MED1stMR Mixed Reality Training

TRAIN [SKILLS. RESILIENCE. PERFORMANCE] SAVE LIVES

D4.6

Generic Integration Framework for Incorporation of Novel First Responder Technologies in MR

Version

V1.0

Authors

Daniel Garcia Guirao (IDENER)

Santiago Masse (IDENER)

Patricia Gamboa (PLUX)

Ronny Tobler (RFNS)

Dervis Demirtas (D2D)

Helmut Schrom-Feiertag (AIT)

Project
MED1stMR

Project number
101021775

Type of Action
RIA

Start date of project
01.06.2021

Duration
36 months

Deliverable
D4.6

Deliverable Lead
IDENER

Related work package
WP4

Dissemination level
Confidential

Due submission date
30.09.2023

Actual submission
29.09.2023

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

HORIZON 2020

Versions

Version	Date	Author(s)	Description
V0.1	28/06/2023	Daniel García Guirao (IDE)	First Draft
V0.2	29/08/2023	Daniel García Guirao (IDE)	Document ready for tech partners contributions
v0.3	12/09/2023	Patricia Gamboa (PLUX)	Addition and revision about wearable
v0.4	21/09/2023	Ronny Tobler (RFNS)	Revision of MR System parts
v0.5	25/09/2023	Dervis Demirtas (D2D)	Additions to manikin parts
v0.6	27/09/2023	Helmut Schrom-Feiertag (AIT)	Sharepoint management
v1.0	28/09/2023	Vendula Rajdlova (AIT)	Final formatting and submission

Report Review

Version	Date	Reviewer(s)	Statement
V0.6	27/09/2023	Helmut Schrom-Feiertag	Complete and ready for submission.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

RajdlovaV
29.09.2023

HSchrom
29.09.2023

List of Acronyms and Abbreviations

Acronym/ Abbreviation	
ADC	Analog Digital Converter
AMS	Arena Management System
API	Application Programming Interface
AR	Augmented Reality
ATTS	Advanced Training Simulator
BPM	Beats Per Minute
CI	Continuous Integration
ESP	Electronic Signal processing
GDPR	General Data Protection Regulation
HAR	Human Activity Recognition
HLD	High-Level Document
IT	Information Technology
JSON	JavaScript Object Notation
LED	Light Emitting Diode
MAS	MED1stMR Analytics & Statistics
ML	Machine Learning
mmHg	Millimetre of Mercury
MR	Mixed Reality
POE	Power over Ethernet
PSS	Protected SharePoint Server
PWM	Pulse Width Modulation
RAAR	RFNS After Action Review
REEL	RFNS Enhanced Level Editor
REST	Representational State Transfer

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

SDK	Software Development Kit
SQL	Structured Query Language
UI	User Interface
URL	Uniform Resource Locator
UUID	Universally Unique Identifier
VPN	Virtual Private Network
VR	Virtual Reality
WI-FI	Wi-Fi is a family of wireless network protocols, based on the IEEE 802.11 family of standards

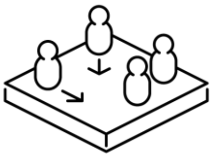
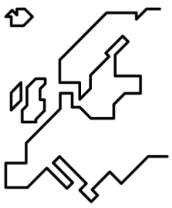
Terms and Definitions

Term	
ATMEGA	The ATmega series features a microcontroller that provides a solid amount of program memory, as well as a wide range of pins available.
Deep Learning	Machine learning method based on neural networks that utilises multiple layers to extract high-level features from raw input.
Manikin ADAM-X	A mixed reality manikin that interacts with the virtual training through advanced sensory and robotics.
Motive	Motion Tracking Software by Natural Point Inc.
Optitrack	Camera-based motion capturing system for animation and virtual reality.
Protected Sharepoint Server (PSS)	A locally hosted instance of Sharepoint within AIT, with heightened security regulations and limited access, for more sensitive data (e.g. raw study data including personal data points)
Raspberry Pi	Raspberry Pi is a series of small single-board computers developed in the United Kingdom by the Raspberry Pi Foundation in association with Broadcom.
REST API	A REST API defines a set of constraints on how the architecture of an Internet-scale distributed hypermedia system, such as the Web, should behave.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

TrueVRSystems	A full-body Mixed Reality System developed for entertainment purposes based in Switzerland.
Unity	Development environment for 3D simulations and games.

Relation to Objectives

Objective	Description
	**Obj. 1: Pioneering MR training approach for enhanced realism** The framework integrates innovative technologies like VR, responsive manikins, biosignals measurement and data analysis, promoting a pioneering and realistic MR training approach. It simulates real-world conditions, enhancing the realism of MR training scenarios.
	**Obj. 2: Effective training scenarios and a training curriculum** The deliverable's architectural design supports the creation of effective training scenarios tailored to modern first responder education. Its guidelines structure a cohesive training curriculum, aligning with educational goals.
	**Obj. 3: Physiological signal and trainee behaviour feedback loop and smart scenario control** This document emphasises real-time feedback on trainee behaviour through physiological signal acquisition, enabling a responsive training environment through its integration with the MR system. This enables intelligent scenario control within the framework through dynamic adjustments to training based on trainee performance.
	**Obj. 4: Position the pioneering MR training approach across Europe** The scalable and adaptable integration framework provides a blueprint for broader application across Europe, enhancing the pioneering MR training approach. Its alignment with technological advancements fosters collaboration and adoption across different European regions and institutions.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Table of Contents

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

List of Figures

List of Tables

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Executive Summary

The primary aim of this deliverable D4.6, titled "Generic Integration Framework for Incorporation of Novel First Responder Technologies in MR," is to lay out the detailed structure, design principles, and potential applications of MED1stMRs integration framework. This is developed to enhance the incorporation of innovative technologies, such as MR Training Systems, Medical Manikins, Wearable Biosignals Sensors, and Data Analytics & Statistics tools within first responder operations. The focus lies on creating a universal structure that allows easy integration and maximizes the efficiency of technological applications in medical response. The content of the deliverable is structured into six main sections: **1)Introduction**: Offers an overview of the document. **2)System Overview**: Describes the various technologies integrated in MED1stMR, like MR Training Systems, ADAM-X Manikin, PLUX Wearable Biosignals Sensors, MAS Tool, including sub-components like data platform services and ML techniques development. **3)Generic Integration Framework Design**: Explains the design principles, architecture, and key interfaces and interactions of the integration framework, including specific integrations with other components. **4)Data Management**: Discusses data flow to the central storage of the integration framework for debriefing of training sessions and analysis of training performance. **5)Conclusions: Evaluation, Future Work, and Potential Applications**: Highlights key findings and observations, scope for future enhancements, and potential for integrating other technologies.

This document includes the description of the successful creation of a Generic Integration Framework that can seamlessly incorporate novel technologies into MR scenarios. The evaluation reveals promising potential for future enhancements and adaptability to other technological platforms. Data management protocols ensure data flow efficiency while maintaining privacy and security standards. The findings of this deliverable will play a pivotal role in shaping the subsequent phases of the project. The Generic Integration Framework's design and architecture demonstrates the actual development and implementation of the system, proving a streamlined integration process. Finally, the observations concerning potential future enhancements and adaptability to other technologies will help in the project's expansion, fostering innovation and applicability to broader first responder and medical fields. All the contributors to this deliverable declare that they:

- Are aware that plagiarism and/or literal utilisation (copy) of materials and texts from other Projects, works and deliverables must be avoided and may be subject to disciplinary actions against the related partners and/or the Project consortium by the EU.
- Confirm that all their individual contributions to this deliverable are genuine and their own work or the work of their teams working in the Project, except where is explicitly indicated otherwise.
- Have followed the required conventions in referencing the thoughts, ideas and texts made outside the project.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Relation to other deliverables and tasks in MED1stMR

Table 1: The work and the document build on results from the following deliverables.

No.	Title	Information on which to build
D1.3	Data Management Plan	It includes a risk evaluation and the data protection measures to minimize the risks.
D2.4	High-Level System Architecture	It lays out the overarching structure of the system, serving as a foundation for all subsequent architectural developments.
D4.1	MR Technology Framework for Responsive Human-Manikin	It outlines the engagement between human operators and manikin systems and lays the groundwork for responsive interaction.
D4.3	Activity Recording for the Exercise Debriefing	It defines the methods for capturing trainees' activities, essential for post-training analysis and improvements.
D4.4	Physiological signals acquisition hardware and software framework	It establishes the framework for acquiring physiological signals from first responders during the scenario
D4.5	Smart Wearables for First Responder Monitoring	It delineates the use of wearable technology for monitoring first responders, forming the basis for real-time insight collection.
D5.1	VR System Design Document	It details the underlying design of the VR system, providing the blueprint for immersive training integrations.
D5.2	MR Trainings Environment	It sets the specifications for the MR training environment, acting as the template for realistic training setups.
D5.3	Integrated Physical Human Manikin	It illustrates the integration strategies for manikin systems in the context of MR training.
D5.4	Integrated Sensorics for Physiological Measurement	It outlines the incorporation of sensors for physiological assessment of first responders, enabling the system's health monitoring capabilities.

Table 2: The results of this work will be incorporated into following work and developments

No.	Title	Basis for
D6.2	Field Trial and Studies Combined Analysis Report	Field Trials analysis will heavily rely on technological availability and integration

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

1 Introduction

The evolving landscape of medical first responders training demands innovative solutions that bring together realism, efficiency, and adaptability. The "Generic Integration Framework for Incorporation of Novel First Responder Technologies in MR" represents a pioneering stride towards fulfilling these demands. By weaving together cutting-edge technologies such as Virtual Reality (VR), human-manikin interaction, and smart wearables, the framework sets the stage for a revolutionary approach to training that is closely aligned with real-world conditions. Its design principles lay the groundwork for creating immersive experiences, rich with insights, and responsive to trainees' physiological signals and behaviour.

This document delves into the architectural intricacies, key interfaces, design considerations, data management, and future potential of the Generic Integration Framework, demonstrating how it contributes to creating effective training scenarios, a cohesive curriculum, and an intelligent feedback loop, all aimed at positioning a leading MR training approach. This report will particularly focus on the data management system (MAS tool) design and architecture, as it represents a centralised communication hub for training data storages, processing and access.

2 System Overview

Section 2 provides an overview of the integral components that constitute the Mixed Reality (MR) training system developed for the project. The system encompasses four primary elements: VR Training System, ADAM-X Manikin, Wearable Biosignals Sensors, and MAS Tool.

It is important to note that the VR Training System, ADAM-X Manikin, and Wearable Biosignals Sensors will be presented briefly in this deliverable, as there are dedicated submitted deliverables providing detailed descriptions of these components. The concise presentation here is intended to set the context before delving into the integration with the MAS Tool as the central data integration hub.

2.1 MR Training System

Built upon the RFNS multiuser VR training platform, it allows the simulation training of scenarios performed in the project as well a training debriefing. The system's architecture is founded upon a robust set of hardware components that facilitate motion tracking, connectivity, and scenario control:

The tracking mechanism is handled **by 32 Optitrack Slim 13 Motion Capture Cameras** connected by **CAT6 Wired cables** with two **POE Switches**. For connectivity of the Slim 13 cameras, **2 NETGEAR ProSafe GS728TPPv2 POE Switches** are utilised, alongside an **Optitrack Wireless Base Station** to communicate with tracked objects such as Mixed Reality Props and Sensors. The system also incorporates **Optitrack Active Tags** to identify tracked objects such as props and participants.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

For network communication and power management, the system includes **1 central Ubiquiti UniFi Switch Pro-24 PoE switch** that connects all MR users to the system. This is further enhanced **by Ubiquiti UniFi AP AC-PRO**, a Wi-Fi Access Point, and a **Meraki Router**, which acts as a VPN gateway to open a secure channel to the RFNS network. An **Internet Router** is also in place to enable an IPsec VPN tunnel to RFNS for support, update, and maintenance purposes.

At the heart of the system's computational and analytical functions lie several high-performance workstations. The **HP Z4 High-Performance Workstation** calculates all motion data from the participants, and an **AMS Server**, an **HP Z1 Workstation**, connects all participants to the same scenario, also serving statistical purposes for system use and event logs such as bug reports. Furthermore, the **Instructor Server**, another **HP Z4 High-Performance Workstation**, hosts and directs the scenario as an instructor, while the **After Action Review Server**, also an **HP Z4 High-Performance Workstation**, analyses the debriefing data with the trainee group.

These components collectively ensure a seamless integration of physical and virtual elements, resulting in a responsive and realistic Mixed Reality training environment. Following Figure 1 shows the hardware diagram of the RFNS system.

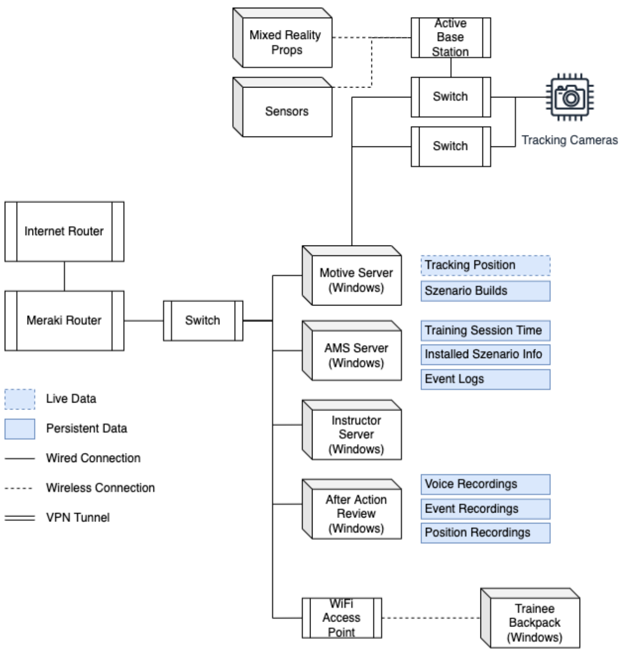


Figure 1 MED1stMR RFNS Hardware Diagram

RFNS uses Unity as a base software to develop the mixed reality training environment for the MED1stMR project. The system is made up of different components, shown in Figure 2 and explained in the following paragraphs.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

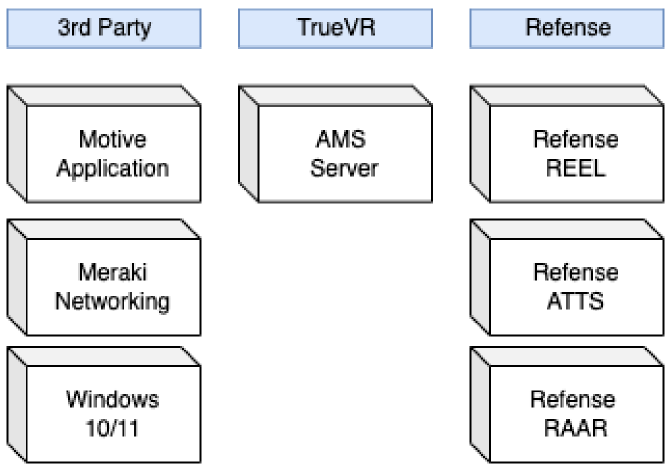


Figure 2 RFNS Software Components

The Mixed Reality training system leverages a blend of specialised software developments, third-party applications, and an integration system.

Key developments include the **REEL RFNS Enhanced Level Editor**, enabling scenario design; the **ATTS Advanced Training Simulator**, providing instructor control; and the **RAAR After Action Review** for training analysis.

Third-party applications enhance the system's functionality, with Motive Application from NaturalPoint for motion tracking, Meraki Networking applications for secure communication, and Windows 10 and 11 as the operating systems.

2.2 ADAM-X Manikin

The ADAM-X patient simulator constitutes an essential component in the field of medical training, particularly for emergency response scenarios. Designed to mimic the male human's skeletal and anatomical structure, ADAM-X bears unique human characteristics that render training sessions more realistic.

Durability and adaptability define ADAM-X, making it suitable for training in any trauma emergency situation across both military and civilian contexts. The wireless system within ADAM-X enhances its utility, with a fully functional wireless computer enabling instructors to monitor and make adjustments during training. With various degrees of fidelity available, the simulator proves ideal for projects like MED1stMR, where first responders must make life-saving decisions under stress.

Within the scope of the project, training is bifurcated into two levels of triage. ADAM-X with limited features is employed for the first triage, while the high-fidelity simulator is reserved for the second. First triage, or resuscitation, necessitates immediate, life-saving intervention for conditions such as cardiopulmonary arrest, major trauma, and severe respiratory distress. The ADAM-X, tailored to

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

support this crucial training phase, integrates mixed reality to simulate different traumas. Essential physical interactions with the manikin include feeling the pulse, repositioning, stopping bleeding, applying a tourniquet, and performing CPR.

By augmenting the physical with virtual elements such as simulated bleeding and emotional distress, ADAM-X for the first triage creates a comprehensive experience. Amputated limbs and wounds that need packing are handled physically, while virtual elements are projected onto the virtual manikin, corresponding as a lay-over to the physical version.

The ADAM-X manikin's architecture (Figure 3) integrates local and remote controllers, along with various I/O components, within an exclusive electrical system, safeguarding sensitive technology. A central Power box efficiently manages connected devices and scenarios. Inside the manikin, a micro-computer expertly oversees slave ADC's and PWM controllers, while peripherals make use of ESP-based ATMEGA microcontrollers. Software is utilized to run the system, transmitting data in JSON format. Communication is supported in Wired, Bridged, and Wireless modes, facilitated by specialized network components. These combined elements give rise to a responsive and lifelike medical training tool, showcasing the technological prowess of the ADAM-X system while maintaining the confidentiality of its intellectual property.

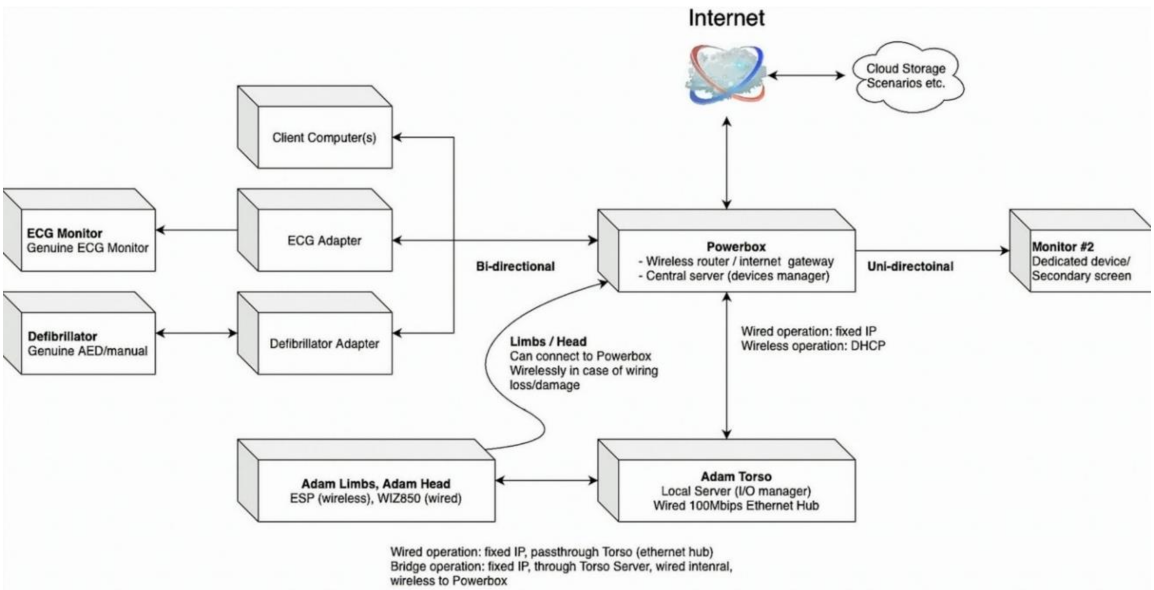


Figure 3 ADAM-X Manikin System Architecture

2.3 Wearable Biosignals Sensors

Within the scope of the MED1stMR project, the monitoring of physiological signals from Medical First Responders (MFRs) during training is paramount. To this end, bespoke wearable devices have been engineered to align with the specific demands of end users and the operational constraints of the

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

MED1stMR system, as shown in the simplified diagram of Figure 4. These wearables facilitate the collection of vital physiological signals, which are then integrated into a real-time dashboard. This dashboard serves to present information on trainees' physiological parameters, offering an assessment of their stress levels based on select parameters.

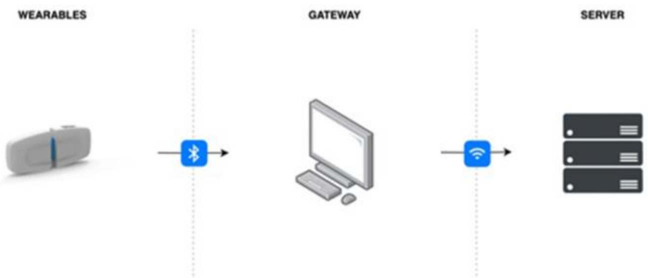


Figure 4 PLUX wearable hardware diagram

Two specific wearables are deployed to gauge the user's stress score: the **cardioBAN**, responsible for Heart Rate (HR) and Heart Rate Variability (HRV) data, and the **edaBAN** (OpenBAN), designated for the galvanic skin response data. Both wearables, constituting a kit, are affixed to the trainee, with a Bluetooth connection established with the scenario control computers running the MED1stMR Biosignals SW Client. This specialised software manages the connection and processes the RAW data received from the wearables, encompassing metrics such as HR, HRV, and the stress score. The integration of these wearables (Figure 5) within the training environment underscores the project's commitment to delivering a nuanced and data-driven understanding of trainee performance, thereby enhancing the overall efficacy and realism of the training simulations.

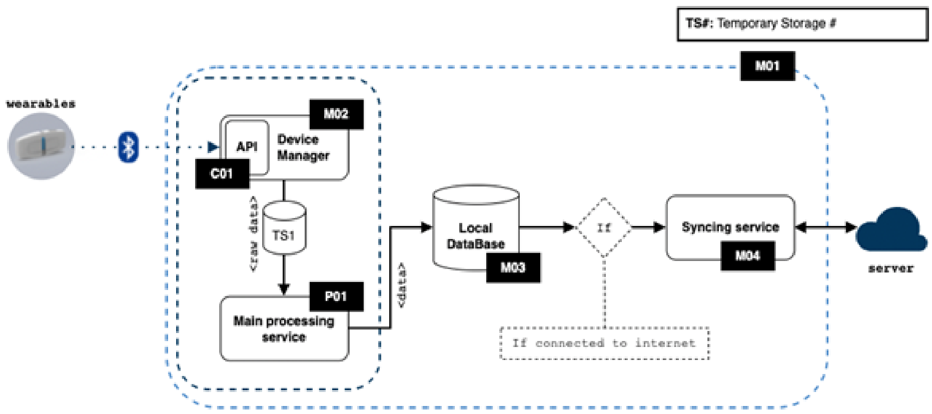


Figure 5 PLUX wearable system architecture diagram

2.4 MAS Tool

The MED1stMR Analytics and Statistics Tool represents a critical component in the modern data-driven landscape. This section will succinctly detail the platform services employed, including synthetic data

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

generation techniques, the development of machine learning (ML) models, and the architecture of processing pipelines. These elements collectively contribute to an advanced and adaptive environment, tailored to meet the intricate demands within the MED1stMR framework.

2.4.1 Platform services

The MAS Tool data architecture follows the Lambda Architecture paradigm, a robust data management system tailored for handling extensive data. It is structured into three principal layers: the batch layer for historical data, the speed layer for real-time-like processing and analytics, and the serving layer, which consolidates information from the former two. This architecture is integral to the integration framework's central storage, facilitating data retrieval for debriefing of training sessions and analysis of training performance. Enhanced with services for security and monitoring, it ensures a comprehensive, accurate, and current view of data, with the flexibility and fault tolerance essential for effective data processing. The full architecture services and their connections are shown in Figure 6.

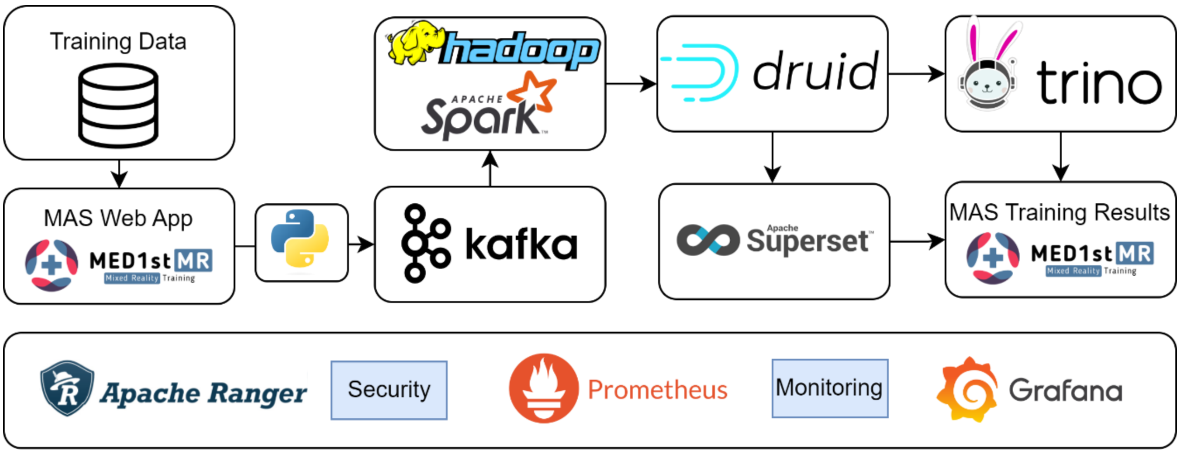


Figure 6 MAS Data Architecture components

Batch services

MAS data architecture includes a layer for storing and processing historical data through batch processing techniques, ensuring a complete and accurate view. This layer incorporates:

- **Hadoop Distributed File System (HDFS):** This distributed system stores large data sets and offers high-throughput access with fault tolerance. It includes two NameNodes (Active and Passive Configuration) for quick failover, three DataNodes for data redundancy, and three JournalNodes for synchronisation.
- **Jupyter Notebook**: An open-source platform used in the MAS Tool for crafting Python scripts, extracting data from HDFS, and processing it using Apache Spark.
- **Apache Spark**: This distributed computing framework handles big data workloads in the setup. It includes a master for task coordination and two workers for processing tasks.
- **Apache ZooKeeper**: Deployed in three instances within MED1stMR's architecture, it ensures fault tolerance and coordination across distributed systems.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

These components collectively contribute to the data management system, allowing for efficient data retrieval, processing, and analytics.

Stream services

This layer in the MAS Tool data architecture manages real-time-like data processing and updates, employing several tools:

- **Apache Kafka:** A high-throughput streaming platform used for real-time data pipelines enabling complex stream processing, consisting of three brokers for resilience.
- **Kafka Connect:** Deployed in two instances, it streams data between Kafka and other systems.
- **Kafka Rest:** A RESTful API for remote access to the Kafka cluster.
- **KSQL:** A stream processing SQL engine for real-time analytics.
- **AKHQ:** A web-based UI tool for managing Apache Kafka.
- **Apache Zookeeper:** Utilised in three instances for managing distributed applications within the Kafka cluster.

These components collectively enable real-time processing and handling of data streams, enhancing the efficiency and resilience of the system.

Serving services

This layer in the MED1stMR data architecture serves and indexes the processed data from both batch and stream layers, employing several tools:

- **Apache Druid**: An open-source, real-time analytics and OLAP platform. Divides data into segments across a cluster, uses a "bitmap index" for quick queries, and requires access to cluster manager, deep storage, and metadata storage.
- **Trino**: An open-source, distributed SQL query engine for big data processing and analytics. Splits a query into tasks, distributes across a cluster, and combines results. Compatible with various data storage systems.
- **Apache Superset**: A platform for data visualisation and exploration. Connects to various data sources and permits exploratory analysis. Enables creating and sharing dashboards and visualisations, with an intuitive interface and robust security.
- **Apache Zookeeper**: Utilised in three instances for managing the distributed applications within the Druid cluster.

These components collectively enhance querying, analysis, and visualisation of large data volumes, increasing the efficiency and versatility of the system.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Security and Monitoring services

The following section shows the pivotal components integrated into the system, ensuring data integrity, control, and continuous insights. The deployment of these services, described in detail below, enhances the reliability, efficiency, and transparency of the data architecture.

Security services:

- **Apache Ranger**: An open-source security framework for Hadoop and other big data ecosystems. Centralizes administration and fine-grains authorization and access control for data, enforcing policies through plug-ins. Ranger Audit feature provides auditing capabilities to meet compliance and monitor suspicious activity.

Monitoring services:

- **Prometheus**: A monitoring and alerting system for cloud-native applications and infrastructure. Collects, stores, and analyses time-series data, offering real-time insights and alerts.
- **Grafana**: An open-source data visualization and analytics platform. Creates, analyses, and visualizes metrics, with alerts based on conditions. Offers a rich set of visualizations and dashboards and integrates with data sources including Prometheus.

2.4.2 Synthetic data

Introduction and chosen technology

Synthetic data, artificially created information, provides a viable solution when genuine data is unavailable or restricted due to privacy or security concerns. This approach offers access to valuable insights while safeguarding privacy, as evidenced by its use in large-scale efforts like the 2020 United States Census and Public Health England.

For the MED1stMR project, creating synthetic data becomes crucial as it ensures the validation of data processing pipelines and machine learning techniques in the absence of real data. The process of synthesis preserves the statistical properties of the original data, enabling analysts to make equivalent statistical conclusions. This can be achieved through various types, including fully synthetic, partially synthetic, and hybrid data, depending on the sensitivity and requirements of the project.

GANs and VAEs are state-of-the-art methods for generating synthetic data. Additionally, numerous documents have been discovered that not only increase the confidence given to these technologies but also contain practical information specifically about medical time-series based data generation. Nevertheless, compared to GANs, VAEs are less effective and require more time for training, making them less efficient. For all the mentioned reasons, GANs have been selected as the starting point to generate synthetic data based on the sample datasets received, particularly pre-trained models, which will be fine-tuned in order to improve their performance. GANs core components are shown in Figure 7.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

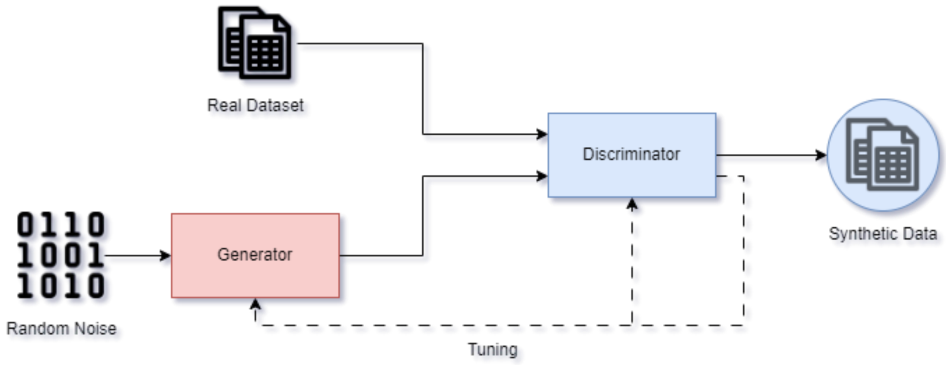


Figure 7 GAN structure

Generation of synthetic VR system data

The simulation data comes in JSON format. Each of the file types that are received will be described in detail below, and their processing pipeline for data integration will be presented in section 3.3.3. In this section, particular focus is given to the generation of synthetic values to emulate a training so that data analytics pipelines could be tested, validated and improved.

ClientData.json

Following is the structure of the data for a client. The data object will get extended, the more data is gathered over time.

ClientId : int	This is the client id
Timestamp : int	The timestamp of the data in unix
Position x,y,z : float	The position on that timestamp
Rotation x,y,z,w : float	The rotation (quaternion) on that timestamp

- TimeSeries data that determines the position and rotation of a Trainee given an instant. For the experiments, a sample was created each second, which was the expected sampling rate.

EventData.json

EventData will hold the information, which EventType was triggered from whom at what time with which Npc.

EventType : int	The enum int representation of an Event Example Enum could be: 0: PulseCheckStart 1: PulseCheckStop 2: TriageCardAssignRed 3: TriageCardAssignBlack etc..
Timestamp : int	The timestamp of the data in unix
ClientId : int	This is the client id
NpcId : int	This is the npc id

- TimeSeries data which represents the events and interactions between Trainees and NPCs. The events emulated a simulation, being each triage 4-6 min long and leaving a window of 10-15 seconds between triages.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

NpcData.json

This will hold the initial data for each npc patient (attention: this is no manikin data).

NpcId : int	This is the npc id
TriageColor : int	This is the representation of the correct triage color Enum TriageColor: 0: Green, 1: Yellow, 2: Red, 3: Black
Pulse : int	This is the initial pulse of the npc
RespiratoryRate : int	This is the initial respiratory rate of the npc
Position : x,y,z : float	Position of the npc
BoundingBox: center: x,y,z : float extends: x,y,z : float	Representation of the height and width of the npc. From this you can infer if they are an adult/kid and whether they are standing/lying down

- Contains information about the NPCs of the simulation, as well as the necessary information to check if the triages from EventData were correct.

Generation of synthetic ADAM-X data

During the development phase, the data instances received were API call examples to the manikin "Medical data" endpoint (Figure 8). These instances were sufficient to identify the column names of the dataset and the human values on which they were based. This data consisted of metrics such as heart rate, respiratory rate, and systolic and diastolic blood pressure. The subsequent step involved searching for reliable sources of standard values, standard deviation, and their variations over time.

```
Request
{"type": "getMedicalData","uuid": "5hjvhkjbhdfbrhjrukjgdfyut43tyutgrygtyu5","simulatorId": "test_client","data": {"valueTypes" :
[{"type" : "heartRate"}, {"type" : "respiratoryRate"}, {"type" : "bloodPressure"}],"updateRate" : 60}}

Response
{"type": "medicalData", "uuid": "5hjvhkjbhdfbrhjrukjgdfyut43tyutgrygtyu5", "simulatorId": "test_client", "timestamp": 1677233819905,
"data": {"heartRate": 72, "respiratoryRate": 50, "bloodPressure": {"systolic": 120, "diastolic": 80}}}
```

Figure 8 ADAM-X API data examples

To establish normal human parameters, a comprehensive range of sources was utilised. This encompassed scientific literature, medical studies, and anthropometric databases. Reputable health organisations, such as the World Health Organization (WHO) and national health institutes, were consulted to gather standardised data on human measurements and vital statistics. Through synthesis and analysis of this information, the most current and accurate values were incorporated, enabling a realistic representation of normal human parameters:

- Systolic blood pressure was referenced from a study published in the National Center for Biotechnology Information (NCBI), reporting a mean value of 120.4 mmHg with a standard deviation of 17.0 mmHg (source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6911645/).
- Diastolic blood pressure was determined from the same study, indicating a mean of 74.0 mmHg with a standard deviation of 12.0 mmHg.
- Respiratory rate data was taken from a publication in Nature, revealing a mean rate of 15.4 min^{-1}, with a standard deviation of 2.35 min^{-1} (source: https://www.nature.com/articles/s41746-021-00493-6).

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

- Heart rate information was referred from an NCBI research article, stating a mean rate of 80.2 beats per minute (bpm) for individuals aged 21 to 30 years, with a standard deviation of 14.8 bpm (source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6592896/).

This collected information was utilised to call a function generating a value for each timestep, considering the relevant parameters required: standard value (the mean value of a specific metric), noise_std_dev (indicating variations in the metric), and window size (specifying temporal changes). This approach ensured that the deliverable was rooted in evidence-based standards, reflecting a robust understanding of human physiological parameters.

Generation of synthetic biosignals anomalies

For the Synthetic Data Anomaly Detection Proof of Concept, the generation of synthetic data, including Synthetic Anomalies corresponding to real possible cases that may occur mainly in real-life scenarios, was essential.

The primary focus centred on identifying and addressing various anomalies related to cardiovascular health, such as heart attacks, blackouts, angina pectoris, and external anomalies (those impacting the vital parameters of the manikin without specific definition). The deliberate inclusion of these anomalies was motivated by their representation of critical events with significant impacts on an individual's well-being, especially during stressful situations. Incorporation of these anomalies into the training data aimed to create a more realistic training environment for the models, pending access to actual data on such occurrences.

Furthermore, the data alterations were consciously designed to emulate the shape of real-life anomalies, by incorporating abrupt changes and realistic noise to align with observations in actual situations. This decision stems from the understanding that cardiovascular health anomalies often appear in sudden, unforeseen ways. By incorporating such alterations, the intention was to enhance the model's recognition and response capabilities to similar patterns in actual anomalies within real-world scenarios. This approach builds on the premise that training models with data analogous to real-world situations can foster better performance and generalisation abilities.

The following official sources guided the synthetic generation of anomalies for each type of anomaly simulated:

Angina Pectoris:

https://www.sciencedirect.com/science/article/pii/S0002870333902100

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4647673/

https://www.sciencedirect.com/science/article/pii/S0002870336908839

Blackout:

https://pubmed.ncbi.nlm.nih.gov/18502909/

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Heart Attack:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1767445/

https://pubmed.ncbi.nlm.nih.gov/8410395/

To achieve the most realistic stressors possible, the generated anomalies needed to closely resemble the real scenario. Therefore, functions generating anomalies, as well as synthetic noisy data from the manikin, were tailored to allow a more accurate shape of representation. The goal extended to adapting these arguments to the data generated during the project demonstrations, ensuring the AI techniques corresponded to the simulation environment devices, sampling rate, and irregularities. A visual representation of a synthetic Medical Data dataset with synthetic anomalies was subsequently created (Figure 9), portraying this multifaceted approach to synthetic anomaly detection.

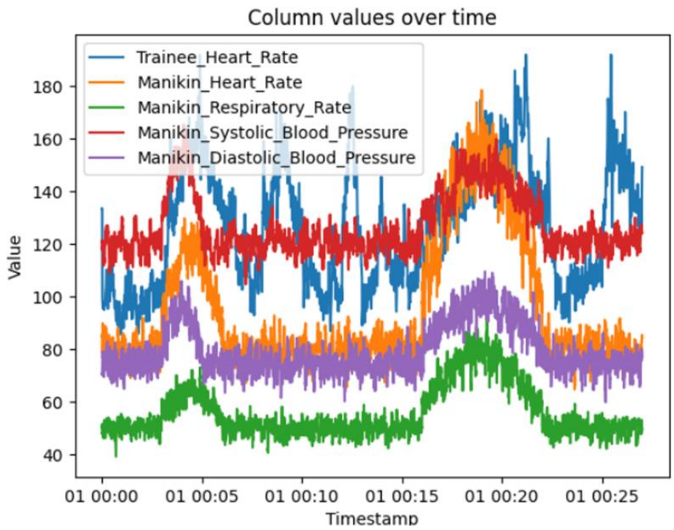


Figure 9 Synthetic multi-variate dataset for anomaly detection training

2.4.3 ML techniques for anomaly detection development

MSCRED, or Multi-Scale Convolutional Recurrent Encoder-Decoder, serves as a sophisticated machine learning model specifically tailored for detecting anomalies in time-series data. Within the context of MED1stMR, it is utilised to discern uncommon patterns or inconsistencies between the manikin, trainee, and event data in the simulated environment.

Understanding MSCRED

- **Multi-Scale**: MSCRED's ability to analyse data at varying scales or levels of detail is encapsulated in this term. This aspect is vital in medical scenarios where anomalies might be noticeable at one scale but hidden in another.
- **Convolutional**: Stemming from Convolutional Neural Networks (CNNs), this part of MSCRED entails the use of convolutional layers to process time-series data as a one-dimensional "image".

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

- **Recurrent Encoder-Decoder**: This structure of the model involves an encoder processing the input data, and a decoder employing this processed data to make predictions, particularly whether there's an anomaly. The term "recurrent" is attributed to the usage of Recurrent Neural Networks (RNNs), apt for handling sequential data like time-series.

Practical Application

MSCRED learns what 'normal' trainee and manikin interaction data appear to be in the simulated environment during a training phase. Once trained, the model examines new data to detect significant deviations from this 'normal' pattern, flagging them as anomalies.

One core advantage of MSCRED is its aptitude to minimise false positives. It does so through a reconstruction-based approach, reconstructing the interaction based on 'normal' interactions, leading to a more reliable detection with fewer false positives.

In essence, MSCRED acts as a robust tool for anomaly detection in virtual medical training, analysing interactions at multiple scales, and utilising a reconstruction-based method to bolster the quality of the detected anomalies.

The model's architecture involves:

- **Encoding Phase**: The input goes through 1D convolutional layers, with variables like the number of filters, kernel size, stride, padding, and activation function defined.
- **Temporal Modelling** Phase: The encoding phase's outputs are processed by a GRU (Gated Recurrent Unit) layer, with necessary manipulations before being fed into the GRU layer.
- **Decoding Phase**: This phase reshapes the temporal modelling phase's output and passes it through a series of 1D deconvolutional layers, reversing the order of the convolutional layers.

Preliminary Results

The matrix reconstruction errors are represented over time, with a suggested threshold stemming from a percentile of true positives identification (Figure 10). Adjustments to the threshold address false negatives, and other features, like background colour, can indicate potential anomalies (Figure 11).

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

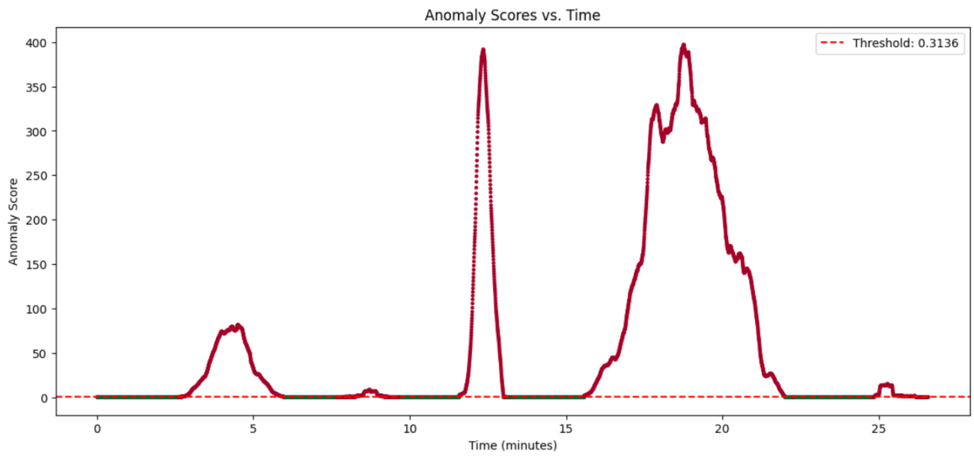


Figure 10 Anomaly scores in test dataset

In real use case scenarios, the threshold optimisation can be challenging, sometimes leading to skewed false positives or negatives. Future fine-tuning of the model may take trainers' criteria into account and may involve ignoring anomalies below a specific time frame to mitigate noise.

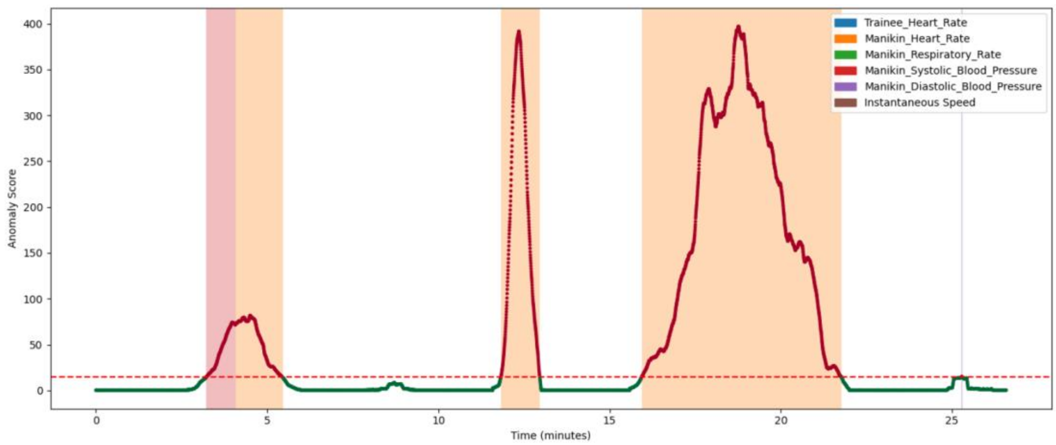


Figure 11 Identified anomalies after adjusting threshold

MSCRED thus illustrates a substantial innovation in anomaly detection within virtual medical environments, drawing on intricate neural network structures and tailored methods to offer precise and flexible analysis. The described architecture and results provide a foundation for ongoing enhancement and potential adaptations to other domains.

2.4.4 Graphical User Interface: MAS Dashboard

The MED1stMR Analytics & Statistics dashboard Is able to collect, process and serve data with low latency, extracting analytics and correlations from the collected data during the training to enhance debriefing and improve efficiency of medical first responders training.

The "Home" section allows for logging and registration into the platform (Figure 12). This is required in order to see the training results.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

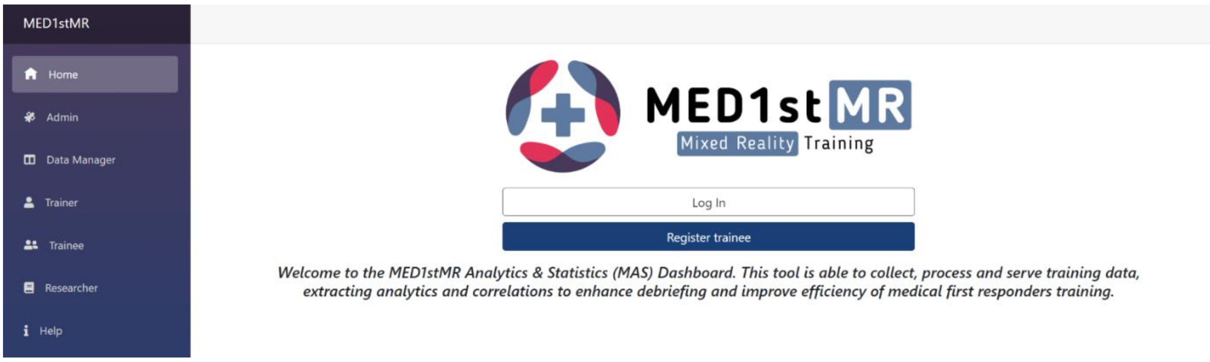


Figure 12 MAS UI Home view

User registration will be one of the early steps of the FT, where trainees will access the MAS tool website (med1stmr.idener.es) and enter their codename and a self-selected password (Figure 13). This will create a profile they will access to visualize training results.

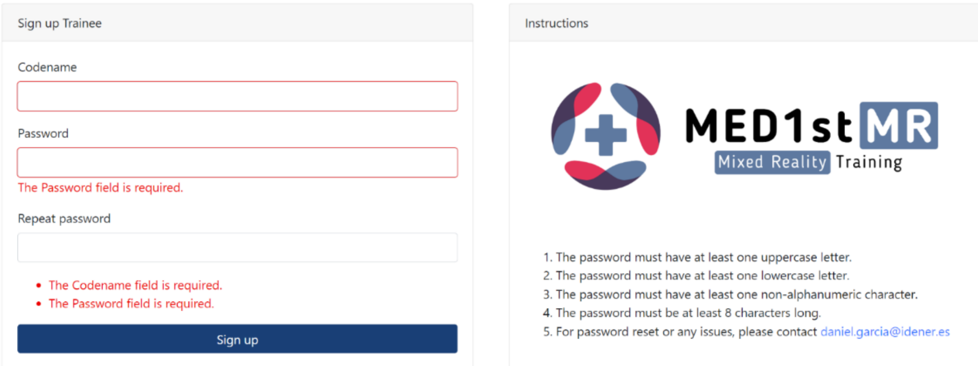
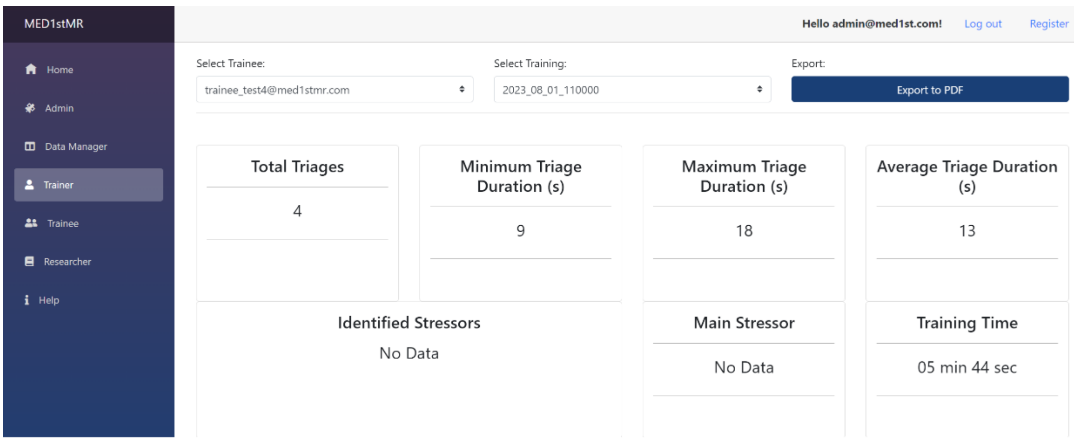


Figure 13 MAS UI Sign up view

Trainee Area

The dropdown menu at the top of the page allows you to swap among the different trainings. The data related to the training should be displayed as shown in Figure 14.



This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Figure 14 MAS UI Training overview

Regarding the metrics displayed on the **Dashboard**, a brief explanation of each element is presented below:

- **Total Triages**: This is the total number of triage processes conducted during the session.
- **Minimum Triage Duration (s)**: This is the shortest amount of time taken to complete a triage process. This metric is recorded in seconds (s).
- **Maximum Triage Duration(s):** Conversely, this is the longest amount of time taken to complete a triage process.
- **Average Triage Duration (s):** This is the mean duration of all triages conducted. It is calculated by adding together the duration of all the triages and dividing by the total number of triages.
- **Triage Accuracy**: This is a measure of how accurately the triage processes have identified the pre-assigned color of the NPCs. Please note that, with this metric, the current main intention is to evaluate the clarity of the simulation to identify the potential unclear context for a correct triage rather than evaluating the trainees' performance.
- **Total Training Time**: Total time spent in the scenario.
- **Identified Stressors**: This is a table with identified high-stress periods, where the following information is provided:
  - **Beginning timestamp**
  - **Ending timestamp**
  - **Anomaly Confidence:** This is how certain we are that there's a noticeable difference or change when we compare a stress score to usual or 'baseline' values.
  - **Anomaly Severity:** This is about how big or serious the change in stress score is. If your stress score increases a lot, then the anomaly or change is considered severe.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

- **Identified Stressor:** This is about figuring out what exactly is causing the stress or change in stress. It's the source of stress that has shown the most change during the time being considered. For example, if your workload increased significantly during a particular period, and your stress levels also went up, the workload might be identified as the main stressor.
- **Stressor Confidence:** This is about how certain we are that the identified stressor is the real cause of the stress. It's determined by looking at how much the identified stressor has changed compared to other possible causes of stress. The bigger the change in the identified stressor compared to others, the more confident we are that it's the real cause of the stress.

- **Main Stressor**: Among all the identified stressors, the main stressor is the one that causes the most severe stress period.
- **Stress During Training**: Level of stress experienced during the training period, measured every second based on heart rate, heart rate variability and baseline measurements.

Trainer Area

The trainer area allows them to see all their assigned trainees processed data. There is a dropdown at the top of the page to choose among the trainees (Figure 15).

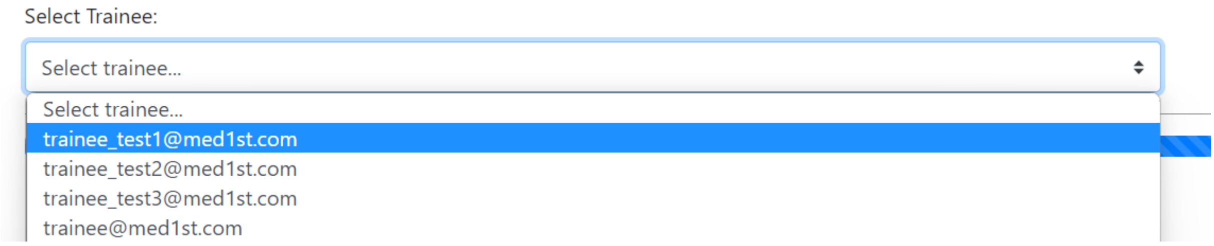


Figure 15 MAS UI Trainee dropdown menu

Once the trainee is selected, select the specific training to check (Figure 16).

Figure 16 MAS UI Training menu

The results related to that training will be displayed.

3 Generic Integration Framework

The Generic Integration Framework forms a critical component of the MED1stMR solution, aiming to seamlessly connect various disparate elements and ensure fluid interaction. This chapter is dedicated to a detailed exposition of the design methodology, architecture, and key interfaces that underpin the integration framework.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

3.1 Design Principles and Considerations

This subsection delves into the essential design philosophies and considerations that guided the creation of the integration framework, laying down the foundation of the design.

In understanding the Generic Integration Framework Design, it is essential to reminisce on the high-level system architecture detailed in Deliverable 2.4 (High-Level System Architecture). This reference serves to remind and pinpoint the most vital information that has shaped the design principles and considerations.

The nature of the MED1stMR system stands out as a collaborative project involving the integration of several essential building blocks. These are developed in unison between the project's technical partners, culminating in an MR training framework that uniquely incorporates haptic responses, live monitoring of participants, and an AI-enabled scenario control and debriefing application. The key components are as follows:

- **A. MR training system**: The multiuser VR training platform developed by RFNS, serves as the base for simulating training scenarios and debriefing, creating a seamless virtual experience.
- **B. Manikin ADAM-X**: A crucial element that offers a full-immersive mixed reality approach to training, being compatible with genuine medical devices and highly customisable.
- **C. Wearable PLUX Biosignals** Sensor: These devices monitor the trainees' physiological signals, sending data through the core MR system to enable live monitoring and AI-supported scenario control.
- **D. MAS Dashboard**: This centric platform processes, analyses, and debriefs training data, leveraging AI to enable advanced customized analytics.

This framework aims to deliver a realistic simulation environment by integrating the patient simulation manikin within a VR scenario, developed in collaboration with the MFR end user. The meticulous design of data flow through the system’s building blocks ensures an effective feedback loop, both live and post-training, empowering smart scenario control. Figure 17 and Figure 18, as provided in the high-level system architecture document, further illustrate the overall diagram and integration of subsystems focusing on data flows.

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

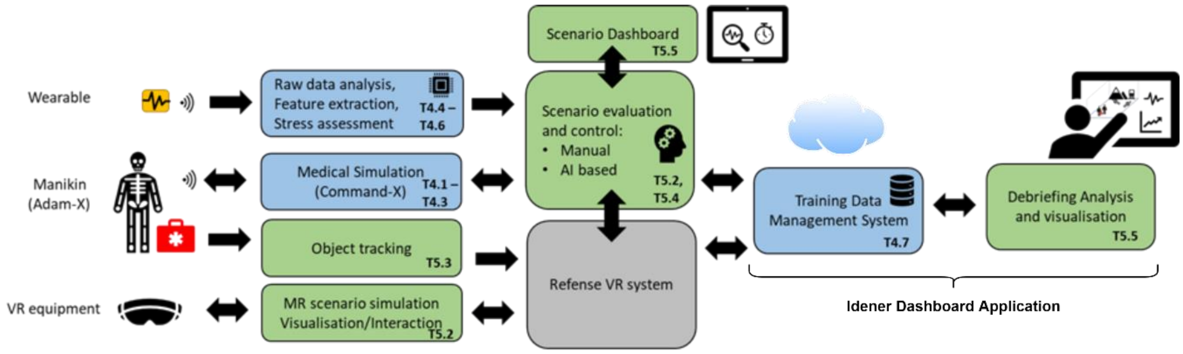


Figure 17 MED1stMR system preliminary design

Combining multi-disciplinary cutting-edge technologies to compose the MED1stMR training system has been a pioneering approach. Therefore, the creation of a robust high-level system architecture document has been indispensable, laying solid foundations for this complex project. This architectural design's general description aligns well with the ambition for a realistic and fully immersive MR training approach, setting the stage for the subsequent sections of this chapter.

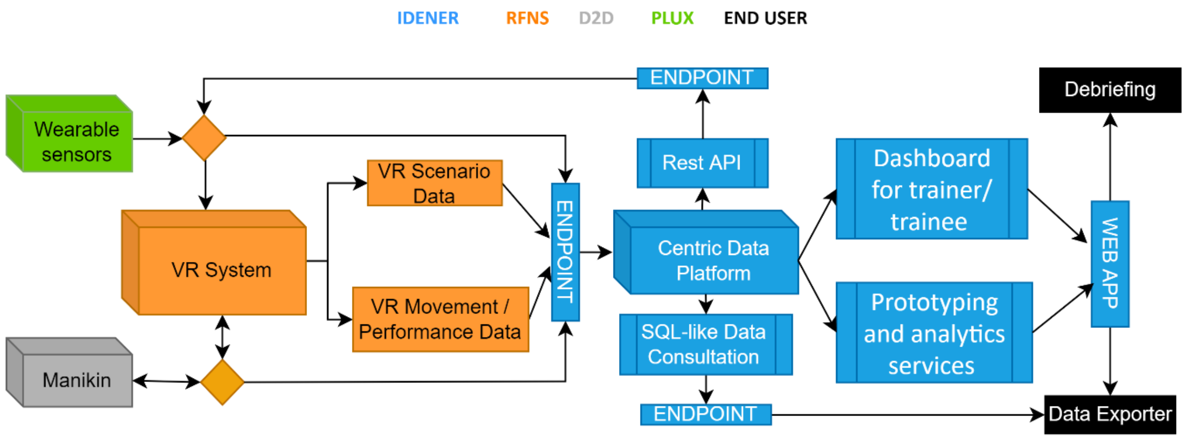


Figure 18 MED1stMR system architecture from D2.4

3.2 Architecture of the Integration Framework

The Integration Framework at the core of the MED1stMR system represents a groundbreaking approach to immersive medical training. It places a strong emphasis on the intelligent fusion of real-world objects and their digital counterparts within virtual simulations. This architectural design is pivotal in creating highly nuanced and responsive medical training scenarios that truly reflect the complexities of the healthcare field.

One of the key aspects of this Integration Framework is its ability to seamlessly bridge the gap between the physical and virtual realms. In the virtual environment, participants not only see themselves

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

represented as avatars but also witness the incorporation of mixed reality objects, such as the Adam manikin, which exists in the real world. This integration is a game-changer, as it allows trainees to interact with both virtual and physical elements in real-time, fostering a sense of immersion and realism that was previously unattainable.

Furthermore, the system meticulously records and transfers tracking data to the debriefing stage for in-depth analysis. This data encompasses a wide spectrum, including participant movements, speech, and sound. By collecting such comprehensive information, the MED1stMR system enables a thorough post-training assessment that can pinpoint areas of improvement, enhancing the overall quality of medical education.

Beyond immediate feedback, the Integration Framework also prioritizes the storage and management of vital participant data in a secure database. This stored information can serve as a valuable resource for ongoing analysis, research, and the continuous improvement of medical training methodologies.

In essence, the MED1stMR system, with its Integration Framework, not only elevates medical training to new heights but also revolutionizes the way healthcare professionals prepare for their roles. By intelligently connecting real-world elements with their virtual counterparts, it paves the way for more immersive, responsive, and effective training experiences in the field of medicine.

3.3 Key Interfaces and Interactions

3.3.1 Integration with Manikin

The ADAM-X is designed to function as a touch-responsive human simulator for realistic medical training scenarios. Within the MR environment, ADAM-X operates autonomously, continuously synchronising its condition and vital data through an interface to ensure visual consistency between the virtual and physical patients (Figure 19). This interface supports bi-directional communication between the manikin and the VR system via a web socket, enabling cohesive interaction between the two. The manikin API, based on WebSocket, will facilitate bidirectional communication between the client (VR system) and the server (Manikin). The data utilised for transmitting the request and receiving the response will be encoded in the JSON (JavaScript Object Notation) format.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

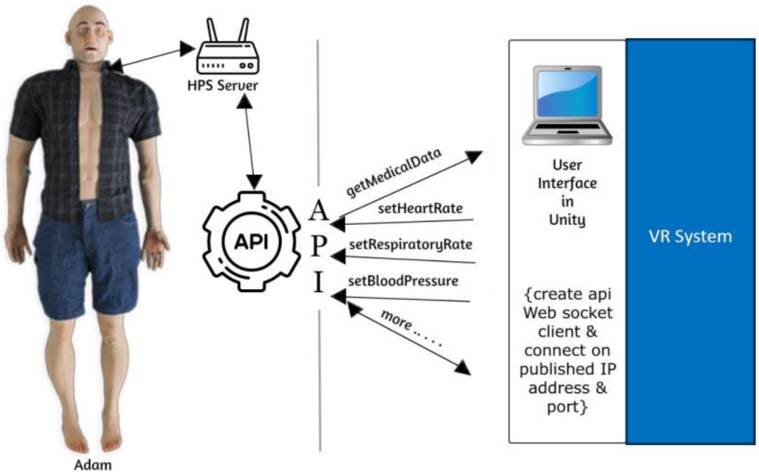


Figure 19 Manikin system integration framework showing the human manikin ADAM-X and the API for the VR System

Tracking within the VR system, in conjunction with vital data, allows for precise representation of the manikin's appearance and posture in the training scenario. The built-in actuators within the manikin can replicate human-like movements, such as chest rising and falling to simulate breathing. Synchrony between the virtual and physical manikin is paramount, especially during interactions like touch or during a cardiopulmonary resuscitation (CPR) simulation. Further details of the implementation for the communication with the Manikin API for Unity in C# are shown in D4.1.

Two ADAM-X units were chosen for the trial: one equipped to simulate breathing and detectable pulses and the other designed to emulate a lifeless yet responsive avatar within the VR environment. The RFNS software was employed to control various functionalities of the manikin through an API. The units were integrated into the virtual reality (VR) system with specialised trackers placed on the arms, body, and head. These trackers enabled the RFNS software to precisely recognise and mirror ADAM-X's movements in the VR setting, overlaying an avatar that closely replicated the humanoid's actions. Figure 20 shows the real manikin and illustrates how the ADAM-X appears to the trainee in VR.

Figure 20 Real manikin (left) and virtual representation (right)

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

3.3.2 Integration with Wearable Biosignals Sensor

The MED1stMR Software (SW) Client is initiated automatically by the Virtual Reality (VR) Scenario Control Software (SW). Within the interface, the MAC addresses of the configured wearable kits are shown, and the status of the connection is also prominently displayed. UI is shown in Figure 21, following the client Operation Manual of Figure 22.

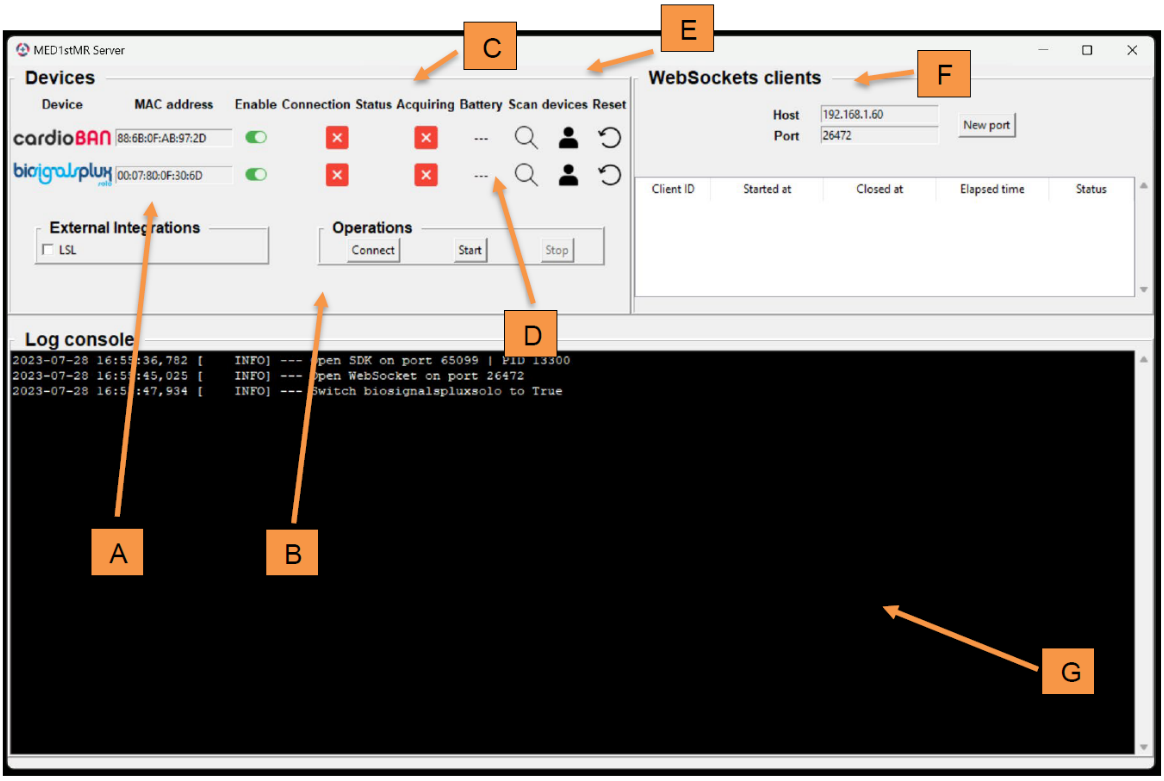


Figure 21 MED1stMR Biosignals SW user interface

Label:	Function	Automatically set via VR Scenario Control	Can be set manually?
A	MAC address of the wearable to be connected.	Yes	Yes
B	Operation: connect to the device and start/stop acquisition.	Yes	Yes
C	Status control: Connection status, Acquisition status.	-	-
D	Wearable Battery Level.	-	-
E	Scan new devices automatically or manually add new device. Reset current configuration.	Yes	Yes
F	VR Scenario Control WebSocket IP address and Port setup.	No	Yes
G	Visual Log screen.	-	-

Figure 22 MED1stMR SW client Operation manual

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

The following Figure 23 illustrates the operational MED1stMR Biosignals software client, functioning on the RFNS computer system. Tasked with the efficient processing and analysis of physiological data gathered from medical first responders throughout training sessions, this client offers immediate insights into vital signs and stress conditions. Through the utilization of the Biosignals software client, RFNS is empowered to supervise trainees' stress accurately, thereby enhancing their training experiences and guaranteeing a secure and immersive training setting.

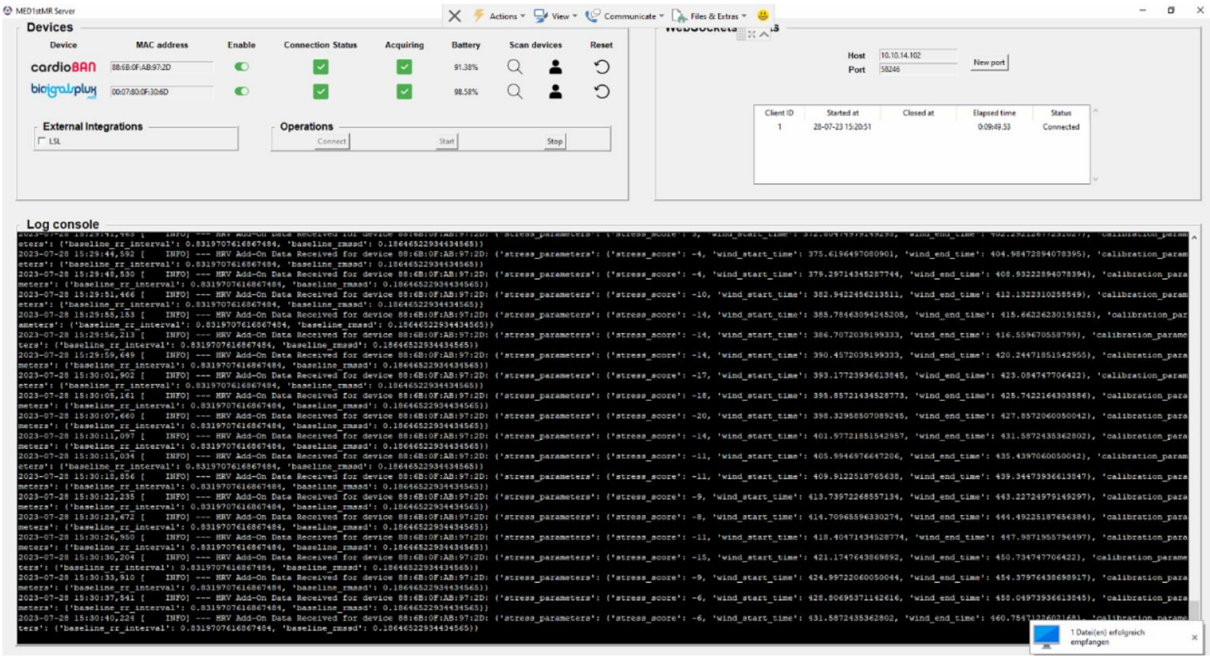


Figure 23 MED1stMR Biosignals SW client running on RFNS computer

3.3.3 Integration with MAS Tool

The integration between the MAS and the core MR system primarily revolves around the data flow connection between the RFNS server and the designated endpoint for data uploading to the remote server (located within the EU) where the MAS Tool is deployed. While Section 4 will delve into the specifics of the system data generation, storage and security, this part will concentrate on the communication protocol that facilitates the link between the core MR system and the central data platform.

3.3.3.1 Data upload

The Data Manager is the person responsible for uploading the files obtained from the RFNS system to the platform. These are the steps to follow to perform a data upload after every scenario:

1. Check that the files' names are in the correct format. This means that there must exist 5 files called ClientData, EventData, ManikinData, NpcData and PluxData, all followed by the training_Id, which is the date and hour of the training, ended in .json extension. An example is shown in Figure 24.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Figure 24 Raw training data files

2. Click on the "Choose Files" button and select the first file (Figure 25). This whole process (steps 2 to 5) must be done for each individual file.

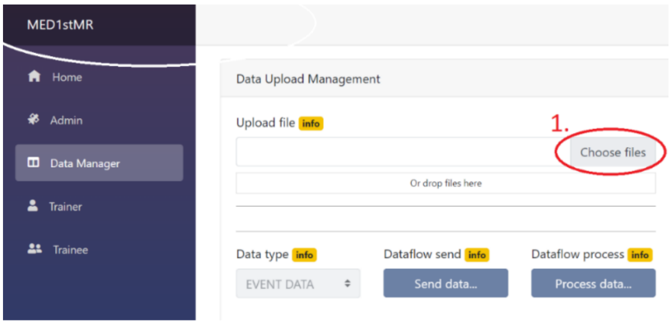


Figure 25 MAS UI Data upload instruction 2

3. Press the upload button in the new view that was just generated (Figure 26).

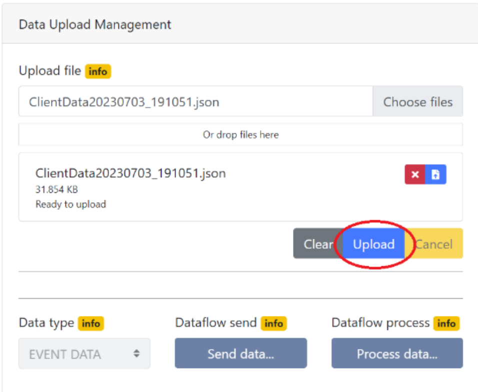


Figure 26 MAS UI Data upload instruction 3

4. Associate each ClientId with the correct trainee username (UHEI team will have this information during the Field Trial), as shown in Figure 27.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

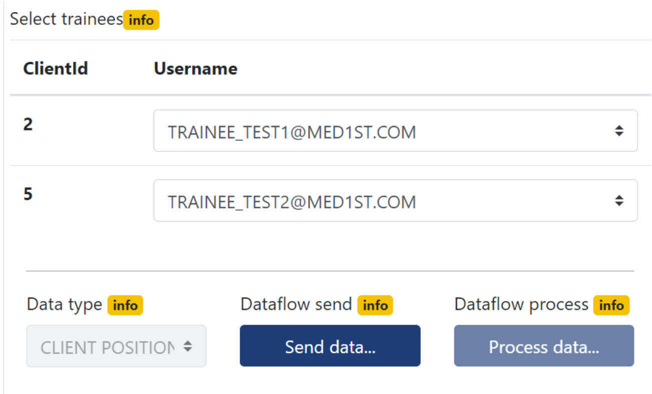


Figure 27 MAS UI Data upload instruction 4

5. Press “Send data” (Figure 28).

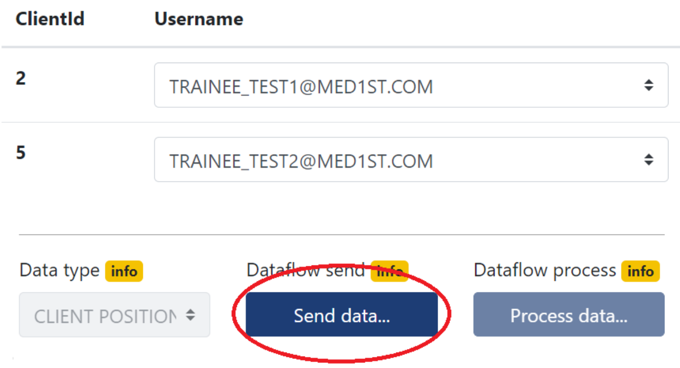


Figure 28 MAS UI Data upload instruction 5

6. When the data is sent, wait for a few seconds. The bottom-right menu will display the data uploaded in green, and the logger info should look like Figure 29.

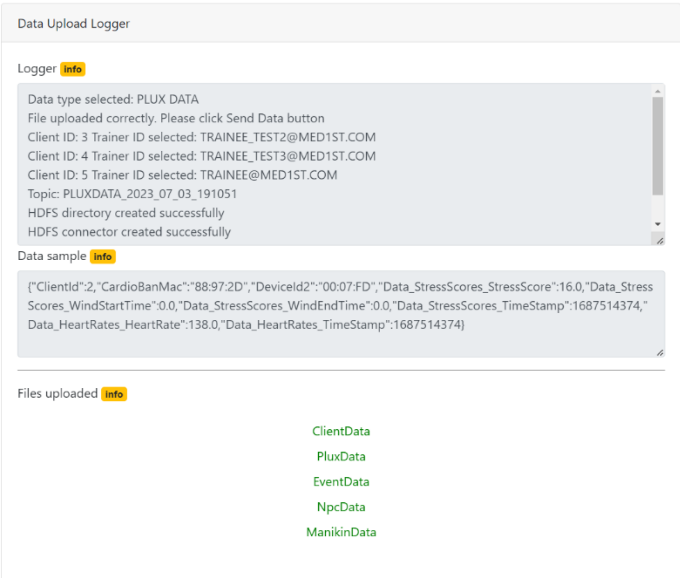


Figure 29 MAS UI Data upload instruction 6

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

7. Press the "Process data" button to initiate analytics calculation (Figure 30).

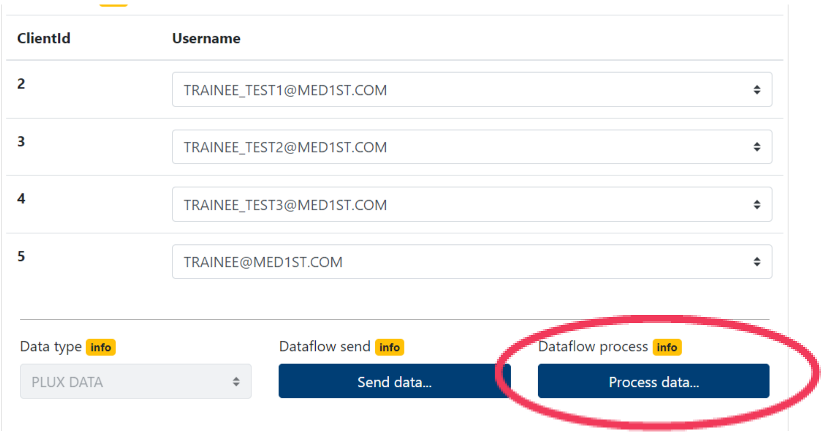


Figure 30 MAS UI Data upload instruction 7

8. Once the button is pressed, the message "Data processed correctly" should appear in the logger (Figure 31). After ~5 minutes, it should be available for the trainer and the trainees to check.

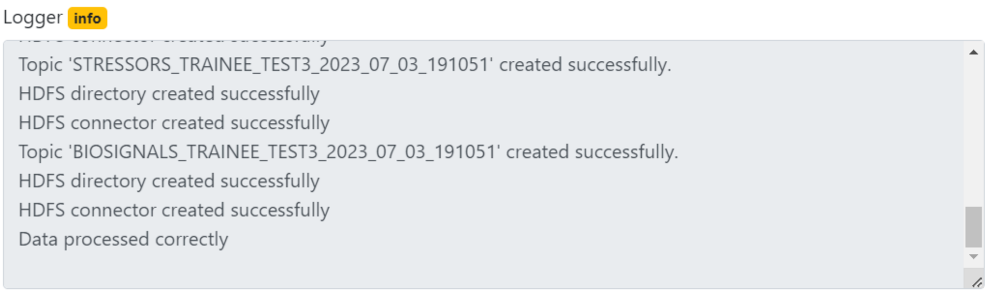


Figure 31 MAS UI Data upload instruction 8

3.3.3.2 Data formatting

For the execution of the analytics pipeline, which includes data formatting, processing, and stressors and statistics calculations, data is consumed from Apache Kafka by a dedicated, Python-based service. Kafka, as detailed in section 2.4.1, acts as the central communication hub within the data architecture, receiving raw training data as different streams or topics, which allows for consumers to ingest data from them.

Checking for data availability

Initially, a check is performed to guarantee that the required datasets for a given trainee (identified by "Trainee_id") are not empty. Depending on which dataset (ClientData, EventData, PluxData, ManikinData, or NpcData) is empty, some of the outputs may vary as they might not be calculated (for example, stressors can't be identified without stress scores). These datasets have Client IDs for each trainee that will be linked to their user codes to ensure anonymity. These datasets, as well as their structure, is detailed in section 4.4.1.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

ML Dataset declaration

Provided that the requisite datasets are sufficient, copies of the dataframes (tabular data structures commonly used in Python) mapped to specific clients (ClientData, EventData, PluxData), are created and filtered to include only data relevant to the current trainee. A new dataframe called DATA is subsequently established based on the ClientData index. The reason behind this is that this dataframe is the one that more accurately represents the timestamps when the training begins and starts, as PluxData contains rows of data before the training starts. This will ensure the integration and synchronisation of all the different data sources for training analysis.

Data incorporation

The DATA dataframe is then prepared for further processing. It contains raw data from PluxData (the stress scores per second) and ManikinData (the two manikins' vital signs per second).

These vital signs of the manikins include heart rate, respiratory rate, systolic blood pressure, and diastolic blood pressure. To allow training with only one manikin, if there is only one unique identifier, the missing data is filled with standard values to compensate for the absence of the second manikin data. This guarantees that the structure of the dataframe remains consistent across different scenarios.

3.3.3.3 Data processing

Events data processing

Based on the events that occurred during the training, a new column of data called 'Triage_Result' is generated, depending on how different the triage colours were assigned to the NPCs from the expected ones. This column can contain the values "Right", "Wrong", or NaN.

Also, extracting information from the triage start times and ends, the new column 'Triaging' is created, with a value of 1 when the trainee is triaging and 0 when there is no triage being done by that trainee. This is necessary for the ML model to detect anomalies and root causes.

Additionally, many checks are implemented to minimise the presence of fake positives and ensure that each triage evaluation belongs to the NPC assigned.

Lastly, the processed data from 'Triage_Result' and 'Triaging' is incorporated into the main DATA dataframe.

Client data processing

The client's instantaneous speed is calculated based on the trainee's position data and its timestamps. Then it's added as a new column, 'Client_Speed', to later include this column in the main DATA dataframe.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Cleaning the dataset

Then, the DATA dataframe is cleaned by replacing missing values with the mean of their neighbouring values. This approach ensures that the data is smooth and continuous, enabling it to be more effectively processed by the subsequent stages of the pipeline. The result of this process is the final version of the DATA dataframe, with a row of data for each second of the training. Each row contains the trainee's stress score and all the potential stressors to be detected, as depicted in Figure 32. This creates the perfect scenario to implement anomaly detection techniques such as MSCRED or isolation forest.

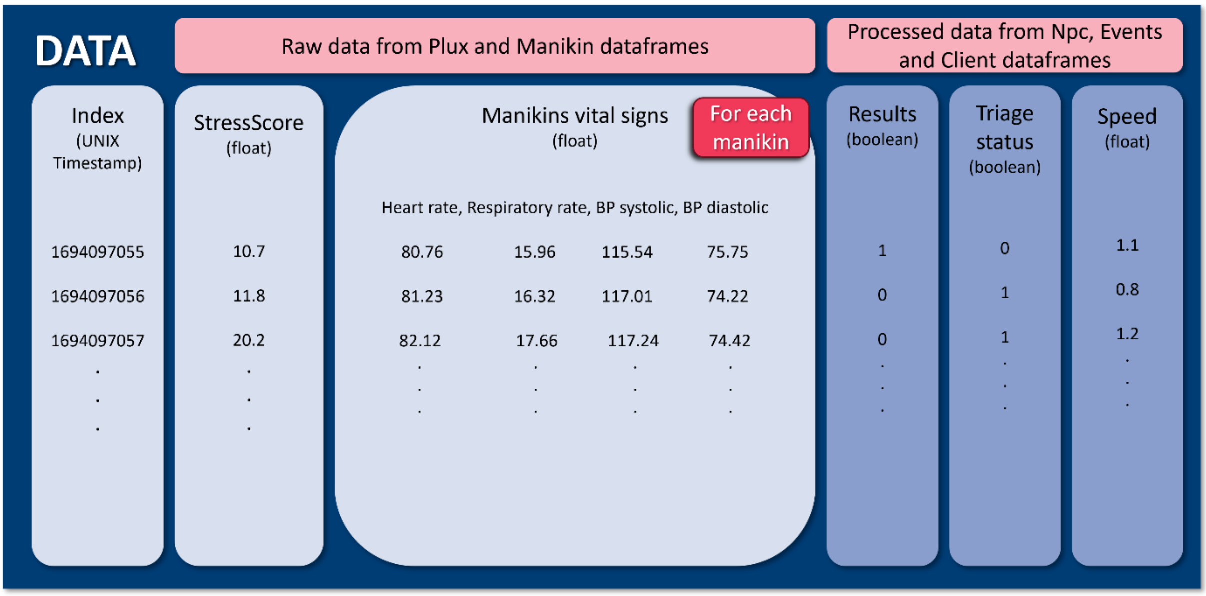


Figure 32 Dataframe for AI anomaly detection structure

3.3.3.4 Statistics calculations

After completing the data processing, the dataframe EventData is subjected to analysis. Should there be an absence of data to assess, the analysis will yield default values. In a correct execution scenario, the function goes through several steps, including determining the NPCs triaged, assigning and comparing the triage colours assigned and the actual ones, tracking the start and end times of triages, and calculating the durations.

The processing pipeline is designed to identify if any issues arise during this process, such as the existence of unfinished triages or simultaneous triages. Should these scenarios occur, the function will provide a notification of the problem and default output values.

The results are then converted into a single-row dataframe dubbed STATISTICS and logged as an accomplished task, noting that the desired statistics have been obtained. This dataframe fields are depicted in Figure 33.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

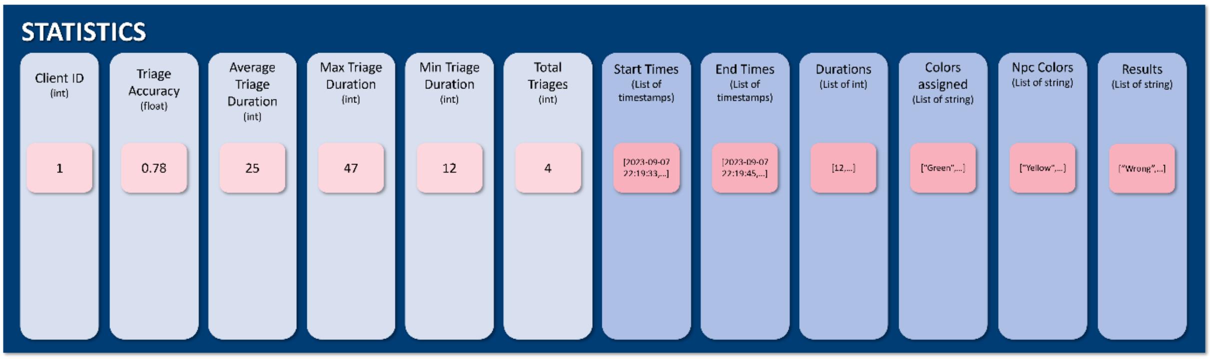


Figure 33: Statistics dataframe structure

3.3.3.5 Stressors calculations

Data Preprocessing

First, it is necessary to transform the original DATA dataframe so each row contains information of previous ones to take into account time dependencies. The dataframe is subjected to normalisation, with data columns being normalised differently depending on their type. This includes specific transformations for the client's stress score, manikin's heart rate, respiratory rate and all the columns of the DATA dataframe depicted in Figure 32. Such modifications aim to equilibrate the influence of each column, thereby enabling them to be evaluated as potential stressors equally.

Anomaly detection: MSCRED

A pre-trained neural network is loaded and used to pinpoint anomalies and potential root causes using non-anomalous training data as the baseline. This will allow for the generation of an abnormality score, which indicates how anomalous is a time frame based on how different the prediction was from the actual values. This enables detecting anomalies specifically regarding the client stress, and the reconstruction of the rest of the variables during this time frame makes MSCRED able to find potential stressors.

Anomaly detection: Isolation Forest

The code also utlises the Isolation Forest algorithm for anomaly detection. After extracting and normalising time series data, it searches for anomalies using random partitioning in a forest of decision trees. This algorithm's results will be utilised during the anomaly confidence calculation.

Potential stressors statistics

Based on the results of MSCRED and isolation forest, each anomaly's confidence, severity, and main stressor (further described in section **Fehler! Verweisquelle konnte nicht gefunden werden.**) are discerned.

Finally, the data pertaining to each anomaly, including its id, timestamps, confidence scores, severity, and main stressor, is collated into a dataframe. As a result, the STRESSORS dataframe is generated (Figure 34).

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

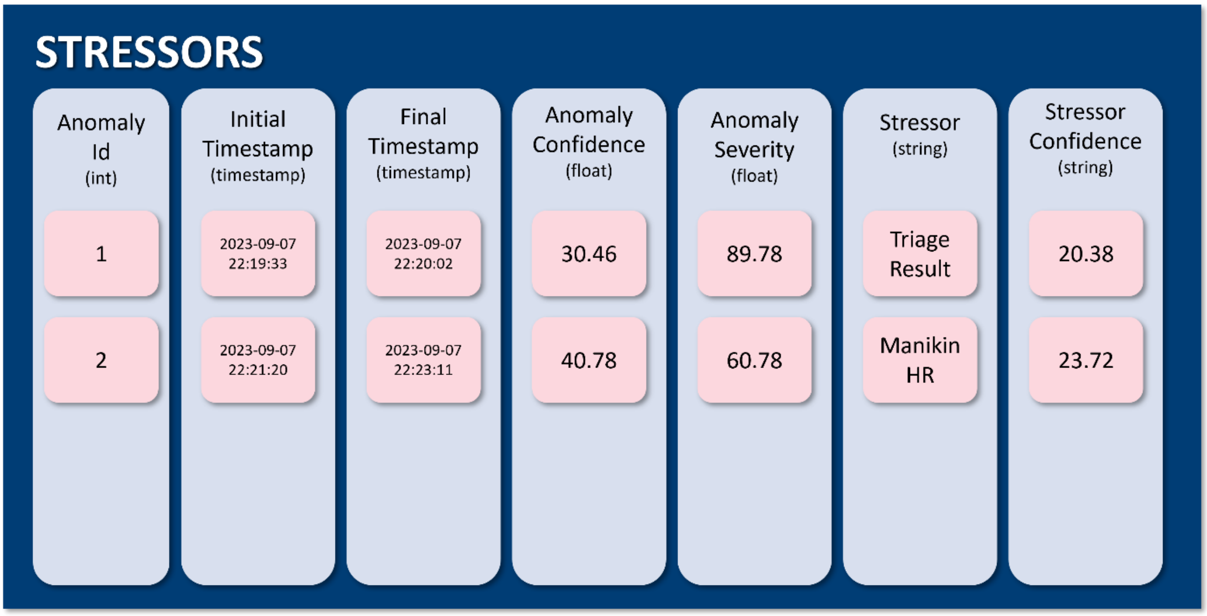


Figure 34: Stressors dataframe structure

4 Data management

In the context of the MED1stMR project, effective data management is pivotal to ensuring both integrity and efficiency. This section delineates the comprehensive structure of data flow and storage, utilising the MAS Tool for core processing and storage, coupled with the AIT Protected Sharepoint Server for enhanced security. Further on, details surrounding data privacy and security protocols will be examined, affirming alignment with relevant legal and ethical standards.

4.1 Data Generation, Flow and Storage

The essential elements of the MR training system, responsible for producing pertinent data for the debriefing, include 1) the VR training system, 2) the manikin ADAM-X, and 3) the wearable PLUX biosignals sensor system. The coordination of these subsystems, with a focus on data flow, is depicted in D2.4. The data from various subsystems are supplied in diverse formats and temporal resolutions. Below, the individual subsystems are detailed, accompanied by a description of the data they provide.

- **VR training system**: The VR training system furnishes data related to the motion of all tracked objects and trainees, including NPCs, trainees, actors, manikins, and other movable items such as medical devices. This encompasses information on object position, rotation, and status. In addition to these, the system also provides supplementary data such as audio recordings, voice clips, and records of activities and events.
- **Manikin ADAM-X**: ADAM-X operates the patient simulation, coordinating and transmitting medical data to the VR system. This medical information includes aspects such as blood pressure, heart rate, respiratory rate, chest expansion, facial and finger cyanosis, pulse,

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

electrocardiogram, CPR metrics (frequency, depth, and release time), tear production, drooling, sweating, eyelid movements (open, closed, blinking), touch on access points, treatments, and more.

- **Wearable PLUX biosignals sensor system**: The wearable PLUX biosignals sensor system supplies live streams of both raw data from the sensor and processed features (such as stress score). Specifically, this data encompasses the electrocardiogram, heart rate, heart rate variability, and electrodermal activity.

The Refense Framework serves as the central generation hub, gathering and exporting training data. Given that low latency is crucial for facilitating real-time virtual reality training, the system's efficiency is of utmost importance. Once the scenario is finished, data is kept in the RFNS system to enable the After Action Review. Before removing it from the core MR system, generated structured data is uploaded to the MAS Tool for long term storage and AI powered analytics calculation, and non-structured data to the AIT Protected Sharepoint Server (PSS). The flow diagram is shown in Figure 35.

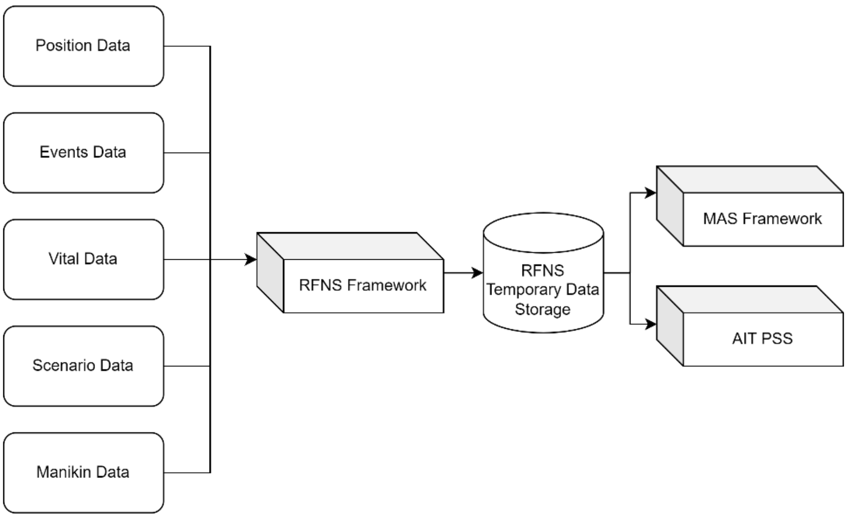


Figure 35 Data generation and flow

4.1.1 MAS Tool

Idener's MAS Tool serves as an integration framework for all structured data generated during training scenarios. Its objective is to offer AI-powered analytics that improve debriefing and facilitate intelligent scenario control and creation.

As outlined in Section 3.3.3, the automated processing pipeline is initiated when training data is uploaded to the MAS framework. As depicted in Figure 6, the data is directly uploaded to Apache Kafka, the communication hub of the data platform. A Python-based container processes this data, generating training statistics, time-based stress scores, and identifying stressors through AI-powered anomaly detection tools.

Subsequently, both raw and processed data are stored in HDFS, utilising its native replicability features. Automated tasks then organise this unformatted data into structured tables within Apache Druid, facilitating efficient querying. The platform provides multiple outputs:

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

- **Grafana**: Utilises processed data to produce graphical visualisations covering training statistics, biosignals, and stressor analyses. These can be tailored to individual trainings or trainees and can also aggregate group and trainee historical data
- **Trino:** Provides fine-grained data access to authorised users, a feature particularly valuable for researchers. It enables downloading of both raw data (e.g., position data, stress score) and processed statistics and analytics.

Access to these outputs is streamlined through dedicated sections in the MAS User Interface, offering an intuitive tool that enhances research activities and facilitates debriefing for first responders. The MAS UI allows for both visualisation and direct querying of the following tables:

Raw data tables:

Table 3 Client Data (position data)

Column	Format	Example
ClientId	Integer	2
Data_Pose_Position_x	Float	1.21039021
Data_Pose_Position_y	Float	-2.84206057
Data_Pose_Position_z	Float	0.9747523
Data_Pose_Rotation_x	Float	-0.0830960646
Data_Pose_Rotation_y	Float	-0.1960247
Data_Pose_Rotation_z	Float	-0.0672847554
Data_Timestamp	Timestamp	1688470587

Table 4 Event Data

Column	Format	Example
ClientId	Integer	2
EventType	Integer	3
NpcId	Integer	673
Timestamp	Timestamp	1688470587

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

EventType can contain values ranging from 0 to 8, which are described in Table 5. This list will be updated as new stressors are emulated in the training scenario.

Table 5 Event Types enumeration

Column	Format
0	None
1	PulseCheckStarted
2	PulseCheckEnded
3	GreenTriageCardAssigned
4	YellowTriageCardAssigned
5	RedTriageCardAssigned
6	BlackTriageCardAssigned
7	TourniquetApplied
8	TriageStarted

Table 6 NPC Data

Column	Format	Example
NpcId	Integer	673
NpcTracked	Boolean	False
Position_x	Float	4.300034
Position_y	Float	0.009000361
Position_z	Float	2.279447
Pulse	Integer [BPM]	90
RespiratoryRate	Integer [per minute]	18
TriageColor	Integer	2

TriageColor can contain values ranging from 0 to 4, which are described in Table 7Table 5.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Table 7 Triage Colour enumeration

Column	Format
0	None
1	Green
2	Yellow
3	Red
4	Black

Table 8 Biosignals Data

Column	Format	Example
CardioBanMac	String	66:6A:0D:AC:46:E2
ClientId	Integer	2
Data_Heartrates_Heartrate	Integer	104
Data_Heartrates_TimeStamp	Timestamp	1688470587
Data_StressScores_StressScore	Integer	32
Data_StressScores_Timestamp	Timestamp	1688470587
DeviceId2	String	00:14:20:0A:10:5J

Table 9 Manikin Medical Data

Column	Format	Example
uuid	UUID	c831399d-3819-4b18-95e6-8cdc4d72f0fe
SimulatorId	String	Test_client
Timestamp	Timestamp	1688470587
MedicalDataDto_heartRate	Integer	80
MedicalDataDto_respiratoryRate	Integer	16
MedicalDataDto_BloodPressure_Systolic	Integer	120

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

MedicalDataDto_BloodPressure_Diastolic	Integer	64

Processed data tables:

Table 10 Training Statistics

Column	Format	Example
Avg_Triage_Duration	Integer [s]	25
Max_Triage_Duration	Integer [s]	35
Min_Triage_Duration	Integer [s]	15
Total_Triages	Integer	5
Training_Time	String	3 min 23 sec
Triage_Accuracy	Float	0.8

Table 11 Identified Stressors

Column	Format	Example
Anomaly_Confidence	Float (%)	24.83
Anomaly_Severity	Float (%)	17.48
Begin_Timestamp	Timestamp	1688470587
Final_Timestamp	Timestamp	1688470597
Stressor	String	Client_Speed
Stressor_Confidence	Float (%)	3.89

4.1.2 AIT Protected Sharepoint Server

The AIT Protected Share-point Server (PSS) is a locally hosted instance of SharePoint within AIT, located in Giefinggasse 4, A-1210 Vienna. The data is only saved on the local servers and not transferred to the Microsoft cloud and is regularly backed up to ensure that data is not lost. The SharePoint server is managed by AIT's IT department and is part of its security concept with heightened security regulations and limited access. On this SharePoint data from the field trial studies are stored that needs to be shared between the research partners for analysis. Only to specific research partners access is granted.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

On this SharePoint data from the field trials are stored and includes data from questionnaires, audio recordings from flashlight interviews, raw sensor data, screen recordings from the MR training system scenario control (mainly from top view), notes from training sessions and a timetable.

4.2 Data Privacy and Security

In the context of the MED1stMR project, safeguarding data privacy and security is paramount, particularly given the sensitive nature of training medical first responders. Since data will be stored both in the MAS Tool and in the AIT Protected Sharepoint Server, the following subsections will describe every storage unit separately.

4.2.1 MAS Tool

The MAS Tool, employed for long-term storage and analytics purposes, is fortified with various layers of security measures to ensure the confidentiality, integrity, and availability of data.

Server Security

The MAS Tool is hosted on a remote server that is duly protected. Access to this server is stringently restricted to authorised team members from Idener. Login requires proper credentials, ensuring that only those with explicit permission can access the system.

Network Security

To limit potential attack vectors, no open ports are exposed on the server, with the exception of the Web User Interface (Web UI).

User Access Control

The Web UI features fine-grained authorization, stratified across different user profiles to manage varying levels of access:

- **Administrators** (Idener Members): Granted full access to all sections of the platform.
- **Trainees**: Restricted to viewing only their own data.
- **Trainers**: Limited to accessing data of the trainees they are supervising.
- **Researchers**: Given permission to query data as specified in tables of Section 4.1.1.

Apache Ranger is deployed to manage and control authorisations within the data platform, serving a dual purpose: not only does it enhance security by managing user permissions, but it also provides rigorous access monitoring through its auditing capabilities. These audit logs offer granular insight into user activity, allowing for real-time oversight and facilitating prompt action in case of any unauthorised access attempts.

Secure Credential Transmission

Credentials required to access the MAS Tool are securely transmitted using multi-channel authentication methods, reinforcing the authentication mechanism.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

By implementing these robust data privacy and security measures, the MAS Tool ensures a secure and reliable environment for acting as a data integration framework within the project's scope.

4.2.2 AIT Protected SharePoint Server

The AIT protected SharePoint server is located in a separate extranet section of the AIT IT infrastructure, can only be accessed via an encrypted connection ("https") and is secured by multiple firewalls and other security measures. Access to this server is only provided to the research partners in the project (namely AIT, UBERN, UHEI, UMU and IDENER), and require authorisation.

A registration process has been enabled to control the users that receive credentials to log into the system. Physical access to the server is strictly secured as well and limited to IT staff at AIT. In case that study data is stored locally for analysis reasons, the respective partner employees will handle the data with necessary care and corresponding security measures. With regard to materials that needs to be deleted within a certain timeframe (e.g. video/audio recordings where the informed consent has defined their deletion after 90 days), the partner employees are also obligated to delete locally saved copies of these materials.

5 Evaluation, Future Work and Potential Applications

5.1 Key Findings and Observations

5.1.1 MR Training System

Mixed and virtual reality (MR and VR) technologies are poised to revolutionize the future of training. These immersive technologies offer unique advantages that are challenging to replicate through traditional methods.

Mixed Reality's Immersion and Multi-User Capability

Mixed reality (MR) is emerging as a key player in future training programs due to its ability to seamlessly blend virtual and real-world elements. This creates an immersive learning experience that is difficult to match using other methods. MR's multi-user capability allows for collaboration and interaction among trainees, enhancing the overall training experience.

Advanced Software Environments

The software environments for mixed and virtual reality have reached a level of sophistication and functionality that makes them highly suitable for practical use today. Extensive studies and research have substantiated the efficacy of these technologies in enhancing learning outcomes. This underscores the readiness of these tools to be incorporated into various training programs.

Full-Body VR Integration

Full-body virtual reality (VR) integration has become increasingly feasible and effective for training programs. This approach allows trainees to engage with immersive simulations that encompass their

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

entire body movements, providing a holistic learning experience. Research and practical applications have demonstrated the benefits of full-body VR in skill development and training.

Challenges of Portability

One current limitation of full-body VR systems is their lack of portability. The hardware required for these systems can be heavy and cumbersome, restricting their use to stationary training centers or fixed locations. As a result, for optimal training experiences, it is currently recommended to utilize these technologies in controlled environments where the necessary hardware and infrastructure are available. Furthermore, the usage of audio headset and their communication needs noise cancelling and reflexion of sound in mind, thus a stationary training center with carpets and sound proofing measures are recommended.

In summary, mixed and virtual reality technologies hold great promise for the future of training and education. Their immersive nature, multi-user capabilities, and advanced software functionality make them valuable tools for enhancing learning outcomes. However, the challenge of portability for full-body VR systems should be considered when planning their implementation in training programs.

5.1.2 ADAM-X Manikin

For the Med1stMR project, we have made adjustments to the ADAM X to enhance the freedom of movement for the body and limbs. We are working on improving the tracking system to encompass all parts of the manikin, rather than being limited to tracking only the feet, hands, body, and head. The incorporation of internal sensors will assist in determining the positions of the movable components of the manikin, ensuring that the tracking in the VR overlay remains synchronized with the physical manikin.

Currently, the manikin features a unibody skin made of silicone, which makes it sensitive to environmental factors when used outdoors or on rough surfaces. To better serve the training purposes and mixed reality applications where tactile feedback is more crucial than visual representation, we are considering changing the skin material and moving away from the unibody skin structure. This change aims to improve mobility and reduce limitations associated with the silicone that holds the limbs in position.

5.1.3 Wearable Biosignals Sensors

The MED1stMR Biosignals software client provides a way to communicate with the VR software, communicating relevant parameters of MFRs, allowing for a smooth integration with external software systems that can communicate through a WebSocket.

The stability of the connection between the sensors and the clients has been compromised due to a very complex setup and limitations of the Bluetooth connection (a lot of obstacles, people, different noise sources, smartwatches and phones). We overcame this issue by exchanging of the Bluetooth dongles and removal of noise sources from the room (e.g., adjusted the wifi of the building by decreasing the signal sources being transmitted in the Bluetooth bandwidth, removed mobile phones from the users).

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

5.1.4 MAS Tool

The capabilities of stream processing and rapid analytics elements have been proven instrumental in facilitating real-time debriefing sessions for medical first responders. One notable challenge was the imperative for a well-functioning system before actual data could be gathered. This issue was successfully navigated through the use of innovative techniques, such as synthetic data generation, to simulate real-world conditions and ensure the system's readiness.

In terms of resilience, the flexibility of the system stands out as a key attribute. It is designed to maintain analytics calculations even when some data sources experience temporary disconnections, thereby ensuring that the analytics and monitoring functions are not compromised. However, it should be noted that the relatively narrow scope of potential stressors has limited the ability of the anomaly detection network to demonstrate its full capabilities, as well as undergo comprehensive validation procedures.

Furthermore, collaboration with end-users proved to be crucial in the development stage, particularly in setting the project's initial requirements. These requirements have been successfully met, affirming the value of engaging with end-users from the outset to ensure the tool meets its intended purposes effectively.

5.2 Scope for Future Enhancements and Other Technologies

5.2.1 MR Training System

Invest in Mixed Reality (MR) Development: Given the advantages of mixed reality (MR) for training, organizations should consider investing in the development and implementation of MR training programs. This could involve creating custom MR environments tailored to specific training needs or partnering with MR development companies.

Research-Backed Implementation: Before adopting VR training, organizations should conduct thorough research and pilot programs to validate the effectiveness of these technologies for their specific training goals. Research-backed decisions can help optimize the allocation of resources.

Portability Solutions: Recognizing the current limitations of full-body VR systems in terms of portability, organizations should explore solutions to make these systems more mobile and accessible. This could involve advancements in hardware design, such as lighter headsets and wireless setups, to enable training outside of stationary centers.

Hybrid Training Models: Consider hybrid training models that combine the strengths of virtual and traditional training methods. VR can be used for immersive skill development, while traditional methods can complement it with theory, assessment, and debriefing sessions.

Scalable Infrastructure: Organizations planning to implement VR training should invest in scalable infrastructure to support the growing demand for VR content. This includes robust hardware setups, sufficient computing power, and network bandwidth to accommodate multiple users.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

Security and Data Privacy: With the integration of VR into training, organizations must pay close attention to data security and user privacy. Implement robust data protection measures and ensure compliance with relevant regulations.

5.2.2 ADAM-X Manikin

In the quest for ongoing innovation and improved functionality, there are several areas where the ADAM X system can benefit from future enhancements and the integration of technologies. One of the key focal points for advancement is the seamless integration of sensors into the hardware framework. Currently, the sensors used in the ADAM X system provide valuable data but can be further optimized through complete hardware integration.

Furthermore, a notable aspect that requires attention is the relationship between the ADAM X software and the Refense system. Presently, these two systems operate independently, necessitating the use of an API to facilitate communication between them. Unfortunately, this separation results in certain essential features being underutilized, preventing users from fully harnessing the potential of both systems.

An exciting prospect for improvement lies in the integration of these two systems, erasing the boundaries that currently exist between them. By doing so, we can substantially enhance communication and the ability to manipulate both hardware and software components as if they were a unified entity. This integration will not only streamline user experience but also unlock the full capabilities of the ADAM X and Refense systems, creating a more powerful and cohesive solution for medical training and simulation.

5.2.3 Wearable Biosignals Sensors

In the future, it may be important to introduce some changes in the MED1stMR Biosignals software client code, namely, modifications focused in the data communication module, in order to ensure an optimized experience to the final user, by improving the stability of the APP (preventing Bluetooth connection lost events).

In what regards the wearables, we could remove the accelerometer and magnetometer from one of the devices, thus reducing the number of channels, contributing to an overall increased performance. It would also be possible to decrease the sampling rate of the devices (ECG could be set up to a 200Hz sampling rate and EDA could be set up to a 10Hz sampling rate).

5.2.4 MAS Tool

The MED1stMR Analytics & Statistics tool presently offers robust data storage and basic machine learning functionalities, yet there exists significant scope for future enhancements. MLOps practices can be seamlessly integrated to facilitate the continuous delivery and monitoring of machine learning models, thereby increasing operational efficiency and model accuracy. Introducing automated pipelines for data ingestion, validation, and model training could accelerate the deployment of analytics solutions and contribute to a more agile development environment.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.

The augmentation of data storage capabilities will directly impact the complexity of machine learning models that can be deployed. Enhanced storage would allow for the handling of large, multi-dimensional datasets, thereby paving the way for more complex and useful machine learning methods, such as ensemble techniques. These advanced algorithms can provide more nuanced insights, increasing the tool's utility. Adopting these technologies will not only increase the scalability of the MED1stMR solutions but also make it more versatile and aligned with Industry 4.0 requirements.

6 Conclusion

This document offers a structured approach to describe the assimilation of innovative first responder technologies within Mixed Reality environments. Through this framework, interoperability between ADAM-X Manikin, wearable biosignals sensors, and the MAS tool has been achieved, fostering an enriched MR training system. This deliverable elaborates on the design principles, architectural considerations, and key interfaces, ensuring a well-orchestrated integration of novel first responder technologies within the MR environment. The document also details the security measures implemented for robust handling and safeguarding of generated data, both raw and AI-powered analytics, including stringent authorization and authentication protocols. This deliverable also shows key conclusions and further enhancements contemplated by the technical developers, hinting at the vast potential applications in enhancing first responder training and operational support.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101021775. The content reflects only the MED1stMR consortium's view. Research Executive Agency and European Commission is not liable for any use that may be made of the information contained herein.