information from others. While working on integrating your own simulator or solution, however, it is very likely that there are no other simulators or solutions running. When sending messages, you can use the Kafka topics UI to verify that your messages have been delivered. And it is the purpose of the **replay service** (see Figure 15) to present you with messages to consume.

For example, assume that you as a developer are tasked to integrate a **COP** solution. It needs to consume the locations of the rescue vehicles, which are normally generated by a simulator. However, it is a commercial simulator that you do not have. In that case, you request the simulator to run a scenario and publish it to the Test-bed. Next, log all the messages to file using the **Kafka-topics-logger** or Kafka Topics UI. This log file is subsequently sent to the **COP** solution developer, who can replay it using the replay service, as if the simulator was present.

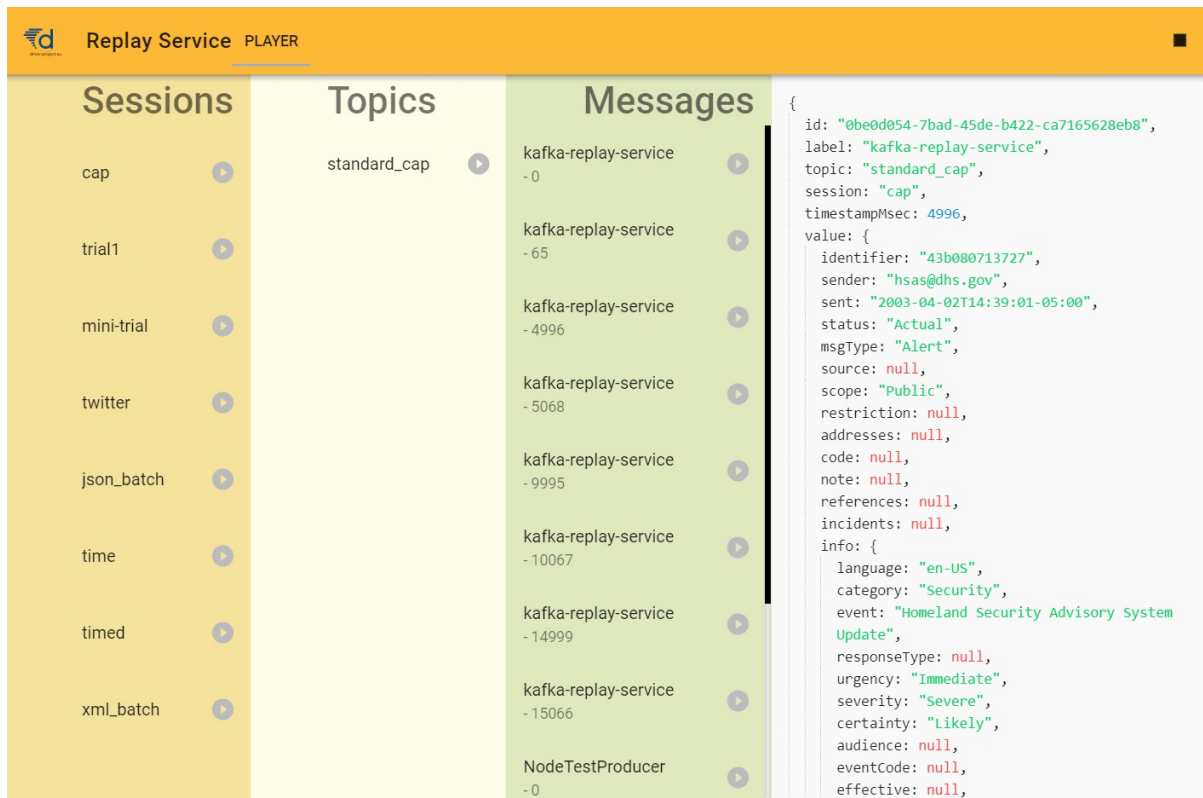


Figure 15. Screenshot displaying the Replay service's GUI interface.

4.3 Use case: Pre-trial integration testing

The procedure for testing multiple solutions and simulators before an actual **Trial** with participants is performed, is similar to the procedure for testing a single application. It is assumed that the single solutions and simulators have already been successfully integrated with the Test-bed, and all required message schemas are defined.

1. system administrator starts up the Test-bed and the Admin Tool, or uses a Test-bed available online. If not done already, all required schema's are registered with the schema registry.
2. system administrator inspects the Admin Tool and verifies that all required solutions and simulators are available and running online without errors.
3. system administrator starts up the **Scenario Manager**, loads the **Trial** scenario, and initializes it. The Test-bed's time service updates the fictive **Trial** time and state, and every application that uses time should reflect that.
4. system administrator runs the **Trial** scenario, either from the beginning or at another point in time, e.g. where issues were discovered. The time-service will update the fictive time accordingly.
5. system administrator resets the **Trial** scenario, and replays it, as many times as required to make sure that everything works as expected.

4.4 Gateways for translating messages

As a developer, you may be confronted with message formats you need to consume, but do not support natively in your application. In that case, you can either:

- Adapt your application to support these message formats natively.
- Create a gateway service which translates messages from one message format to a format that your application does understand.

To create such a gateway service is simple: you consume messages from one message topic, convert them, and publish them on another topic. The validation services follow the same approach, and several dedicated services are already available within the [DRIVER+ space on GitHub](#).

For example, the [Twitter-gateway](#) translates messages from the Test-bed to Twitter, ready to be consumed via Twitter, or the [XVR-GeoJSON-gateway](#) converts XVR simulator messages to the GeoJSON standard.

4.5 Large file service

Kafka and [AVRO](#) are ideally suited for smaller-sized messages, i.e. typically not exceeding 1Mb compressed. However, a typical flooding file or a drone video file may well exceed 1Gb of data. Instead, adapters can upload a file to the [large file service](#) and send out a [Large-data message](#) sharing its location. Alternatively, the URL may be embedded in a standard document, like a CAP message.

The large file service currently supports two types of messages:

- Public messages: they can be browsed in a folder like structure.
- Private messages: although not secret, they are shared via an obfuscated URL, similar to services like [wettransfer.com](#), so you get security through obscurity.

4.6 Data services and data sets

Within a [Trial](#), we need to create a virtual environment where we can safely experiment. This virtual environment is created using data, such as maps, census data, height data, power lines, cell towers, hospitals and care providers, etc. As it is a lot of work to create such a rich data environment, the effort should be shared among the [Trial](#) owners, solution and simulator providers. Not only to reduce the workload for a specific organisation, but also to make sure that all parties use the same data. Otherwise, a traffic simulator may use a different roadmap than the simulator that provides a 3D environment, and some roads may be blocked by buildings.

In many cases, real-world data is used, optionally enriched with scenario-specific information. Sometimes, a virtual environment is created, based on real-world data but with altered names.

So in order to share all this gathered data, the Test-bed offers two types of services:

- [Docker volume images](#) to store all this information together, so the data can be easily shared. A Test-bed user can simply pull the volume image from the [Docker](#) hub to have all data instantly available
- [Data services](#), to share this data with all users, e.g. there is an [MBtiles service](#) to offer map images to [COP](#) and [COP](#)-like tools, or a [WMS service](#) that translate Test-bed messages to WMS map layers, which makes the information available to legacy systems too.

Security is yet another reason to have these data services and data sets as part of the Test-bed. Not all Trials have open access to the Internet, but they still need access to this kind of data.

4.7 Time management

A [Trial](#) typically is not performed in real-time: either because the incident occurs at night, and people prefer to [Trial](#) during working hours, because of the limited availability of participants, or because it would simply take too long. An example of the latter is a flooding incident, which can start days before any flooding actually occurs, so you need to compress the scenario to normal working hours.

Within the Test-bed, therefore, the scenario time (a.k.a. [Trial](#) time or fictive time) is controlled via the [time service](#) (see Figure 16) using [two types of messages](#): one for controlling the time, and one for informing adapters about the current scenario time.

As a developer, you do not need to interact with these messages directly, since:

- Every adapter has a time interface to get the current scenario time. Even as a solution developer, you should also use this time to timestamp the messages that you send. For example, if inside your message you refer to a particular time, always base it on the scenario time.
- Every adapter has a state describing the current scenario phase, which you can optionally use during the integration:
 - **Idle**: no scenario has started. The time interface returns the system time (in UTC).
 - **Initialized**: the scenario is ready to be started. All adapters will receive the scenario start time, and can use this to initialize their service. In the near future, adapters have the ability to inform the Test-bed when they are initialized and ready to start.
 - **Running (started or paused)**: the scenario time is moving forward, either in real speed or slower/faster than normally. In case the scenario is paused, the current scenario time is still actively being distributed, but does not progress (speed is 0).
 - **Stopped**: The scenario stops, and the simulation time is no longer being updated.

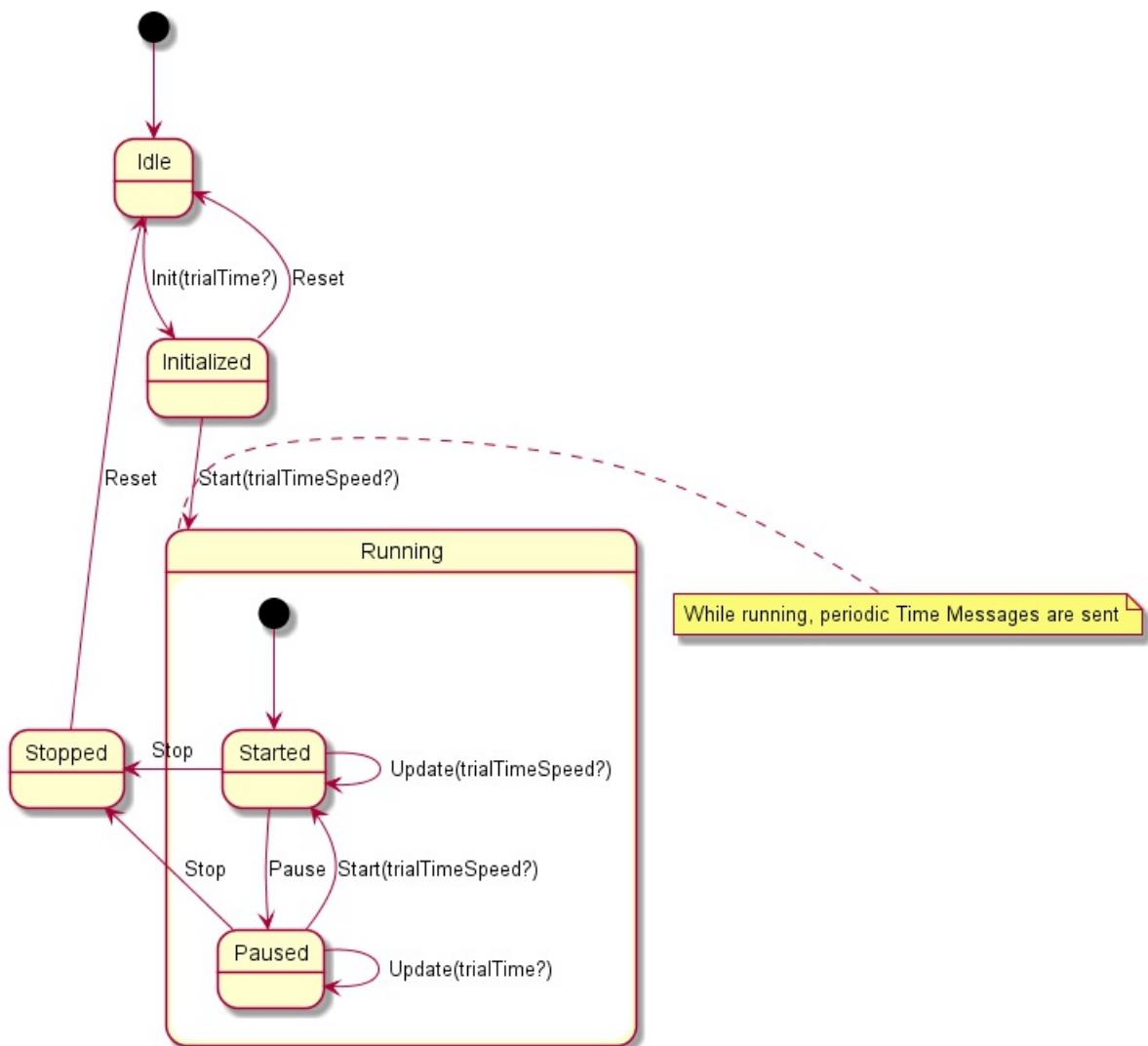


Figure 16. State diagram of the time service.

NOTE: Even when you do not interface with the time messages, you still must use the time interface when you want to publish a message with a timestamp inside. This timestamp should use the current scenario time. Similarly, in case you display the 'actual' time in your user interface, please also use the current scenario time.

System time versus scenario time

In Trials executed in the past, the operating system (OS) time was also adjusted to match the scenario time. The advantage was that if you would check the time in your status bar, it would display the current scenario time instead of the real time. Although this is straightforward to do, your OS does not like it, as it will generate files in the past or future, and may mess up your system. Especially when the scenario is paused. That is why the current Test-bed does not require you to synchronize your system time to the scenario time.

A word about HLA and DIS

Within the Modelling & Simulation community, especially for military use, there are two simulation standards, [HLA](#) (High Level Architecture) and [DIS](#) (Distributed Interactive Simulation), which are the norm. The reasons why we did not use these standards, not even for the [CSS](#), are:

- They are used for connecting simulators to each other, not for connecting solutions to simulators nor solutions to other solutions.
- Their message format is fixed: if you want to send other information, you have to 're-purpose' existing fields, which is not considered a best practice. Also, they have no support for any [CM](#) standard.
- Both have a steep learning curve.
- [HLA](#) and [DIS](#) form a very small community, so it is difficult to hire people with this knowledge, and you typically have to train general software engineers by yourself. Second, it is difficult to find solutions for a particular problem on the Internet.
- [HLA](#) and [DIS](#) expect everyone to use Java or C++, and there is even less support for the 'newer' programming languages, like C#, JavaScript, Python, etc.
- [HLA](#) requires a run-time infrastructure, which is a kind of test-bed: there are two commercial providers that are expensive. Although there is one [open source version](#), it is feature incomplete and not well maintained. Furthermore, even though these versions should be interoperable, they are not, and they cannot be mixed easily.

That is why this Test-bed is using open source software, so it is easy to find:

- Open source tools to support it, or to connect to it, in many programming languages.
- Answers to questions.
- People that can use it.
- A new schema representing your message.
- And there is no financial hurdle preventing adoption.

Even though the Test-bed does not use [HLA](#) or [DIS](#) internally, there are many simulators that provide a [HLA](#) or [DIS](#) export, and that can be useful for a [Trial](#). In those cases, a [HLA](#) or [DIS](#) simulation environment can be created, as is done normally, including a gateway service to bridge the gap with our test-bed: typically, such a gateway has an [HLA](#) connector to retrieve information from the [HLA/DIS](#) side, and a subset of the information is published in the [CSS](#). And vice versa. Even though this kind of integration is suboptimal, in practice, this is not really noticeable.

4.7 Security

Security is an integral part of the Test-bed: although in most crisis management use cases, deciders consider that safety prevails anyhow, to such an extent that security never comes into the picture or merely as a measure of last resort, a lack of security controls in crisis management solutions from the ground up may have a disastrous impact on crisis management decisions, operations and, in the end, on people's lives; therefore, DRIVER's test-bed has *security by design*. We focus especially on the security of information exchanged in [CIS](#) and [CSS](#) topics, because this is where critical or sensitive information flows. We have three information security objectives:

- Integrity of information exchanged in [CIS](#) and [CSS](#) topics: messages should not be tampered without notice;
- Authenticity of information exchanged in [CIS](#) and [CSS](#) topics: the origin of the messages published to certain topics should be authenticated, and, by extension, only legit/trusted users may publish on certain topics;
- Confidentiality of information exchanged in [CIS](#) and [CSS](#) topics, such as critical infrastructure information or personal information (beware the GDPR): only authorized Solutions (adapters) may have access to the messages published to certain topics.

To achieve these objectives, the test-bed includes an access control framework in which both system administrators and developers have a role to play.

Authentication

The [CIS/CSS](#) Kafka broker enforces SSL/TLS transport security with mutual authentication. This means that adapters are required to authenticate with SSL client certificates. Developers shall get such SSL client certificates from the Admin Tool, with the approval of a system administrator. The subject name of the certificate must uniquely identify the adapter within the organization. More specifically, the subject name must include an Organization name (O) identifying the Organization that owns the Solution or Simulator, and a Common Name (CN) identifying the Solution or Simulator instance within that organization. The Admin Tool uses a Certificate Authority (CA) provided with the testbed in the backend, to issue those certificates.

Developers then configure their adapters with those certificates as client certificates (keystore), the aforementioned CA's certificate in their truststore (trusted CAs) in order to authenticate the broker (using a certificate issued by that same CA as well), and recommended TLS parameters according to current best practices: TLS v1.0 or later (as of writing), strong cipher suites, etc. Developers must take good care of protecting the confidentiality of the private key associated to their client certificate according to best practices and the risk level. If the key is compromised, authentication is useless. Developers must report any compromised key to system administrators so that the certificate be revoked.

By default, the [CIS/CSS](#) broker trusts only that backend CA for client certificates. If developers wish to use client certificates issued by another CA, system administrators may grant their wish by modifying the broker's SSL configuration. This change consists to add the other CA's certificate to the broker's [SSL truststore \(JKS\)](#) and restart the broker service.

Once all adapters are properly configured by developers for SSL client authentication, they are able to connect to the secured [CIS/CSS](#) broker and at least access public topics such as *system_* topics.

Authorization

For stronger security, whenever [trial](#) owners want to protect specific [CIS/CSS](#) topics, system administrators shall enable topic authorization. By default, this test-bed security feature is disabled, i.e. all authenticated users (according to previous section) have access to all topics. System administrators enable topic authorization by using an [extra Docker Compose file](#) that extends the default one with authorization enforcement components.

Once enabled, access to any topic is denied by default, except for certain public topics such as *system_* topics. This means that for other topics, access must be granted explicitly by system administrators. More specifically, for each sensitive topic X, the system administrator shall configure the topic access policy via the Admin Tool. A topic access policy is set on a specific topic X and consists of a list of access rules. Each access rule consists of:

- Authorized subject name, as in the adapter's SSL certificate (aka Kafka client ID in this case), OR Kafka consumer group ID;
- A list of *permissions*; each *permission* is a couple (*ACTION*, *bool*), where *ACTION* is the action considered on the topic (in Kafka API model), e.g. *READ* (subscribe a topic) or *WRITE* (publish on a topic), and the boolean *bool* is true if and only if the action is permitted (positive rule), else denied.

If a consumer group ID is used as first item (instead of subject name), the system administrator must also declare the corresponding group memberships in the Admin Tool, i.e. who is authorized to join this group.

In order to improve performances, system administrators can enable the authorization decision cache (disabled by default) in Kafka's configuration via [Docker](#) Compose environment variables. This allows Kafka (the Kafka authorizer in particular) to cache decisions to avoid requesting the remote PDP every time. The downside is that changes to the topic access policies that occur in the remote PDP during the cache interval may be ignored.

4.8 Online Test-beds

As mentioned in section 4.3, it is possible to make use of an online test-bed that is hosted in a Cloud setup. This serves as an alternative to hosting a test-bed yourself and is useful for integration testing: whenever two or more parties wish to test their integration via the test-bed, they can request a cloud-hosted test-bed that is available within a few minutes. All parties can then remotely connect to this test-bed, without requiring any prior setup and configuration.

The current Test-bed cloud consists of four servers configured as a [Docker Swarm](#) which allows various test-bed compositions to be hosted in parallel. [Docker](#) swarm allows any Test-bed [docker](#) composition (configured manually, or with the [online tool](#) to run on the [Docker](#) Swarm servers. Each Test-bed can make use of one of the ten available host-names for temporary online test-beds: <https://tb1.driver-testbed.eu> to <https://tb10.driver-testbed.eu>.

4.9 Reverse Proxy for Test-beds

Optionally the Driver Test-bed can be configured to work with a Reverse proxy called [Traefik](#). This has several advantages:

- The Test-bed Services (i.e. Topic UI, Schema UI, etc) are not separately exposed on their own port, but via a relative URL on a shared proxy that can be reached via a configurable hostname. For example instead of exposing the Topics UI at <http://hostname:3601> and the Schema UI at <http://hostname:3602>, they can be exposed at <http://hostname/topics-ui/> and <http://hostname/schema-ui/> respectively. They will then both share the same HTTP endpoint at <http://hostname>.
- The shared HTTP endpoint can be secured with an SSL certificate, for example automatically created via [lets-encrypt](#). Because all web services in the test-bed use the same reverse proxy, securing this reverse proxy entry point will secure the HTTP traffic for all services behind it without requiring any configuration on the test-bed services.
- Traefik monitors and logs requests so allow for tracing and monitoring health and load on services in the test-bed.

Traefik is built to integrate seamlessly with [Docker](#) Swarm. For setting up the Test-bed with Traefik [these](#) instructions are followed. Traefik runs in a separate container, on a shared [Docker](#) network with the Test-bed containers to allow routing of traffic to the Test-bed services. It listens to events from [Docker](#) stating that a container is started. Metadata provided on start-up of the container (labels, see [here](#)) specifies how the service should be exposed by Traefik. For example Traefik can expose the service at a specified hostname (domain or subdomain) and at a specific relative path. Moreover, the URL may be manipulated (for example strip the relative path) to allow compatibility with the services. Whenever a new service is hosted on a specified hostname, Traefik automatically ensures that a valid lets-encrypt certificate is present or requested.

There are two beta Test-bed compositions available for usage with Traefik on the test-bed repository 'traefik' branch:

- A composition for a local test-bed with Traefik at <https://github.com/DRIVER-EU/test-bed/tree/traefik/docker/local>. This allows running the test-bed on your local machine. The external hostname, Kafka broker port, and Schema Registry port can be specified in the .env file.
- A composition to run in the cloud using [Docker](#) swarm at <https://github.com/DRIVER-EU/test-bed/tree/traefik/docker/swarm>. This is built for running on the TNO hosted cloud servers. The external hostname, Kafka broker port, and Schema Registry port must be specified using ENV variables `TESTBED_HOST` , `BROKER_PORT` , and `SCHEMA_REGISTRY_PORT` respectively.

Abbreviations

Abbreviation	Definition
AAR	After Action Review tool, which supports reviewing a Trial when it is finished
AVRO	Open data serialization system supported by the Apache Organisation. avro.apache.org
C++	[C plus plus] Programming Language
C#	[C-sharp] Programming Language
CAP	Common Alerting Protocol, standard data format for exchanging public warnings
CIS	Common Information Space for exchanging crisis management messages
CM	Crisis Management, see also Annex 1
CSS	Common Simulation Space for exchanging simulation data
COP	Common Operational Picture tools for creating a shared situational awareness
CoPCM	Community of Practice in Crisis Management
DIS	Distributed Interactive Simulation, a simulation standard en.wikipedia.org/wiki/Distributed_Interactive_Simulation
Docker	Container environment to enable independence between applications and infrastructure
EDXL	Emergency Data Exchange Language, set of message standards defined by OASIS to share emergency information, docs.oasis-open.org/emergency
EMSI	Emergency Management Shared Information, message format for the exchange of emergency information
GitBook	Open Source service for creating online books
GitHub	Repository for managing DRIVER+'s software code
GT	Guidance Tool
GUI	Graphical User Interface
HLA	High Level Architecture, a simulation standard en.wikipedia.org/wiki/High-level_architecture
Java	Programming Language
JavaScript	Programming Language
Kafka	An open source distributed streaming platform supported by the Apache Organisation that is used as the basis to exchange information between simulators and solutions
KPI	Key Performance Indicator
MBtiles	Single file database format to store images of a map
MGT	Management
PoS	Portfolio of Solutions, a DRIVER+ content management system to maintain a list of CM solutions, their application, strength and weaknesses, and user reviews.
Python	Programming Language
REST	Representational State Transfer (common interface allowing you to read and write data from a service)
RTI	Run-time infrastructure, a kind of HLA -based Test-bed
SA	Situational awareness, basically do you know on the map where your people and other resources are, as well as all relevant crisis management related incidents and activities.
SMT	Scenario Management Tool, allows you to create new scenarios
SUMO	Simulation of Urban Mobility, a traffic and pedestrian simulator

TGM	Trial Guidance Methodology, as defined in deliverable D922.21, " Trial guidance methodology and guidance tool specifications (version 1)".
TGT	Trial Guidance Tool, an online application that supports a practitioner in setting up a Trial
TypeScript	Programming Language
WFS	Web Feature Service (serving a map layer as vectors)
WMS	Web Mapping Service (serving a map layer as picture)
XACML	eXtended Access Control Markup Language, a standard for describing security permissions to resources
XML	eXtended Markup Language, a textual representation of a message that is easily readable by computers

Annex 1 DRIVER+ Terminology

In order to have a common understanding within the DRIVER+ project and beyond and to ensure the use of a common language in all project deliverables and communications, a terminology is developed by making reference to main sources, such as ISO standards and UNISDR. This terminology is presented online as part of the Portfolio of Solutions and it will be continuously reviewed and updated¹. The terminology is applied throughout the documents produced by DRIVER+. Each deliverable includes an annex as provided hereunder, which holds an extract from the comprehensive terminology containing the relevant DRIVER+ terms for this respective document.

Terminology	Definition for DRIVER+	Source
Crisis management	Holistic management process that identifies potential impacts that threaten an organization and provides a framework for building resilience, with the capability for an effective response that safeguards the interests of the organization's key interested parties, reputation, brand and value creating activities, as well as effectively restoring operational capabilities. Note to entry: Crisis management also involves the management of preparedness, mitigation, response, and continuity or recovery in the event of an incident, as well as management of the overall programme through training, rehearsals and reviews to ensure the preparedness, response and continuity plans stay current and up-to-date.	ISO22300:2018 (en)
Evaluation	Process of estimating the effectiveness, efficiency, utility and relevance of a service or facility.	ISO 5127:2017(en) Information and documentation — Foundation and vocabulary, 3.1.3.02.
Exercise	Process to train for, assess, practise and improve performance in an organization. Note 1 to entry: Exercises can be used for validating policies, plans, procedures, training, equipment, and inter-organizational agreements; clarifying and training personnel in roles and responsibilities; improving interorganizational coordination and communications; identifying gaps in resources; improving individual performance and identifying opportunities for improvement; and a controlled opportunity to practise improvisation. Note 2 to entry: See also test.	ISO22300:2018(en) 11
Experiment	Purposive investigation of a system through selective adjustment of controllable conditions and allocation of resources. DRIVER+ Note 1: Please consider also the notes in the original definition. DRIVER+ Note 2: In the context of DRIVER+ Trials are executed - and not experiments.	ISO/TR 13195:2015(en) Selected illustrations of response surface method — Central composite design
Trial	An event for systematically assessing solutions for current and emerging needs in such a way that practitioners can do this following a pragmatic and systematic approach.	Initial DRIVER+ definition.
Trial Guidance Methodology (TGM)	A structured approach from designing a Trial to evaluating the outcomes and identifying lessons learned	Initial DRIVER+ definition
Trial Guidance Tool	A software tool that guides Trial design, execution and evaluation in a step-by-step way (according to the Trial Guidance Methodology) including as much of the necessary information as possible in form of data or references to the Portfolio of Solutions	Initial DRIVER+ definition
Legacy systems	(Crisis management) system currently in operational use.	Initial DRIVER+ definition
Observer	Observer participant who witnesses the exercise while remaining separate from exercise activities. Note 1 to entry: Observers may be part of the evaluation process.	ISO 22300:2018(en) Societal security — Terminology.

Portfolio of Solutions (PoS)	A database driven web site that documents the available Crisis Management solutions. The PoS includes information on the experiences with a solution (i.e. results and outcomes of Trials), the needs it addresses, the type of practitioner organisations that have used it, the regulatory conditions that apply, societal impact consideration, a glossary, and the design of the Trials.	Initial DRIVER+ definition.
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¹. The Portfolio of Solutions and the terminology of the DRIVER+ project are accessible on the DRIVER+ public website <https://www.driver-project.eu>. Further information can be received by contacting coordination@projectdriver.eu. ↩

Annex 2 Change history

This annex documents the changes with respect to previous versions. The returning reader is therefore urged to only review the recent changes.

Version 2

The changes with respect to the first version are described in the following.

Executive Summary

- Added a reference to the change history.
- Added link to deliverable D922.21 which is now publicly available.
- Added link to Test-bed animation.
- The Python adapter has become available.
- Added links to the eBook versions (PDF, epub and mobi formats).

Introduction

- Added a reference to the change history in [section 1.3](#).
- Clarified the scope and aims of the document, based on the EU reviewers comments.
- Removed a duplicated picture.

Test-bed for Crisis Management Practitioners

- Before discussing the Test-bed, first discuss it from the perspective of the [Trial](#) owner (chapter 2 and 3 were swapped with respect to the previous version, thereby addressing the reviewers comments).
- Added an description of the Test-bed composer, in order to distinguish it better from the PoS of TGT.
- Embedded Test-bed overview animation (only in the online version).
- [Scenario manager](#) use case is expanded.
- Rewrote the use cases, to enhance the role of Monica.
- Removed a duplicated picture.

Test-bed description

- Added a brief description in [section 2.1](#) on how to [trial](#) non-technical solutions, i.e. processes.
- Rewrote subsection [Adapters](#) and added two new features: security and support for large files.
- [Messages](#): added link to our public [AVRO](#)-schemas repository.
- [CIS and CSS](#): wording has slightly changed.
- [Gateways and Validation Services](#): improved the clarity.
- In section 2.2 [Test-bed administration tool](#): improved the wording.
- Added a new image for the Gateway.
- In section 2.3 [2.3 Trialling, Exercising and Scenario Management](#):
 - Added link to [TGM](#) and functional specification document.
 - Added link to [Scenario Manager](#) and [AAR](#) website.
 - Added screenshot of time service.
 - Mentioned TNO's critical infrastructure simulator.

Test-bed for Trial developers & sysops

- New section on Security
- New section on the Large File service
- Embedded Test-bed developer animation (only in the online version).
- Added link to the report "Solution testing procedure".
- Added link to the Python adapter which has become available.
- Added information about two gateways on GitHub (Twitter gateway and XVR-GeoJSON gateway).
- Updated information.
- Updated screenshot of the Replay service.
- Added section on online Test-beds and reverse proxy.

Test-bed design

- Moved to Annex 3.
- Moved section on large data to Chapter 4.
- Truncated section on the Adapters, and referred to Chapter 3.

Annex 3. Test-bed design

The Test-bed is designed to fulfil the functional requirements, as described in D923.11, [Functional specification of the Test-bed](#). Clearly, different designs can be created that all fulfil these requirements, so this chapter provides a brief explanation of the major design decisions that underlie the current Test-bed's reference implementation. Its intended audience is core developers, who want to improve its functionality, or other backend developers, who want to create an alternative Test-bed that also satisfies these requirements.

Annex 3.1 Lessons learned from the Functional Specification

Part of the functional specification describes the [lessons learned](#) from D923.11. To summarize the most important technical lessons that have influenced the current design significantly, are:

1. The Test-bed should be open source.
2. The Test-bed should have a message-oriented architecture.
3. The Test-bed should use well-defined, easily accessible, syntactically correct messages, and close to common standards.
4. The Test-bed should be easily reproducible, and offer administrative as well as supporting tools and services.

Annex 3.2 Distributed message bus using Apache Kafka

Based on the functional requirements and lessons 1 and 2, and an analysis of many existing message-oriented systems, the Test-bed's backbone is built upon the distributed streaming service, [Apache Kafka](#). The main reasons to use Kafka are:

- Kafka allows for high performance sending and receiving of a very large number of messages.
- Kafka allows for fast data replication and supports multiple receivers on the same message topic.
- Kafka is a highly durable messaging system, persisting messages on the server or complete distributable file systems.
- Kafka is a distributed system, making it scalable in the amount of message topics, senders and receivers.
- Kafka already has a large developer community, making it possible to easily use community-released tools to the current framework and assuring sustainability of Kafka.
- Kafka already has several security and message validation modules present, that will make it easier for simulators to safely connect to the [CSS](#).

Besides Apache Kafka, there are numerous popular open source messaging systems that were considered: [ActiveMQ](#), [RabbitMQ](#), and [ZeroMQ](#). The main reason for using Kafka, however, is its speed, low latency, and the fact that it is built from the ground up to be distributed. Especially for the simulators that are connected to the Test-bed, speed and low-latency are very important. And Kafka can easily process up to 100,000 messages per second, 10 times as much as the others. Its distributed nature allows to not only separate simulators and solutions, if required, but also supports having a reliable cross-site communication framework. Additionally, with its schema registry, it has excellent support for message validation out-of-the-box, which is detailed in the next section. The same applies to message persistency. Each message is immediately persisted to disk for a set time, which is easy for After-Action-Reviews, but also for clients that are not continuously online. In most messaging systems, when a consumer is briefly offline, the message is lost forever unless special care is taken to persist them.

Annex 3.3 Well-defined messages using Apache AVRO

Being able to communicate using well-defined messages is of primordial importance for any messaging system, and the Test-bed uses [Apache AVRO](#).

[AVRO](#) provides:

- Rich data structures.
- A compact, fast, binary data format.

- A container file, to store persistent data. For example, you could save all logged [AVRO](#) messages into a file, which also includes the schema file. This means that you will always be able to read the file at a later date, as it contains all the information to decode the messages.
- Remote procedure call (RPC).
- Simple integration with dynamic languages. Code generation is not required to read or write data files nor to use or implement RPC protocols. Code generation as an optional optimization, only worth implementing for statically typed languages.

In the Test-bed, each message consists of a key and a value, with:

- The **same** [AVRO](#)-encoded [key](#), based on the core attributes from the [EDXL DE](#) envelope (distributionID, senderID, dateTimeSent, dateTimeExpires, distributionStatus, and distributionKind). It can be used to support easy filtering and routing, and have a consistent message timestamp.
- A potentially different [AVRO](#)-encoded value, containing the actual message.

Each adapter verifies the key and value of each message before publishing (producing in Kafka terms) it. As Kafka limits you to have only one key/value schema pair per topic, there is no confusion when consuming a message about the schema's to use to decode a message's key and value.

Other evaluated candidates for defining message formats were [XML schema](#), Google's [Protobuf](#), and [HLA](#).

- XML schema is arguably the most popular format, especially when dealing with standards. However, it is very verbose, being text-based, which makes all messages very large. And it does not allow for schema migration, i.e. different versions of a message. This often leads to a 'creative re-use' of existing fields, which is common practice but not recommended.
- Protobuf is also a binary message format, like [AVRO](#), but also lacks schema migration.
- [HLA](#), yet another binary message format, is standard in the (Defence) simulation world, but of no use when defining messages in the [CIS](#) space.

Annex 3.4 CIS and CSS adapters in several programming languages

On top of the communication framework, a set of guidelines need to be present that allows for external components and Test-bed components to communicate effectively. In this case, this set of guidelines is packed into a simple library called the adapter.

The adapter is the only form of connection between an application (solution, simulator, gateway, or otherwise) and the Kafka communication framework. There should be no other way to connect to it.

The adapter sets up and maintains the connection between application and the communication framework via several system message topics. The adapter deals with error handling and additional message validation, allowing the application to send and receive messages easily.

To read more about the implementation, see [Chapter 2 Adapters](#).

Annex 3.5 Security architecture

The testbed Security Architecture consists of the following elements:

- Security Services;
- [CIS/CSS](#) broker security features;
- [CIS/CSS](#) adapter security features.

For more details, read on the next sections.

Security Services

There are two security services running in the test-bed:

- Certificate Management Service;

- Authorization Service.

Certificate Management Service

The Certificate Management Service provides:

- A Certificate Authority (CA) that issues SSL/TLS client (resp. server) certificates to the [CIS/CSS](#) adapters (resp. broker);
- A [REST](#) API - backed by the aforementioned CA - for managing the lifecycle of X.509 (standard) certificates used for SSL/TLS authentication in client-server communications on the testbed. This is the API used by the Admin Tool on behalf of system administrators, to issue SSL client certificates to developers for their adapters. The API is described on the [testbed's Github repository](#).
- An endpoint for verifying certificate revocation status (CRL or OCSP standard). This is the endpoint used by the [CIS/CSS](#) broker and adapters to validate the status of the certificate of any remote peer they are establishing a SSL session with.

The Certificate Management Service is based on the open source project EJBCA (Community Edition).

Authorization Service

The Authorization Service provides two endpoints:

- PAP (Policy Administration Point);
- PDP (Policy Decision Point).

The Authorization Service is based on the open source XACML 3.0 PDP implementation project [AuthzForce](#) (Thales).

Policy Administration Point

The PAP (Policy Administration Point in [ABAC \(Attribute-Based Access Control\)](#) standard model) endpoint exposes a [REST](#) API for managing [CIS/CSS](#) topic access policies. System administrators interact via the Admin Tool with this API for defining and managing the access policies for [CIS/CSS](#) topics. The API is described on the [Authorization Service's Github repository](#).

Policy Decision Point

The PDP (Policy Decision Point in [ABAC \(Attribute-Based Access Control\)](#) standard model) exposes a [REST](#) API for requesting an authorization decision (Permit/Deny) according to the policies defined via the PAP, and an input authorization request. The [CIS/CSS](#) broker (via its PEP, aka Kafka *authorizer* in this case) interacts with this API for deciding whether to reject (if PDP returns Deny) or let a message go (if PDP returns Permit) through the broker. We say that the [CIS/CSS](#) broker enforces the PDP's decision.

The PDP interface complies with the standards:

- [REST Profile of XACML 3.0](#) for the transport protocol (HTTP) and entry point;
- [JSON Profile of XACML 3.0](#) for the API request-response payload formats (XACML Request/Response).

CIS/CSS broker security (Kafka)

The broker security consists of the following:

- Kafka SSL/TLS layer;
- DRIVER+'s custom Kafka *authorizer* (XACML-driven).

Kafka TLS layer

The TLS term is used instead of SSL because we mandate the use of TLS 1.0 or later in DRIVER+.

The Kafka broker exposes a TLS server interface that enforces the confidentiality, integrity and mutual authentication of communications with [CIS/CSS](#) adapters. It authenticates to Kafka consumers with a TLS server certificate issued by the Certificate Management Service's CA mentioned earlier. The Kafka broker is configured to require TLS client certificate authentication with client

certificates issued by that same CA. The TLS setup follows the official Kafka documentation's section: [Encryption and Authentication with SSL](#).

Custom Kafka Authorizer (XACML PEP)

The Kafka broker's configuration is modified to use a [custom Authorizer](#) implementation that can interact with the Authorization Service's PDP endpoint mentioned earlier. This Authorizer plays the role of PEP (Policy Enforcement Point) in the [ABAC \(Attribute-Based Access Control\)](#) standard model), and more specifically in the [XACML standard](#) architecture. Therefore, this custom Authorizer supports the required XACML standards ([REST](#) and JSON profiles) and rejects (resp. accepts) messages if the PDP's returned decision is Deny (resp. Permit).

In order to improve performances, this Authorizer may cache decisions to avoid requesting the remote PDP every time. The downside is that changes to the topic access policies that occur in the remote PDP during the cache interval may be ignored. This decision cache is enabled and configured via [Docker](#) Compose environment variables.

The Authorizer's source code is open and available with technical documentation on a [dedicated Github repository](#).

CIS/CSS adapter security

[CIS/CSS](#) adapters are Kafka clients. Therefore, they are required to use TLS (1.0 or later) for communicating with the [CIS/CSS](#) Kafka brokers, and TLS client certificates (X.509) provided by the aforementioned Certificate Management Service. In order to properly authenticate the [CIS/CSS](#) broker, adapters must use a TLS truststore (set of trusted CAs) that contains the certificate of the Certificate Management Service's backend CA, or preferably of the Root CA (that the backend CA is a subordinate of).

The Kafka documentation gives an example of [Kafka client SSL configuration](#).

List of Figures

1. [Process-Methods-Tools-Environment \(PMTE\) paradigm applied to DRIVER+.](#)
2. [The Common Information and Simulation Space allow the exchange of well-structured, informative messages.](#)
3. [Test-bed reference implementation: the components inside the yellow rectangle are being developed as open source tools in the DRIVER+ project.](#)
4. [Test-bed composer's home page.](#)
5. [Test-bed composer: Selecting a solution.](#)
6. [Test-bed composer: Downloading the docker-compose.yml file.](#)
7. [Conceptual diagram of gateways translating messages back and forth between CIS and CSS.](#)
8. [Admin tool.](#)
9. [JEMM exercise script example.](#)
10. [Exonaut timeline example.](#)
11. [Observer Support Tool: Left, an overview of available observation templates. Right, one of the observation templates is selected.](#)
12. [The Test-bed time-service GUI can be used to start/stop/pause a Trial, as well as set the simulation speed.](#)
13. [Screenshot of Landoop's Kafka topics UI, which is part of our test-bed.](#)
14. [Screenshot of Landoop's AVRO schema registry, which is part of our test-bed.](#)
15. [Screenshot displaying the Replay service's GUI interface.](#)
16. [State diagram of the time service.](#)