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Big Data technologies and extreme-scale analytics

Multimodal Extreme Scale Data Analytics for Smart Cities Environments

D4.6: MARVEL's decision-making toolkit – final version[†]

Abstract: The purpose of this deliverable is to describe all activities related to the process, design, implementation, and final release of MARVEL's Decision-Making Toolkit. This document sets the scope and the goals of the Decision-Making Toolkit, as well as discusses the process to achieve these, the definition of the user journeys, the creation of the mock-ups, and demonstration of the use cases. More specifically, the document details the design process followed for MARVEL, the internal architecture and its features, the requirements and specifications of the Toolkit, and an extensive demonstration of all the use cases from the end user's point of view. Finally, a detailed description of the conclusions and the contributions to MARVEL's objectives is provided.

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Table of Contents

DRAFT

DRAFT

List of Tables

DRAFT

List of Figures

DRAFT

List of Abbreviations

AAC	Automated Audio Captioning
API	Application Programming Interface
AT	Audio Tagging
AV	Audio-Visual
AVAD	Audio Visual Anomaly Detection
AVCC	Audio Visual Crowd Counting
DFB	Data Fusion Bus
DMT	Decision-Making Toolkit
E2F2C	Edge-to-Fog-to-Cloud
FFMPEG	Fast Forward MPEG
GUI	Graphical User Interface
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
MQTT	Message Queuing Telemetry Transport
MVP	Minimum Viable Product
REST	Representational State Transfer
RTSP	Real-Time Streaming Protocol
SED	Sound Event Detection
SELD	Sound Event Localisation Detection
UCD	User-Centric Design
UI	User Interface
UX	User experience
VAD	Voice Activity Detection
ViAD	Visual Anomaly Detection
VPN	Virtual Private Network
VRU	Vulnerable Road User
WP	Work Package

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Executive Summary

This deliverable describes all activities related to the design, implementation, and release of the final version of the MARVEL Decision Making Toolkit (DMT), namely the interface between the end users and the MARVEL framework. At this stage of the project, the scope of the DMT included the advanced visualisation of information used in all the MARVEL use cases in the smart cities of Valetta in Malta, Trento in Italy, and Novi Sad in Serbia.

Having set the scope for the final version of the MARVEL DMT, the goal was to develop and demonstrate advanced visualisations of real-time and historical data which would allow users to:

- timely intervention to address a traffic anomaly or to manage traffic flow conditions in real-time;
- plan urban infrastructure developments that will facilitate and/or improve mobility based on historical data;
- timely intervention to address and/or prevent incidents that may occur in crowded areas;
- study the behaviour to better organise large events such as festivals or better monitor regularly crowded areas such as urban markets.
- explore and understand audio-visual and other context-enriching data.

This document describes in further detail the methodology followed for the requirements, specifications, and design of the DMT features, as well as for its internal architecture. An extensive demonstration of the selected use cases from the end user's perspective is also included in the document. Screenshots from the actual DMT depict almost every step in the user journeys and are accompanied by explanations about the workflows linked to each interface component.

Finally, a detailed description of the conclusions and contributions to the objectives of the MARVEL project is provided at the end of the document.

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1 Introduction

1.1 Purpose of this document

The purpose of this document is to outline the design, implementation, and updates made to the Decision-Making Toolkit (DMT) for the MARVEL project. It provides a comprehensive overview of the toolkit's functionalities, user-centric design process, and initial requirements and specifications for the DMT.

The document also presents the user journeys and requirements for various use cases, demonstrating the toolkit's adaptability and relevance to end user needs. The updates in this version are based on a well-defined User-Centric Design (UCD) process that aims to achieve a high degree of usability for the MARVEL DMT.

The continuous evaluation of the MARVEL framework, including the DMT and validation of its functionalities in real-world scenarios, was identified as the next step. This validation will allow us to further align with the users' expectations and adjust future development activities. Furthermore, a focused evaluation of usability will reveal any possible early deviations from what the users expect from the DMT, thus allowing us to perform corrective actions and update the way that the DMT's capabilities are presented to the end users in view of the final release.

Thus, this document serves as a comprehensive guide for the updated DMT, detailing its design, functionalities, and the process behind its development. It is intended for stakeholders, developers, and end users who are involved in the MARVEL project or who may benefit from the application of the DMT.

1.2 Contributions to WP4 and project objectives

The previous version of the document (D4.3[1]) highlighted the significant contributions made towards WP4 -and more specifically in T4.4- and the overall project objectives. The MARVEL project has made significant strides in developing a DMT that is designed to visualise the collected and processed relevant data and detected events. The toolkit has been demonstrated to support selected use cases, such as traffic condition monitoring, junction traffic trajectory collection, monitoring of crowded areas, and monitoring of parking places.

In this updated version, we have built on these contributions. We focus on enhancing the functionalities of DMT and improving its usability based on user feedback. We will also work on expanding the use cases supported by the DMT, incorporating more real-world scenarios to validate its functionalities.

1.3 Relation to other WPs, deliverables, and activities

The MARVEL project is a comprehensive initiative involving various Work Packages (WPs), deliverables, and activities. The previous document outlined the relationship of the DMT with other WPs and deliverables. Similarly, this deliverable, rooted in the UCD approach of the MARVEL project, ensures alignment with user needs and stakeholder acceptance. This relates to WP6's evaluation of DMT usability through real-life experiments and is closely tied to technical WPs (WP2, WP3, and WP5), as the visualisations and interfaces utilise their outputs.

In this updated version, we highlight how the DMT's development and improvements are intertwined with the progress made in the aforementioned WPs. We also discuss how the

[1] MARVEL D4.3: MARVEL's decision-making toolkit – initial version, 2022. https://zenodo.org/record/7543685

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feedback and findings from the DMT's real-world validation will inform and influence the activities of other WPs.

1.4 Structure of the document

The deliverable begins with an Introduction (Section 1) that sets the context and outlines the purpose, contributions, and structure of the document. Section 2 provides a comprehensive overview of the DMT, including technical details, functionalities and highlights the updates made in the second release based on user requirements and feedback.

Section 3 describes the Design Process, offering an overview of the design and development process of the DMT for the MARVEL project. In Section 4, demonstrations of the DMT for each use case are presented, showcasing its adaptability and versatility in various scenarios.

In Section 5, we discuss how the DMT contributes to the overall objectives of the MARVEL project, including project-related Key Performance Indicators (KPIs) and component-related KPIs. Section 6, Conclusions, summarises key points and outlines the next steps for the DMT's development.

Overall, this document offers a comprehensive overview of the design, development, and application of the DMT within the MARVEL project. Its structured format allows readers to easily navigate through different sections and gain a clear understanding of the discussed topics.

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2 Decision-Making toolkit, updates, and progression

2.1 Decision-Making toolkit

The DMT is the key means of interaction with MARVEL end users. It serves as the key interface of all processes performed in MARVEL so that users can consume the extracted insights. The DMT receives input from the Data Management and Distribution subsystem and leverages insights from the Edge-to-Fog-to-Cloud (E2F2C) deployed models to visualise recommendations for medium to long-term decisions. It is designed as a dashboard with preconfigured widgets tailored to the user's preferences.

SmartViz serves as the user interface (UI) of the DMT. It enables the visualisation of incoming detected events, anomalies, and alerts generated through the analysis of data collected at the edge layer. SmartViz consists of a collection of visualisation tools that facilitate exploratory analysis by providing interactive representations of data. It empowers end users to interact with the data, gain a comprehensive understanding, delve into detailed information, and identify patterns and correlations.

2.2 Technologies and Architecture

SmartViz is designed to handle various types of data from different workflows and pipelines. These data can have different characteristics such as velocity, format, and type, and can be delivered through live or batch streams. SmartViz, as the main part of the toolkit, accepts and transforms input data into meaningful visualisations based on their nature and format. The primary goal of the toolkit is to effectively support and accommodate these different data scenarios while meeting the needs of end users and facilitating decision-making processes.

The internal architecture and underlying technologies of SmartViz have largely remained the same from a high-level perspective since R1 (1st Release of the MARVEL framework). However, the R1 use cases were enriched with filters and the support of new component visualisations based on valuable user feedback. For further details regarding the internal architecture of SmartViz, please refer to Section 3.2 in D4.3[2]. Nevertheless, significant enhancements have been made in R2 (2nd Release of the MARVEL framework) to introduce new visualisation widgets and dashboards for new use cases. To facilitate the enhancements along with the new visualisations, SmartViz has established connections with additional components beyond what was available in R1. These connections were showcased within the DMT dashboards. To support these connections, the necessary mechanisms were developed, and new libraries written in Typescript and JavaScript were integrated into the toolkit. These additions have expanded the range of available visualisation widgets.

In the internal architecture of SmartViz in R2 (Figure 1), there is a notable addition of a connection with MARVdash, which introduces a new functionality that empowers users with service-control capabilities. MARVdash is a Kubernetes dashboard provided by FORTH and it is used to instantiate services as orchestrated containers and deploy them to desired execution sites, following an optimisation strategy.

The functionality is achieved through the interaction of SmartViz and MARVdash via a REST API. Through this REST API, SmartViz can communicate with MARVdash and retrieve

[2] MARVEL D4.3: MARVEL's decision-making toolkit – initial version, 2022. https://zenodo.org/record/7543685

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information about the services that are currently deployed within MARVEL. Based on this information, SmartViz allows users to initiate or terminate selected services within the system.

In addition to the connection with MARVdash, a new connection was established between SmartViz and AudioAnony. This connection introduces a new functionality in the toolkit that is specifically designed to support audio streams and audio snippet playing. This integration enables SmartViz to receive audio streams and snippets and provides the necessary capabilities to play and interact with them within the toolkit.

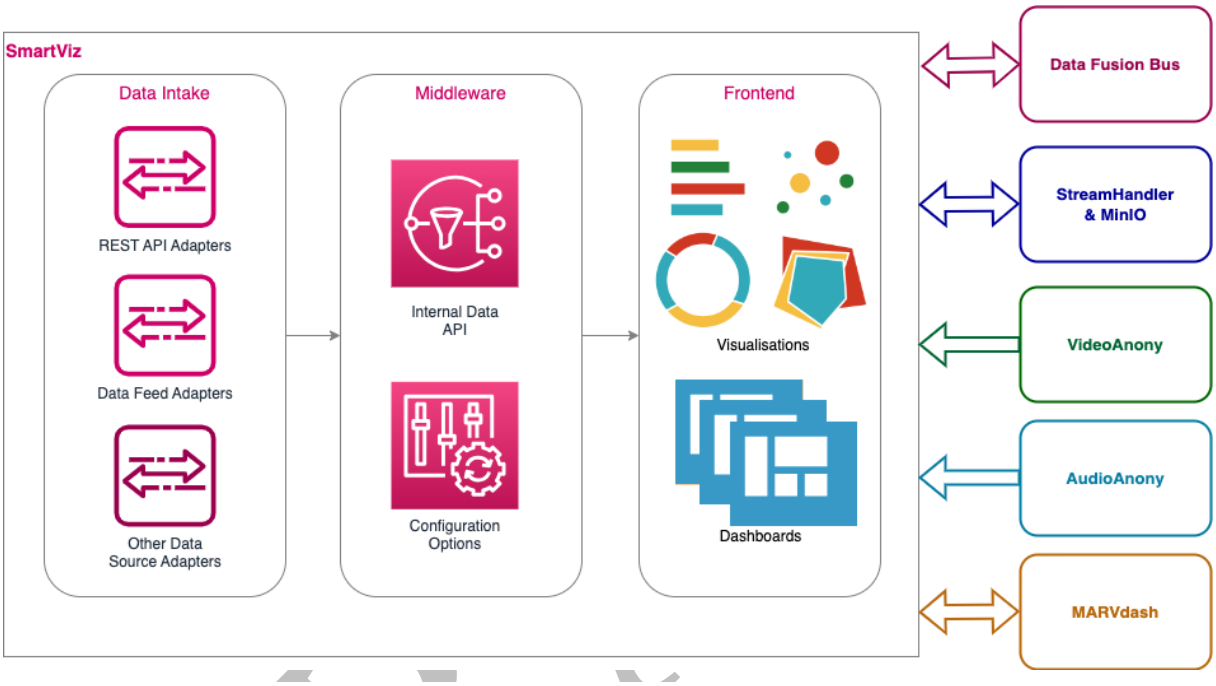

Figure 1: Internal architecture of SmartViz

2.3 Additional Features in R2

SmartViz performs visualisations through a pool of visualisation widgets. The widgets used for MARVEL's DMT were carefully selected to satisfy both user and data needs. The widgets assigned to each pilot use cases are displayed in Table 1, Table 2, and Table 3 below.

Table 1: Assigned widgets per use case for GRN

Widgets	GRN1	GRN2	GRN3	GRN4
Temporal Representation	-	YES	-	YES
Crowd Density Heatmap Representation	-	-	-	YES
Details Widget	YES	YES	YES	YES
Vehicle Trajectories	-	-	-	YES

Statistical Representation	-	YES	YES	YES
Video Player	YES	YES	YES	-
Real-time Map Representation	-	-	YES	-
Summaries	YES	YES	-	-
Weather information	YES	YES	YES	YES
Sound Localisation Map	-	-	-	-
Alerts	YES	-	-	-
Comparison	-	YES	-	-
Download Data (JSON)	YES	YES	YES	YES
Download PDF Report	YES	YES	YES	YES
Word Cloud	-	-	-	-
Audio Player	-	YES	YES	-
Police Intervention	-	-	-	-
Service Management	-	-	-	YES

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Table 2: Assigned widgets per use case for MT

Widgets	MT1	MT2	MT3	MT4
Temporal Representation	YES	-	YES	YES
Crowd Density Heatmap Representation	YES	-	-	-
Details Widget	YES	YES	YES	YES
Vehicle Trajectories	-	-	-	YES
Statistical Representation	YES	YES	-	YES
Video Player	YES	YES	YES	YES
Real-time Map Representation	YES	-	-	-
Summaries	YES	YES	YES	-
Weather information	YES	YES	YES	YES
Sound Localisation Map	-	-	-	-
Alerts	YES	YES	YES	-
Comparison	YES	-	-	-

Download Data (JSON)	YES	YES	YES	YES
Download PDF Report	YES	YES	YES	YES
Word Cloud	-	YES	-	-
Audio Player	-	YES	YES	YES
Police Intervention	YES	YES	YES	YES
Service Management	-	-	-	-

Table 3: Assigned widgets per use case for UNS

Widgets	UNS1	UNS2
Temporal Representation	-	-
Crowd Density Heatmap Representation	YES	-
Details Widget	YES	YES
Vehicle Trajectories	-	-
Statistical Representation	-	-
Video Stream Player	YES	-
Real-time Map Representation	-	-
Summaries	YES	-
Weather information	YES	YES
Sound Localisation Map	-	YES
Alerts	YES	-
Comparison	-	-
Download Data (JSON)	YES	YES
Download PDF Report	YES	YES
Word Cloud	-	-
Audio Player	YES	YES
Police Intervention	-	-
Service Management	-	-

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To provide a customisable user experience, each widget in SmartViz offers the flexibility to resize and change its order based on user preferences. This allows users to easily arrange and

organise the widgets within the dashboard so they can create a personalised layout that best suits their needs.

In the following subsections, we describe the requirements, functionalities, and operations of widgets used in the visualisation toolkit.

2.3.1 Sound Localisation Map

The Sound Localisation Map widget (Figure 2) displays a map that visualises the direction of sound events detected by the Sound Event Localisation and Detection (SELD) component. Users can interact with this widget to view consecutive detected events within a selected time period, with each event represented by an arrow indicating its direction.

When utilising the Sound Localisation Map widget, users can observe the spatial distribution of sound events on the map. The arrows provide an intuitive representation of the direction of the detected event, allowing users to identify the source or origin of the sound quickly.

This widget enhances the understanding and analysis of sound events within SmartViz. It provides a visual representation of the direction of detected sound events, enabling users to explore the spatial characteristics of sound in a selected time period and make data-driven observations or decisions based on the displayed information.

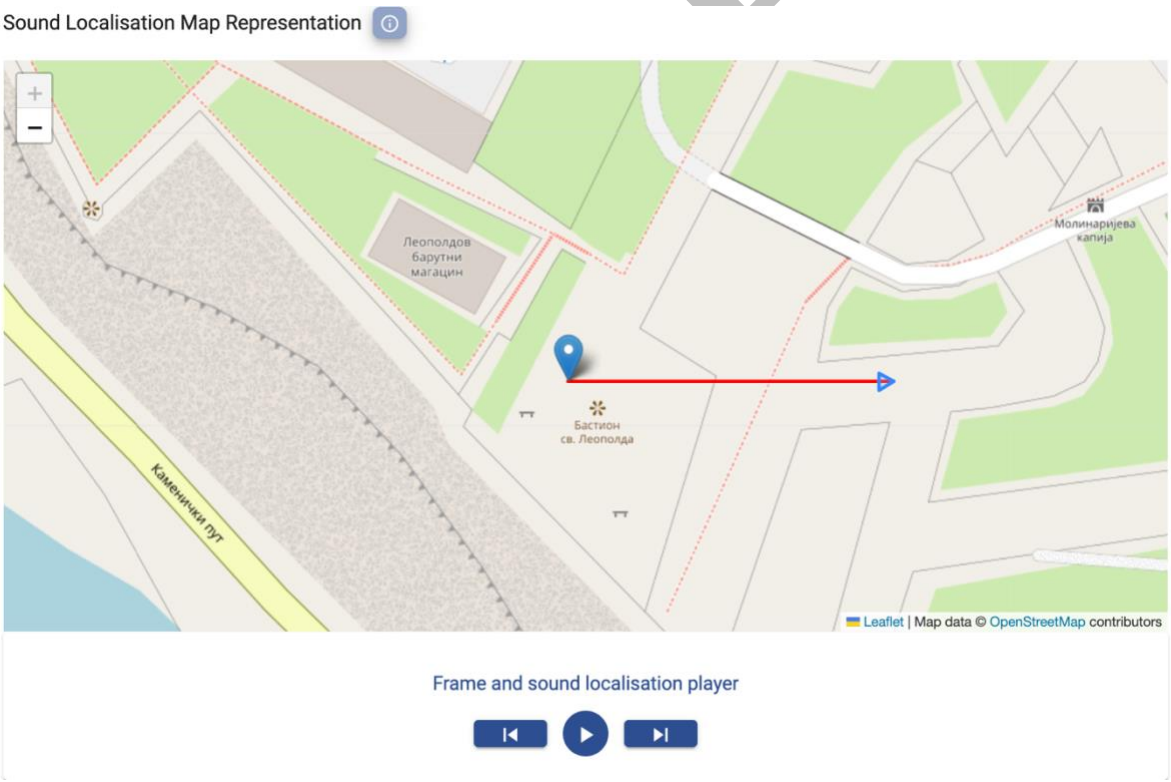

Figure 2: Sound Localisation Map widget

2.3.2 Weather Information

The Weather Information widget (Figure 3) provides a representation of weather-related data for the analysed area within MARVEL. Users can interact with this widget to view weather

information for a selected time period, with the ability to drill down into 3-hour time slots. The widget displays details such as visibility, humidity, temperature, and an overall summary of the weather conditions in the area.

By visualising these weather variables, the widget helps users understand the weather factors that may contribute to detections and events within the MARVEL system. It allows users to gain insights and a comprehensive understanding of how weather conditions may influence the overall context of the analysed area.

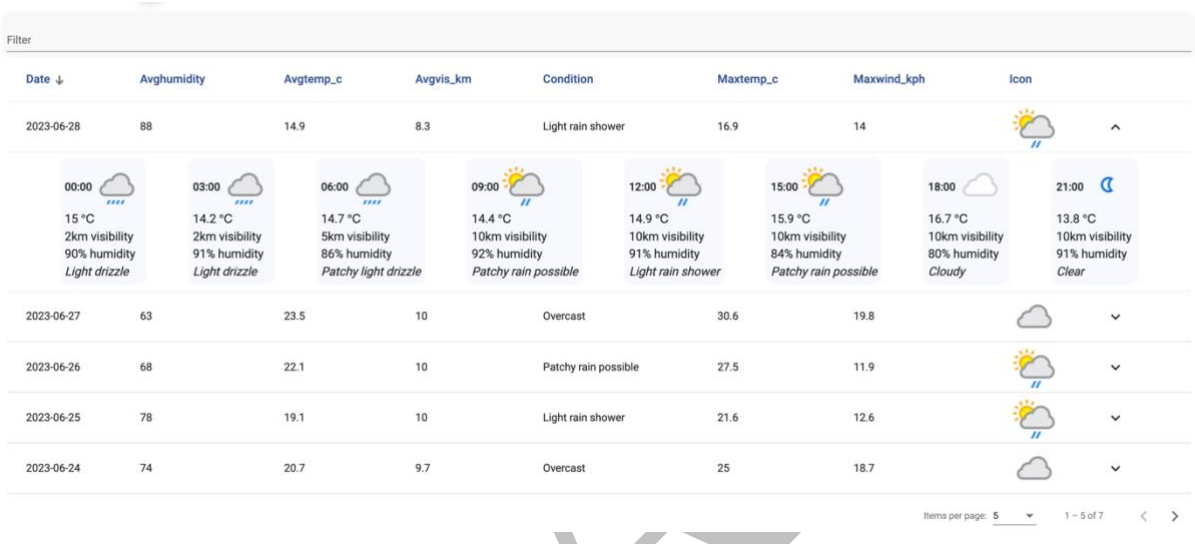

Figure 3: Weather Information widget

2.3.3 Alerts

The Alerts widget (Figure 4) serves as a functionality within the MARVEL system, catering to both real-time and historical data. The primary objective of this widget is to notify users whenever an alert is detected. When an alert occurs, a pop-up notification is displayed to the user in the centre bottom of the screen, indicating the camera where the alert was detected, along with relevant information regarding the alert.

In addition to real-time notifications, the Alerts widget also provides users with a summary of detected events from the past 24 hours. This feature allows users to review and gain insights into previously detected events. By offering both real-time alerts and a historical event summary, the widget enables users to remain informed about ongoing activities and provides a comprehensive overview of the alert history of the use case within the MARVEL system.

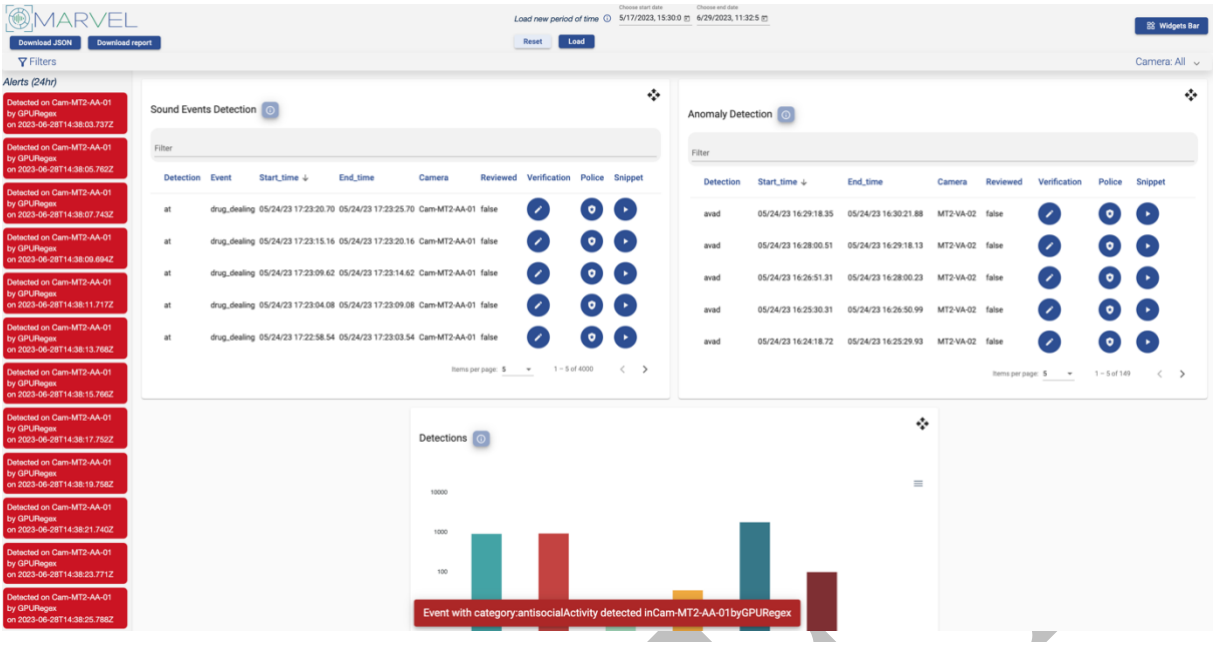

Figure 4: Alerts widget

2.3.4 Comparison

The comparison functionality within the MARVEL system allows users to view two separate time periods side-by-side, displaying the same widgets for each period (Figure 5). This feature enables users to compare and analyse the detected events within each time period.

By examining events across different time periods, users can identify hidden correlations between them. This comparison can be particularly useful for identifying patterns or trends, evaluating the effectiveness of educational campaigns, and drawing conclusions regarding their performance. The ability to visually compare detected events provides users with a valuable tool for data analysis and decision-making.

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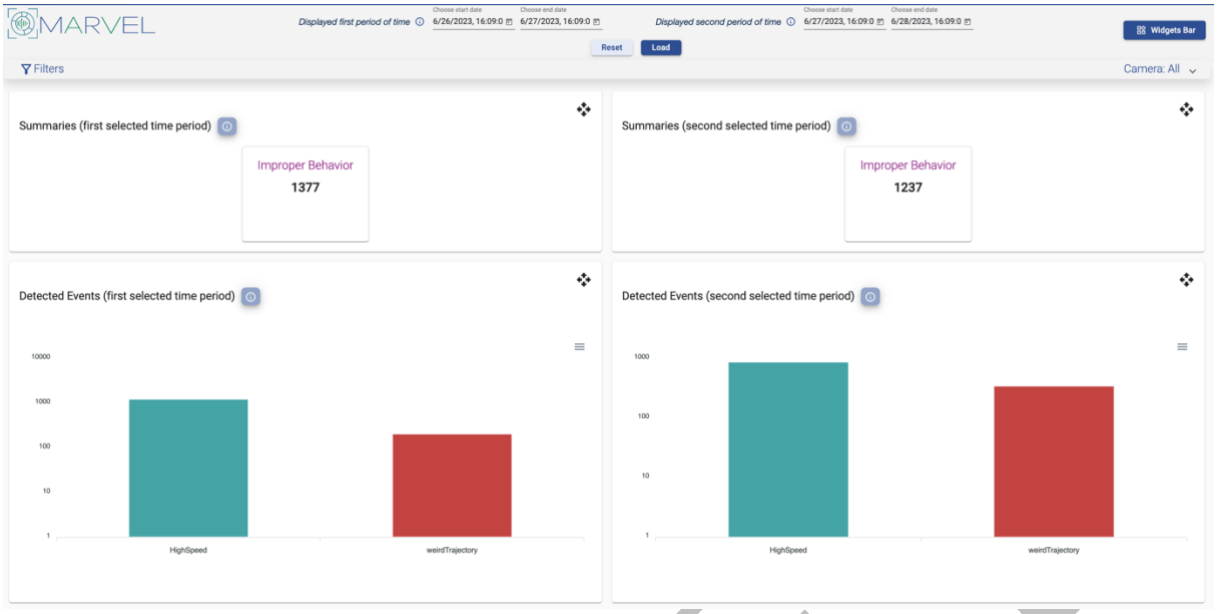

Figure 5: Comparison functionality

2.3.5 Word Cloud

The Word cloud widget in the DMT (Figure 6) enables users to visualise the most common keywords and descriptions associated with the detected events. The data used for this widget is the output of the Automated Audio Captioning (AAC) component that creates textual descriptions with full sentences for audio segments. The caption that the component outputs describes what is happening in the audio signal, for example, “people yelling while siren wails”. In this widget, more frequently occurring captions are displayed with greater prominence, whereas less frequently used captions are shown with less emphasis.

By analysing the prominence of the captions in the word cloud, users can quickly identify the words that appear most frequently. This visualisation technique is particularly valuable for gaining insights into the main trends or keywords associated with detected events, and it allows users to extract meaningful information from textual descriptions.

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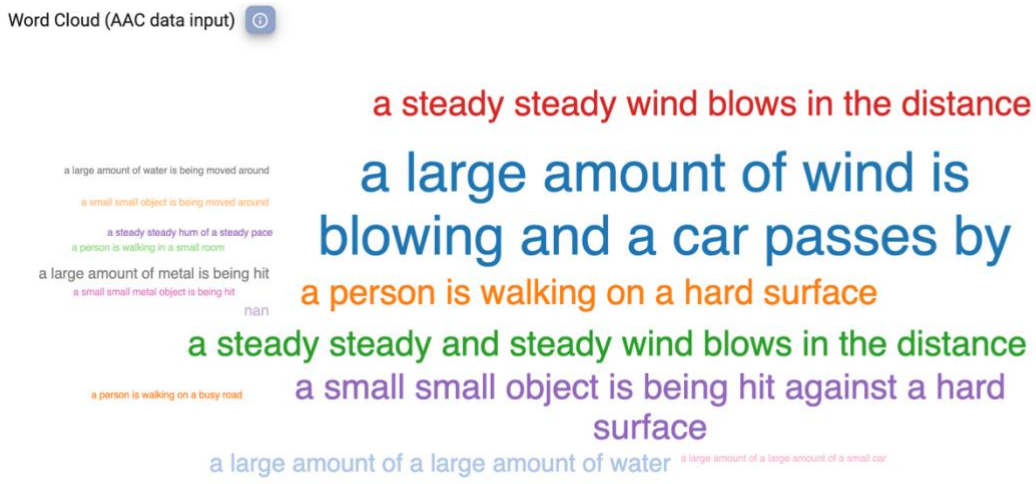

Figure 6: Word Cloud widget

2.3.6 Service Management

In the final version of the DMT, users are empowered with service control capabilities. They can initiate or terminate specific services according to their needs. This functionality is made possible through the interaction between SmartViz and MARVdash via a REST API.

By utilising this functionality (Figure 7), SmartViz can communicate with MARVdash and retrieve information about the services that are currently available and deployed within the system. Users can then initiate and terminate selected services. This interaction provides the end users with the ability to control and manage services within the system, empowering them to tailor the functionality of the DMT to suit their specific needs and preferences.

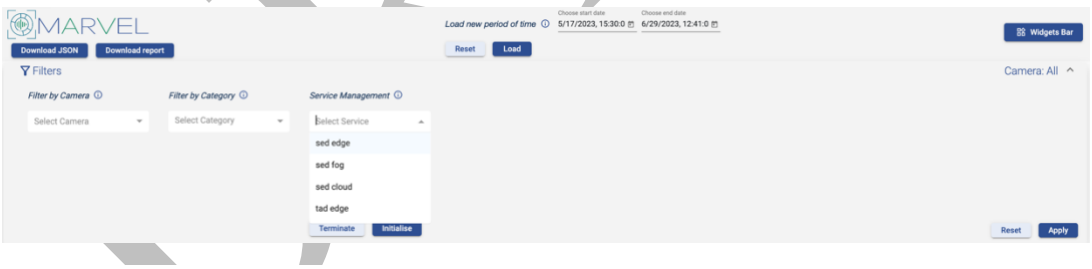

Figure 7: Service Management functionality

2.3.7 Audio player

The Audio player widget (Figure 8) in SmartViz provides users with the capability to interact with audio data within their visualisations. This widget offers two main functionalities: real-time audio streaming and the playback of audio snippets related to specific events or detections.

Real-time audio streaming functionality is made possible by integration with AudioAnony. Users can listen to audio streams in real-time, allowing them to monitor and analyse ongoing audio data as they are being captured or recorded. This feature is particularly useful for

applications that require real-time audio analysis, such as monitoring live events or detecting specific sound patterns in audio streams.

The snippet playback functionality allows users to request and listen to audio snippets associated with specific events or detections. Users can trigger the playback of the corresponding audio snippet when they select a particular event or detect an interest. This functionality enhances the user's ability to explore and understand the audio content within the broader context of their analysis, providing valuable insights and facilitating informed decision-making.

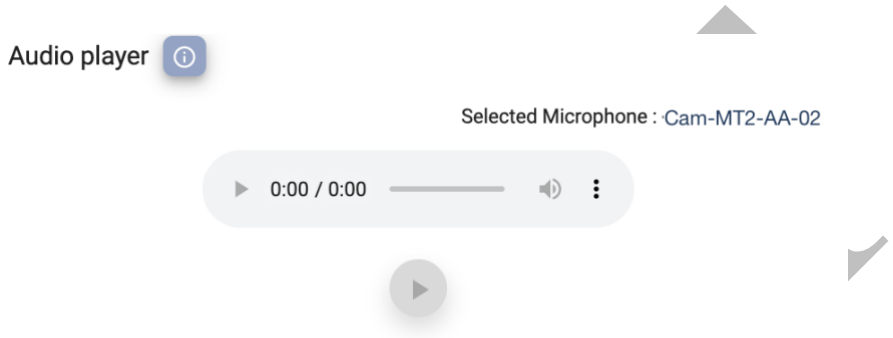

Figure 8: Audio Player widget

2.3.8 Download Data (JSON)

In the final version of the DMT, users have the option of downloading the visualised data in a JSON format. These downloadable data include any applied filters and preferences that the users have used during their interaction with the DMT. By providing this functionality, users can easily retrieve and utilise the visualised data for further analysis or reference purposes.

2.3.9 Download PDF Report

In the final version of DMT, users can download a PDF version of the dashboard view. This allows them to save the entire dashboard as a PDF file, providing a convenient way to store and use the dashboard according to their preference. Users can refer to the downloaded PDF version of the dashboard offline or share it with others as needed.

2.3.10 Police Intervention

In the MT use cases involving local police authorities, a specific requirement was identified to provide users with the ability to mark an event if they deem it important and in need of police intervention. This functionality (Figure 9) allows the users, particularly police authorities, to flag specific events within the visualisation interface. When a user observes an event being visualised and determines that it requires police intervention, they have the option to mark or flag that event. By marking the event, the user indicates that it is significant and warrants attention from the authorities.

It is important to note that this functionality does not automatically alert authorities or initiate immediate action. Instead, it provides a means for users to annotate and highlight events that they believe are of particular importance.

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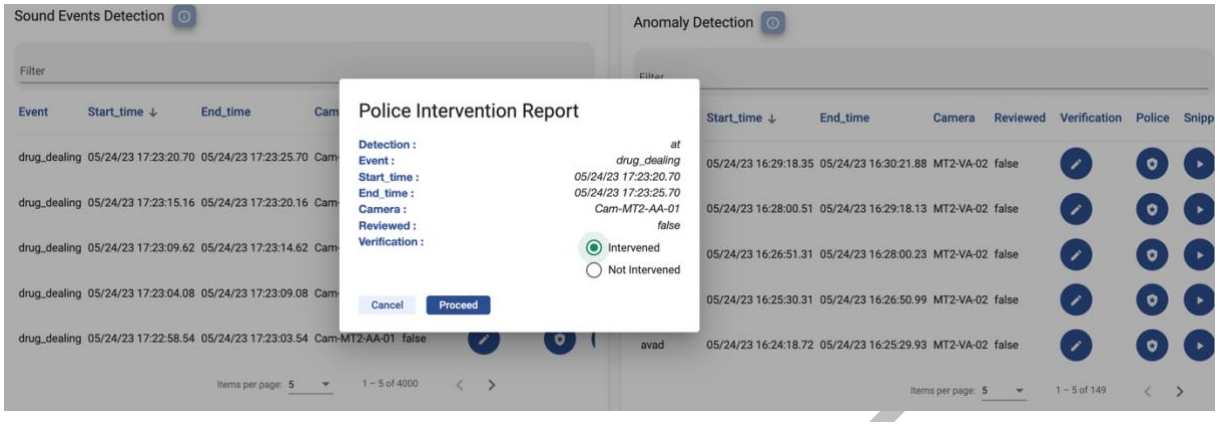

Figure 9: Police Intervention

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3 Design Process

In this section, we will describe the design and the development process of the use cases, for the releases of the DMT. To begin with the first phase, the pilots designed the user journeys and defined user requirements, with the goal of attaining a profound comprehension of the end users' needs and requirements. To enhance alignment with end users' needs, mock-up screens were generated by the ZELUS development team, which were then shared with the pilots for their invaluable feedback. This led to the next phase, where constructive feedback was received from the pilots, which was utilised to iteratively modify and refine the mock-ups, ensuring a closer resonance with the requirements and preferences of the end users. The feedback received from the pilots, as well as the collaborative efforts between the pilots and the ZELUS team, played a crucial role in the creation of the mock-ups. By actively engaging with the pilots, the ZELUS team could understand their needs and preferences and incorporate them into the design process. This collaborative approach fostered alignment between the stakeholders and the results, ensuring that the mock-ups effectively addressed the specific requirements and goals of the project. The final phase refers to the development and improvement of the toolkit. The DMT and its features have been designed and developed with the goal of accommodating use cases and incorporating any necessary adjustments for existing ones.

This approach ensures that the dashboard is flexible and adaptable to meet the evolving needs of users. By considering potential new use cases and addressing feedback from current ones, the design aims to provide a versatile platform that can effectively support a wide range of scenarios and user requirements. The aim is to empower end customers to make informed decisions and navigate complex scenarios with confidence. By actively engaging with consumers, incorporating their input, and ensuring that the toolkit is constantly updated, the goal is to deliver a powerful tool that aligns closely with the requirements and preferences of end users.

3.1 Definition of the user requirements and journeys

3.1.1 GRN1 – Safer Roads - User journey and requirements

The GRN1 use case was implemented during R2 to address the need for increased safety on urban roads for vulnerable road users, with the aim of encouraging the uptake of active travel modes in Malta.

Specifically, this use case targets cycling and walking. Malta has witnessed a significant effort from both the authorities and the bicycle commuting lobby to encourage cycling and walking, mainly through infrastructural changes. The use case requires further effort and aims to detect cyclists, including e-bikes and pedestrians, exiting a junction, and alerting car and motorised-vehicle drivers of their presence via variable message signs in the hope that car drivers take greater care and concentrate more in such circumstances.

The user journey for this use case was designed to address the needs of the Maltese vulnerable road users (VRUs) and potential clients (such as local councils and authorities) of the MARVEL platform who are interested in promoting active mobility. The GRN team regularly interacts with such entities, which leads to the creation of this use case and user journey.

The user needs were set and then communicated to the ZELUS team. GRN and ZELUS teams discussed the layout and widgets that would help us present all the information clearly and concisely to the customer. Table 4 lists the user journey for this case.

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Table 4: User journey for GRN1

Title	Main user stories	Sub user stories and user intent
Safer Roads	**As a** Vulnerable Road User **I want** vehicles to be aware of my presence on the road, **such that** I feel safer sharing the road with the other vehicles.	As a VRU (cyclist, pedestrian) I would like vehicles such as cars and vans to be more aware of my presence on the road. Many rural roads in Malta, for example, do not have pavements for pedestrians. Most roads do not have infrastructure for bicycles, like a cycle lane. Thus, in many cases, a road will be shared between fast moving vehicles and the occasional vulnerable road user. Many people do not consider using alternative/active modes of transport due to concerns for safety. If vehicles are made aware of the VRUs), they would (theoretically) slow down and be more careful when driving in their presence. Thus, the goal of this use case is to have an AI-powered, low-latency road traffic sign which lights up to alert drivers whenever a VRU is present on the road. This road traffic sign will increase the perceived safety for VRUs which will increase the uptake of active modes of travel. The detections are also sent to the MARVEL platform to be displayed in Smart Viz such that the situation can be monitored remotely by the respective entity. **As a user:** - I want to see the real-time alerts from the AI models; - once an alert is flagged, I can request and see the video of the alert; - have the VRU and alert counts for long-term data collection and analysis; - download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes; - save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference; - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts

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3.1.2 GRN2 – Road User behaviour - User journey and requirements

The GRN2 use case was implemented during R2 to address the need to monitor the behaviour of road users at a junction. This use case demonstrates tools that are useful in law enforcement and education campaigns targeting responsible driving, cycling, and other road uses.

Malta has experienced rapid changes in its transport landscape, to which human responses often lag technical progress. Educational campaigns are one way to close this gap and have shown to be effective in the past. This use case involves the classification of actions into a spectrum of examples demonstrating various types of behaviours. This use case will not be implementing

the latter campaigns or policies; however, it could be tried in different places and its output could be observed.

GRN designed the user journeys with the aim of meeting the needs of entities involved in implementing educational campaigns, focusing on providing easily viewable data and facilitating comparisons before and after these campaigns. Collaborating with the ZELUS team through meetings and communications, the layout of the dashboard and the design of widgets were planned to enable the simultaneous display of two time periods on the screen, ensuring convenient data visualisation. Surveys will be conducted to gather feedback and assess the effectiveness of the tool in assisting local authorities with their campaigns under WP6. Table 5 shows the user journey for this use case.

Table 5: User journey for GRN2

Title	Main user stories	Sub user stories and user intent
Road User Behaviour	**As a** Local Authority **I want to** be aware of the number of bad behaviour instances in a certain time period, **such that** I can assess the success of an educational campaign.	**As a local authority:** - I would like to know how well my educational campaigns are performing by comparing road users' behaviour before and after the roll-out of educational campaigns. - I would like to get counts of the amount of bad behaviour that is detected automatically using AI models. Without the use of AI models an educational campaigner would not be able to determine whether the number of occurrences pertaining to a specific type of bad behaviour is decreasing, especially if this bad behaviour does not directly lead to an accident. - I would like to be able to see graphs and tables displaying the events detected by the AI models, easily and concisely. - I would like to have the ability to access more detailed data for further analysis. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

3.1.3 GRN3 – Traffic Conditions and Anomalous events - User journey and requirements

The third use case of GRN was implemented during R1. In this case, the traffic conditions were monitored to detect anomalous events. Such events include traffic jams, accidents, cars stuck to and obstructing a junction, very slow vehicles, and service vehicles parked on the side or

DRAFT

obstructing a carriageway. The latter event is frequent in Malta's narrow one-way urban streets and often causes ripple effects that extend beyond the immediate area. The detection of anomalous events can be used to alert personnel stationed in traffic management control rooms, who can then interpret the data and take necessary action. The latter application is particularly attractive because it promises to reduce the detection time for anomalous events.

The users of this system are intended to be traffic managers who can give directives to authorities to react to, for example, traffic incidents. The widgets were designed to alert users in real-time, provide long-term analytics of all anomalies, and show snippets of past anomalies for confirmation. The User Stories for this use case are listed in

Table 6, and they provide a better understanding of the functionality expected by the intended user.

Table 6: User journey for GRN3

Title	Main user stories	Sub user stories and user intent
Anomaly detection	**As a** Traffic Manager, **I want** to be alerted if an anomaly occurs on the road **so that** I can analyse it and determine a course of actions.	**As a traffic manager:** - Once informed of anomalous events on the roads, I can take appropriate actions, like dispatching the relevant civil protection authorities. - Once an anomaly is detected, I can see a live feed from the camera where the event occurred, as well as a few minutes before the anomaly happened, to help me accurately assess the cause. - Once I review the camera feed of an event, I can have the option to mark this event as anomalous or not and continuously improve the system and in this case, allowing for the augmentation of additional annotated data which is needed for training or testing of AI models, and measuring the accuracy of the models and in general the evaluation of the system. - If anomalies happened in the past or in my absence, I could still view them and access historical data around them, therefore such data is stored and managed. - Since I am observing multiple locations, I can see observed anomalies and related data on a map. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference.

DRAFT

Traffic Conditions	**As a** Traffic Manager **I want** to monitor the traffic conditions easily and efficiently on various roads and junctions **so that** I can monitor events such as traffic jams, congestion levels and traffic flow rates.	As the traffic manager, I can be alerted whenever traffic conditions or states change substantially. With the knowledge that a road is obstructed, I can alert the appropriate authorities. With long-term data, infrastructural changes that might be needed can be flagged, for further processing by the traffic and infrastructure engineers. - Since I am observing multiple locations, I can see observed anomalies and related data on a map. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts

3.1.4 GRN4 – Junction Traffic Trajectory Collection - User journey and requirements

GRN4 was implemented for the MARVEL Minimum Viable Product (MVP). Junction Traffic Trajectory collection is focused on the requirement of long-term data analytics that shed light on both the behaviour of road users (e.g., car drivers, motorcyclists, cyclists, pedestrians, etc.) and on gathering traffic statistics at road network junctions. This case is of interest for long-term transportation planning and evaluation. There is currently significant interest in studying active travel modes, such as cycling, walking, and micro-mobility. Authorities in Malta are interested in, for example, determining the optimal position of pedestrian crossings, whether provisions for cyclists at complex junctions are adequate, and whether installed provisions are being used as intended.

This use case requires entity detection and its trajectory across a junction or road segment as well as descriptive statistics of network junction traffic. Therefore, it follows that entity detection and tracking models can potentially be used as a first processing stage, followed by further processing to generate descriptive statistics.

The users of this system are intended to be traffic engineers who need data to make informed decisions about infrastructure changes and upkeep, as well as transport researchers who are interested in user behaviour. Thus, ZELUS designed various widgets through discussions with the GRN team. All widgets were intended to summarise long-term traffic analytics while still allowing the user to obtain detailed information if required. The User Stories for this use case are listed in Table 7 and provide a better understanding of the expected functionality.

DRAFT

Table 7: User journey for GRN4

Title	Main user stories	Sub user stories and user intent
Vehicle and Pedestrian Trajectories	**As a** Traffic Engineer, **I want to** view the trajectories of vehicles across a junction, **so that** I can analyse the most preferred paths vehicles take and make decisions on infrastructure. For example, whether large vehicles should be allowed on a particular street.	**As a traffic engineer:** - Once I view the trajectories by each type of vehicle or entity, I can make decisions on any infrastructure upgrade needed at each location. For example, I can note that cyclists take a certain path, and thus plan a cycling lane accordingly. The trajectories can also give insights into frequent recurring obstructions (i.e., cars parked at an inappropriate spot) which force temporal changes in the trajectories. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts
Vehicle and Pedestrian Counting	**As a** Traffic Engineer, **I want to** view the number of different types of vehicles that use certain types of roads, **so that** I can track the frequency of road usage per vehicle.	**As a traffic engineer:** - I want to easily view the traffic counts of all types of vehicles per vehicle, per time period and per road or junction, so that I can track the usage of a road per vehicle and estimate when and how the infrastructure needs to be upgraded. For example, stronger materials might be needed if the roads are used frequently by heavy vehicles or maybe wider pavements are needed if the road is a frequent walking route. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

DRAFT

3.1.5 MT1 – Monitoring of Crowded Areas - User journey and requirements

The MT1 was implemented for the R1 integration. Its objective is to select views of relevant areas for various reasons such as monitoring exceptional crowds, suspect or unusual crowd movements and more.

The specific areas chosen for monitoring in this scenario are Piazza Fiera, a square that hosts the “Christmas Markets” in Trento, and Piazza Duomo, where the weekly market takes place. Both locations are known to attract large crowds and host various other events.

The citizens of Trento have expressed an increasing perception of antisocial behaviours in certain areas, as highlighted by the results obtained from the "eSecurity - ICT for knowledge-based and predictive urban security" project in 2015[3]. This awareness has led to a need for increased measures to ensure public safety. Furthermore, the Local Police, in collaboration with law enforcement agencies, aims to monitor popular events like the Christmas Market or the Patron Saint's festival to prevent fights, terrorism, and other unsafe behaviours. All the MT use cases align with the concerns raised by the Commander of the Local Police of the City of Trento. There is constant discussion and collaboration with the Commander to validate the implemented solutions and address the identified issues.

The end users of this system are intended to be the local police authorities. ZELUS designed various widgets based on the discussions with the MT team. All the widgets and the entire dashboard layout were intended to support the objectives of this use case. The User Stories for this use case are listed in Table 8 and provide a better understanding of the expected functionality.

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[3] https://ict.fbk.eu/wp-content/uploads/2020/03/ecrime-esecurity-guidelines_compressed-1.pdf

Table 8: User journey for MT1

Title	Main user stories	Sub user stories and user intent
Exceptional crowd, suspect or unusual crowd movements	**As a** Local Police officer, **I want** to be alerted if an anomaly, such as an overly-dense crowd, and unusual crowd movement, occurs in the squares, **so that** I can further focus on the relative views, analyse them and determine a course of actions.	**As a Local Police officer:** - Once being informed of anomalous events in crowded areas, I can take the appropriate decisions such as dispatching the relevant authorities. - Once there is an anomaly flagged or the number of people present exceeds the predetermined maximum number (80 people in Piazza Fiera and 80 in Piazza Duomo), I am alerted and notified which live feed from which camera (the one capturing the location of the event) should be checked with attention and I should be able to view the feed, to accurately assess the cause. - Once I review the camera feed of the flagged anomaly, I have the option to verify if this event analysis is indeed correct or not and report on whether police intervened or not. These options allow the continuous improvement of the system. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I also want to: - view the anomalous events on the map, - compare events in different contexts (e.g., weekly market vs Christmas market), - view the timeline of events. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

3.1.6 MT2 – Detecting Criminal and Anti-Social Behaviours - User journey and requirements

The objective of the MT2 use case selected for the R2, is to monitor specific areas in order to detect criminal or anti-social behaviours. The system is designed to trigger an alarm or present a custom view in the control room when such behaviours are detected.

The MARVEL framework was deployed to identify potentially dangerous situations, particularly during night-time, in areas such as Piazza Santa Maria Maggiore. This includes monitoring for gatherings, robberies, aggressions, and drug trafficking activities.

The users of this system are intended to be the local police authorities. The widgets and the dashboard layout were designed by ZELUS through many discussions with the MT team. All the widgets and the entire dashboard layout were intended to support the objectives of this use

DRAFT

case. The user story for this use case is shown in Table 9, and provides a better understanding of the expected functionality.

Table 9: User journey for MT2

Title	Main user stories	Sub user stories and user intent
Detecting criminal and anti-social behaviours	**As a** Local Police officer, **I want to** be alerted if an anomaly, such as aggressions, robberies, fights and drug dealing occurs **so that** I can further focus on the relative views and analyse and determine a course of action.	**As a Local Police officer**: - I want to view the total numbers of the detected events and anomalies. - I want to view the statistics of the detected behaviours and the most commonly used descriptions associated with the detected events. - I want to view the available information regarding the detections observed. - Once an anomaly is flagged, I am alerted and notified which live feed from which camera should be checked with attention and I should be able to access the audio and video feed a few minutes before the anomaly happened, to accurately assess the event. - Once I review the audio and video feed of the flagged anomaly, I have the option to mark this event as anomalous or not and the report on whether police intervened or not. These options allow for continuously improving the system. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

3.1.7 MT3 – Monitoring of Parking Places - User journey and requirements

The MT3 was implemented during R1, and it focuses on the "Ex Zuffo" Parking Area, which is one of the largest parking areas in Trento, accommodating approximately 1000 slots. This parking area serves as an interchange car park, allowing citizens to leave their cars and commute to the city centre using public transportation, rentable bikes, and e-scooters.

To prevent robberies or damage to parked cars, the MARVEL framework supports prevention activities through audio-visual analysis of cameras and microphones. This analysis will enhance security measures and help to identify potential threats or suspicious activities within a parking area.

The users of this system are intended to be the local police authorities. The widgets and the dashboard layout were designed by ZELUS through many discussions with the MT team. All

DRAFT

the widgets and the entire dashboard layout were intended to support the objectives of this use case. The user story for this use case is shown in Table 10 and provides a better understanding of the expected functionality.

Table 10: User journey for MT3

Title	Main user stories	Sub user stories and user intent
Monitoring of parking places	**As a** Local Police officer, **I want to** monitor the use of the parking lot and detect an anomaly activity in parking spaces, **so that** I can take corrective /supporting actions.	**As a Local Police officer**: - in order to properly monitor the parking area, I want to view: · the timeline distribution of the vehicles in the parking; · the total number of vehicles; · the clustering of vehicles and/or events; · the information of detections observed. - Once an anomaly is flagged, I am alerted and notified which live feed from which camera should be checked with attention and I should be able to access the feed a few minutes before the anomaly happened, to accurately assess the event. - Once I review the feed of the flagged anomaly, I have the option to mark this event as anomalous or not and the report on whether police intervened or not. These options allow for continuously improving the system. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts

3.1.8 MT4 – Analysis of a Specific Area - User journey and requirements

The MT4 use case selected for R2 focuses on monitoring key areas within the Municipality of Trento to support decision-making by the local administration. The MARVEL framework plays a crucial role in this process by providing various functionalities, including person and vehicle counting, trajectory calculation, and detection of notable events within specific timeframes.

Available objective data will allow political decision-makers to make informed decisions based on facts and not on sensations perceived by the population (e.g., safety of pedestrians, decisions to change mobility). This data-driven approach enables evidence-based decision-making, particularly in areas related to pedestrian safety and mobility planning. The data collected through the project is enriched by integrating it with existing data already collected and analysed by the Municipality of Trento through its Digital Hub. This integration includes data

DRAFT

on e-scooter rentals, bike-sharing usage, and public transport utilisation. A comprehensive understanding of a city's dynamics and mobility patterns can be achieved by combining these datasets.

Overall, the MT4 use case demonstrates the value of the MARVEL framework in providing objective data and insights to support decision-making processes within the Municipality of Trento. By combining various data sources and maintaining regular communication with policymakers, the framework enables informed decisions and effective monitoring of the city's main areas. Table 11 shows the user journeys set by MT for this use case and gives a better understanding of the expected functionality.

Table 11: User journey for MT4

Title	Main user stories	Sub user stories and user intent
Analysis of a Specific Area	**As a** Local Police officer, **I want to** monitor the number of aggressions occurring **so that** I can take supporting actions.	**As a Local Police officer**: - In order to properly analyse the monitored area, I want to view: · the timeline distribution of the anomalies and events; · the clustering of anomalies and/or events; · the severity, type and information of anomalies observed; · the statistics of the anomalies and/or events. - Once I review the video or audio snippet of a detected anomaly/event, I have the option to mark this as anomalous or not and report on whether the police intervened or not. These options allow for continuously improving the system. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

DRAFT

	As an MT policy-maker/Mobility manager, **I want to** monitor the number of persons, cars, buses, bikes and their behaviours **so that** I can increase the efficiency of traffic management and traffic city planning.	**As an MT policy-maker/Mobility manager**: - In order to properly analyse the monitored area, I want to view: · the timeline distribution of the vehicles; · the total number of vehicles; · the statistics of vehicles and/or events; · the trajectories by traffic entities; · the total number of persons. - Once I review the video or audio snippet of a detected event, I have the option to mark this event as anomalous or not. These options allow for continuously improving the system. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detected anomalies and alerts.

3.1.9 UNS1 – Drone experiment - User journey and requirements

The purpose of the UNS1 is to evaluate the potential of drones for monitoring large open-space public events. The use case was implemented during R1. The UNS drone experiment setup includes computational resources, video recording from the drone and audio recording from the ground. Such a setup could be useful for a quick security check in the case of a crowded space. Commonly, street cameras can record only a frontal view of the event and inner details cannot be observed. Furthermore, there are angles or even whole spaces that are not covered using cameras. Flying over the crowd zones of interest, it can be quickly checked if there is some unusual problematic behaviour. Activity detection in the zones of interest could be quickly done using ground-based microphones, which fed the SED component.

UNS is an experimental pilot provider, i.e., it is not an end user. Creation process, including definition of user journeys, requirements and goals are set according to the discussion with the organisers of EXIT festival – one of the largest European music festivals that is being held in Novi Sad each summer. The user story for this use case is shown in Table 12.

DRAFT

Table 12: User journey for UNS1

Title	Main user stories	Sub user stories and user intent
Crowd counting and anomaly detection	**As an** organiser of a large public event, **I want to** have information of the number of people in the event, or a specific part of it – either through a heat map or count and be alerted if there is an overcrowded place and have real-time access to the corresponding AV stream, **so I can** inspect and determine the corresponding course of action.	**As an organiser of a large public event:** - I would like to have information on the number of visitors. - I would like to be informed in real-time if there is anomalous behaviour in a part of the crowds. - I would like to have the option to have a live stream from drone-based videos, accompanied by audio-visual recordings from the ground. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detect anomalies and alerts.

3.1.10 UNS2 – Localising audio events in crowds - User journey and requirements

The purpose of UNS2 is to explore the possibility of localising and detecting audio events in crowds from audio streams. Current state-of-the-art sound event localisation and detections components are developed using data recorded in laboratories, which is not efficient enough for detection of high precision due to different recording conditions. Such a component could be crucial from the perspective of organisers of large public events to monitor crowds and quickly detect location of anomalous events of interest, such as gunshot. Detection of such events is difficult in crowded and low-visibility areas. Creation process, including definition of user journeys, requirements and goals is common sense and they were defined within a discussion with consortium members as UNS is an experimental pilot provider (i.e., not an end user). The user story for this use case is shown in Table 13.

DRAFT

Table 13: User journey for UNS2

Title	Main user stories	Sub user stories and user intent
Localising audio events in crowds	**As a** member of a security crew, **I want to** be alerted if there is an anomalous sound event in the crowd, have an automatic detection of the event and its location and see the city map and direction of the sound event for inspection **so I can** determine the corresponding course of action.	**As a security crew member of large public events:** - I need more details about people in crowds and their safety. Safety cameras can provide us with visual inspection of the people and their behaviour. However, the course of action depends also on the type of anomalous event that occurs. Quick recognition of events such as gunfire and further reaction may be crucial for saving lives. As fixed cameras cannot provide visibility of all areas, sound event localisation and detection can speed up the decision process. - I want to download the visualised data in a JSON format so I can easily retrieve and utilise them for further analysis or reference purposes. - I want to save the entire dashboard as a PDF file, so I can store, share, and access the dashboard offline according to my preference. - I want to see available weather information so I can correlate weather conditions to detect anomalies and alerts.

3.2 Interpretation and mock-up screens design

This section highlights the importance of interpretation and mock-up design in the project's use case. It explores how the initial step towards the final development of the toolkit described in Section 4 involves creating mock-up screens based on user requirements. The interpretation entails a thorough analysis and understanding of the project's findings, data, and outcomes. Concurrently, the mock-up design phase focuses on creating visual representations or prototypes that demonstrate the envisioned user interface and functionality of the project. These mock-ups serve as tangible examples that demonstrate how the proposed solutions will look and function. Through iterative refinement and validation, the project team ensures that the final design aligns with the desired user experience and project objectives.

Achieving reciprocity between the pilot and SmartViz development is essential for aligning pilot requirements, MARVEL's development capabilities, and the quality of service provided by the user interface. This reciprocal approach facilitates a seamless integration of user feedback, project constraints, and technological advancements. By establishing a dynamic feedback loop, the pilot team can communicate their specific requirements, challenges, and expectations to the SmartViz development team. Likewise, the development team can leverage their expertise and technological capabilities to propose innovative solutions that meet the pilot's needs.

This relationship ensures a collaborative and iterative approach to development, allowing for continuous improvement and optimisation. By facilitating effective communication and collaboration, the project team strives to achieve an optimal balance between the pilot and user

DRAFT

requirements, technological capabilities, and the quality of service provided by the user interface.

3.2.1 R1 use cases and progress within R2

3.2.1.1 GRN3 – Traffic Conditions and Anomalous events – Mock-up screen

The goal of SmartViz for GRN3 is to allow the traffic managers who can give directives to other authorities, to react to any disruptive event such as traffic incidents, anomalous queue lengths, and roadside breakdowns. Please refer to section 3.1.3 for more information.

The implementation of the user intentions for the GRN3 as shown in the mock-ups, concludes the dashboard layouts and widgets around the main goals of this use case. The mock-up screen created for the R1 version of the toolkit is shown in Figure 10 below.

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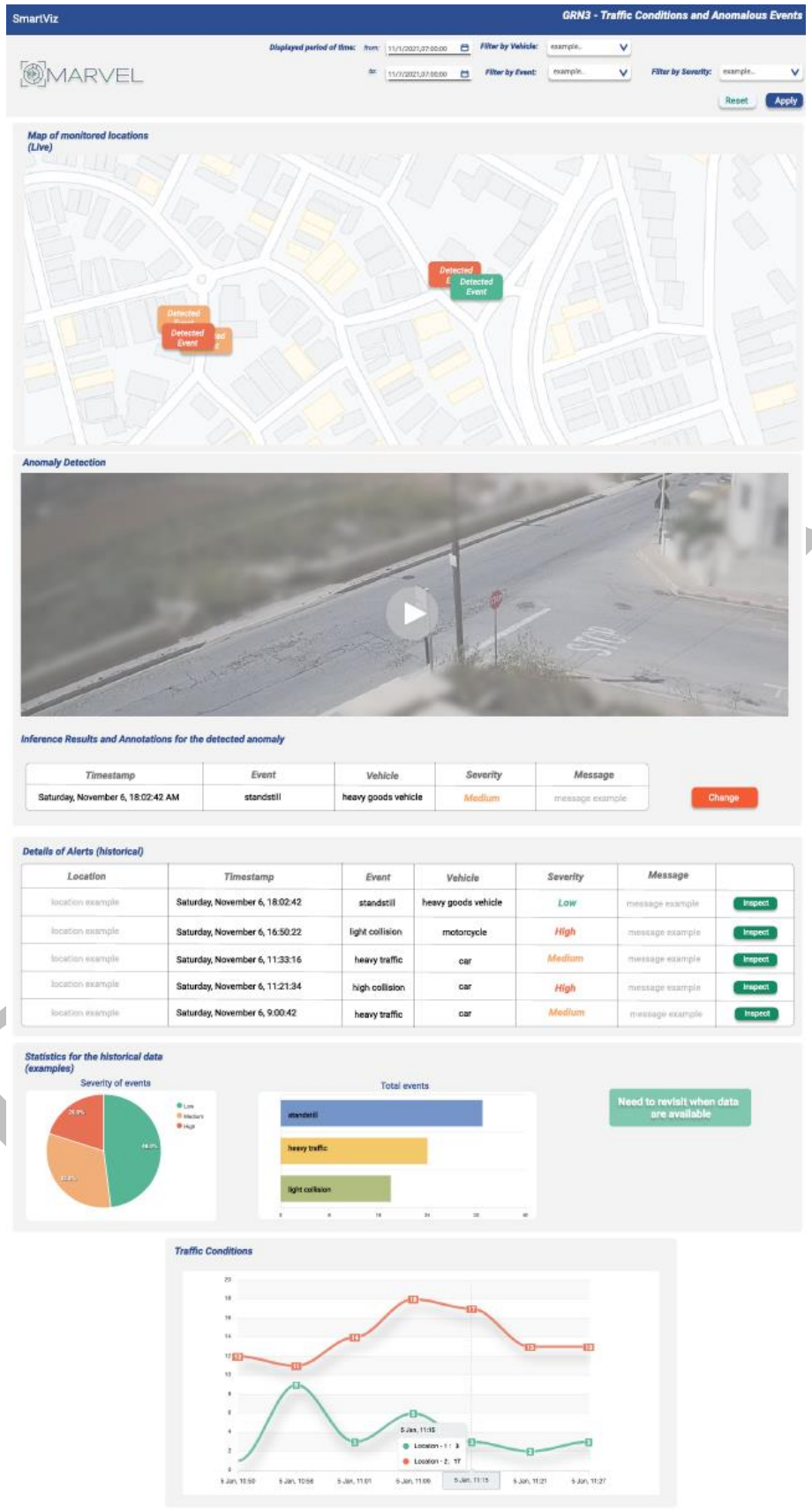

Figure 10: Mock-up screen of GRN3 in DMT (R1)

In response to the updated user requirements and feedback received from the pilots, several changes were made to the mock-up screen of GRN3 for the R2 (Figure 11). These changes were implemented to enhance the user experience and align the dashboard with the evolving needs of the project.

Firstly, the Live Map's functionality was updated to allow users trigger the playing of the video stream, providing them a more interactive experience. Additionally, the playback of the selected video snippet from the Details widget was incorporated. To improve usability, the Details widget was split into two tables, allowing for better organisation. Furthermore, the Audio player was added in this use case allowing users to listen to audio recordings. The inclusion of the Weather widget and the download options for the dashboard data were also implemented. Lastly, significant changes were made to the Statistical widget to enhance data visualisation and improve the representation of data and its information.

These updates and additions to the mock-up screen were decided and implemented in collaboration with the GRN team to ensure that the dashboard meets the specific needs of the users and enhances their overall experience in utilising the DMT.

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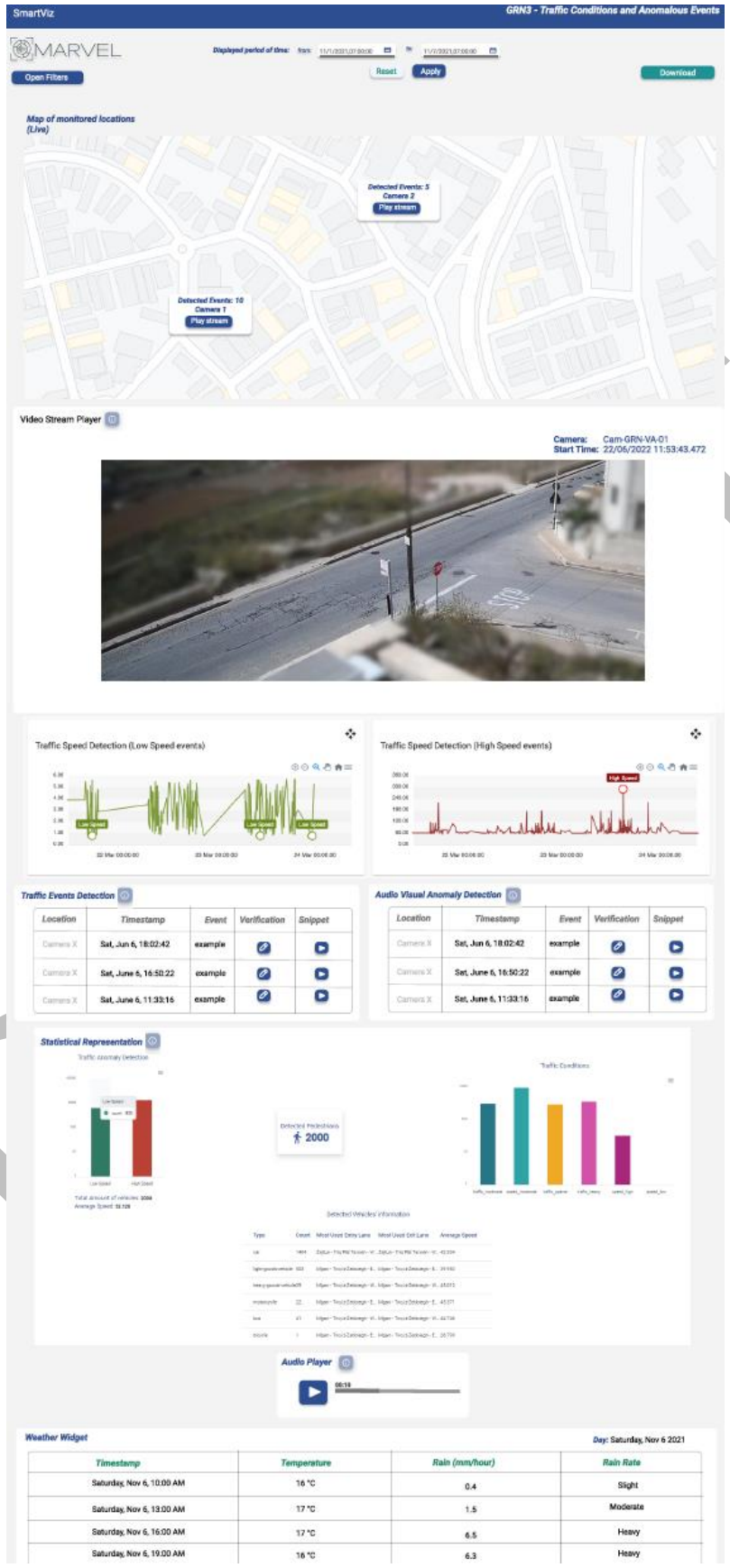

Figure 11: Mock-up screen of GRN3 in DMT (R2)

3.2.1.2 GRN4 – Junction Traffic Trajectory Collection – Mock-up screen

Based on the requirements of the GRN4, we focus on the road users' behaviour and on gathering tracking statistics at road network junctions over a long period of time. The main goal is to provide a safety study of how vulnerable road users make use of facilities provided to them, sustainable mobility, and active travel modes. Please refer to section 3.1.4 for more information.

Within the user requirements, the GRN4 mock-up screen for R1 was formed as seen in Figure 12 below.

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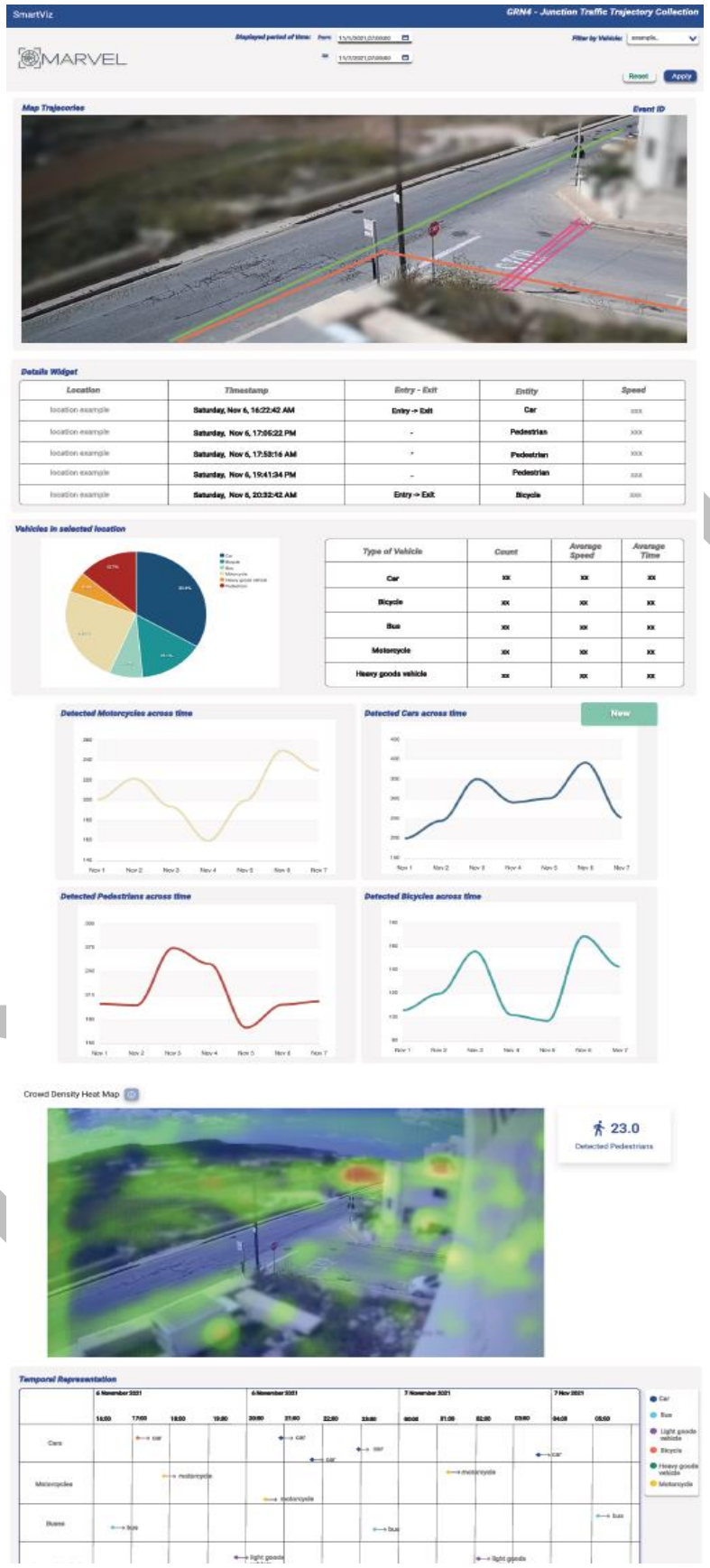

Figure 12: Mock-up screen of GRN4 in DMT (R1)

In response to the feedback from the pilots and to fulfil the user requirements, several updates were made to the mock-up screen of GRN4 for the R2 (Figure 13). First, a Weather widget was added to provide users with access to weather data for the monitored area. The Details widget was also modified to improve usability. In the Statistics widget, based on pilot feedback, the charts were simplified to focus only on the essential information that is directly relevant to the user requirements. Furthermore, download options were included, allowing users to easily export the visualised data in their preferred format.

These updates to the mock-up screen reflect the collaborative effort to address user feedback, enhance data representation, and incorporate additional features to meet the needs of the end users.

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Figure 13: Mock-up screen of GRN4 in DMT (R2)

3.2.1.3 MT1 – Monitoring of Crowded Area– Mock-up screen

The MT1 use case is designed to facilitate effective crowd monitoring and provide timely alerts to help users address potential security or safety concerns in crowded areas. By leveraging the capabilities of the MARVEL system, the objective is to empower users to respond promptly and efficiently to any anomalies or unusual crowd behaviour that may arise. Please refer to section 3.1.5 for more information.

Within these requirements, the MT1 mock-up screen for R1 was formed as seen in Figure 14 below.

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Figure 14: Mock-up screen of MT1 in DMT (R1)

Based on valuable feedback from the pilots and with the aim of meeting user requirements, several enhancements have been implemented in the mock-up of this use case for R2 (Figure 15). These updates improve the overall functionality and user experience of the dashboard. Notable additions are the inclusion of a Weather widget and a Crowd Density heatmap widget for the Visual Crowd Counting (VCC) events. The map functionality has been enhanced to allow users to trigger the playback of the video stream. Users have the option to download the data for offline access. The Details widget has undergone modifications to improve usability so it includes features such as inference verification, video playback triggering, and the ability to generate police intervention reports. Furthermore, the final version of the mock-up screen incorporates a Comparison view for the available Statistics and Summaries widgets. This allows users to compare and analyse data from different time periods or scenarios, providing valuable insights into crowd behaviour patterns and changes over time. Finally, the user can see the distribution of the detections of Audio Visual Anomaly Detection (AVAD) across time.

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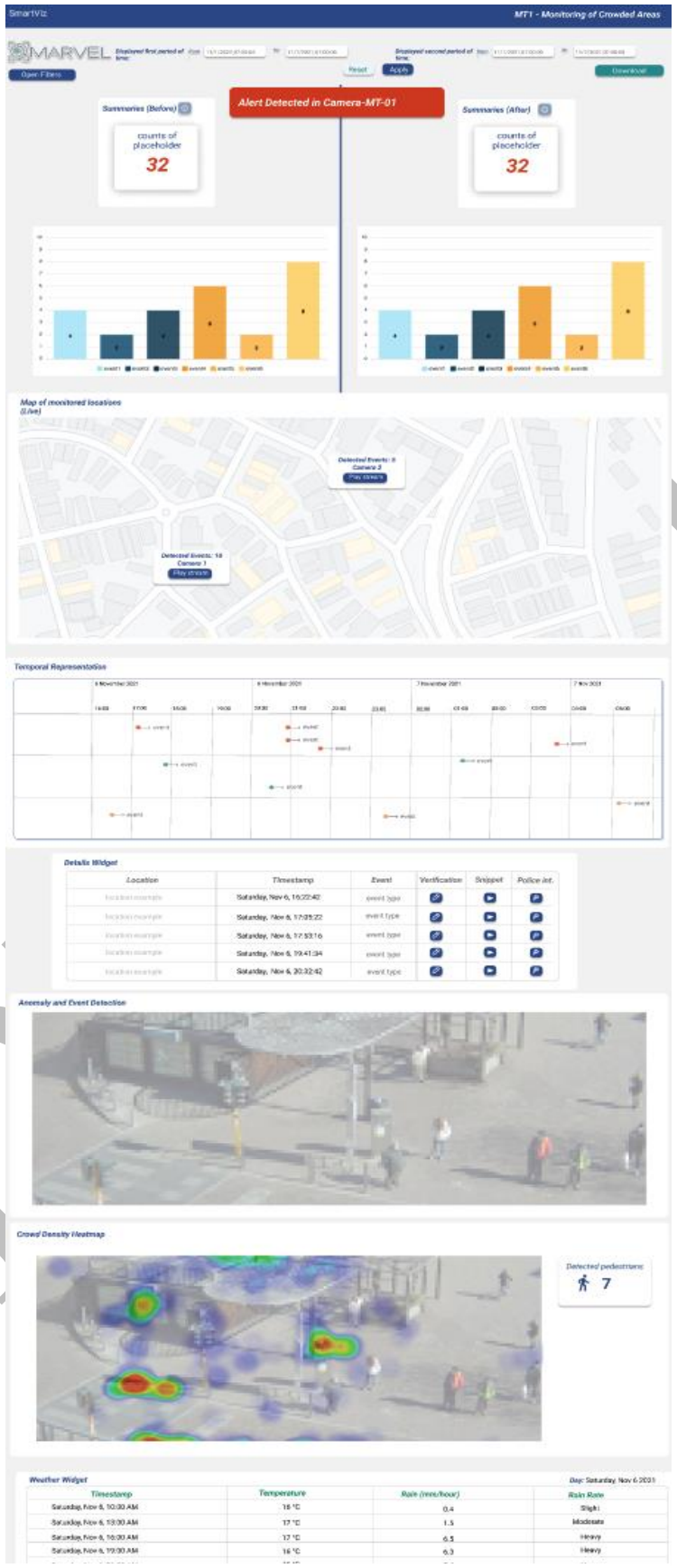

Figure 15: Mock-up screen of MT1 in DMT (R2)

3.2.1.4 MT3 – Monitoring of parking places – Mock-up screen

The main goal of the MT3 use case is to identify anomalies, including acts of vandalism and other irregular behaviours, while also examining the temporal distribution of parking activity and uncovering patterns of vehicle clustering or noteworthy occurrences. Please refer to section 3.1.7 for more information.

Within these requirements, the MT3 mock-up screen for R1 was formed as seen in Figure 16 below.

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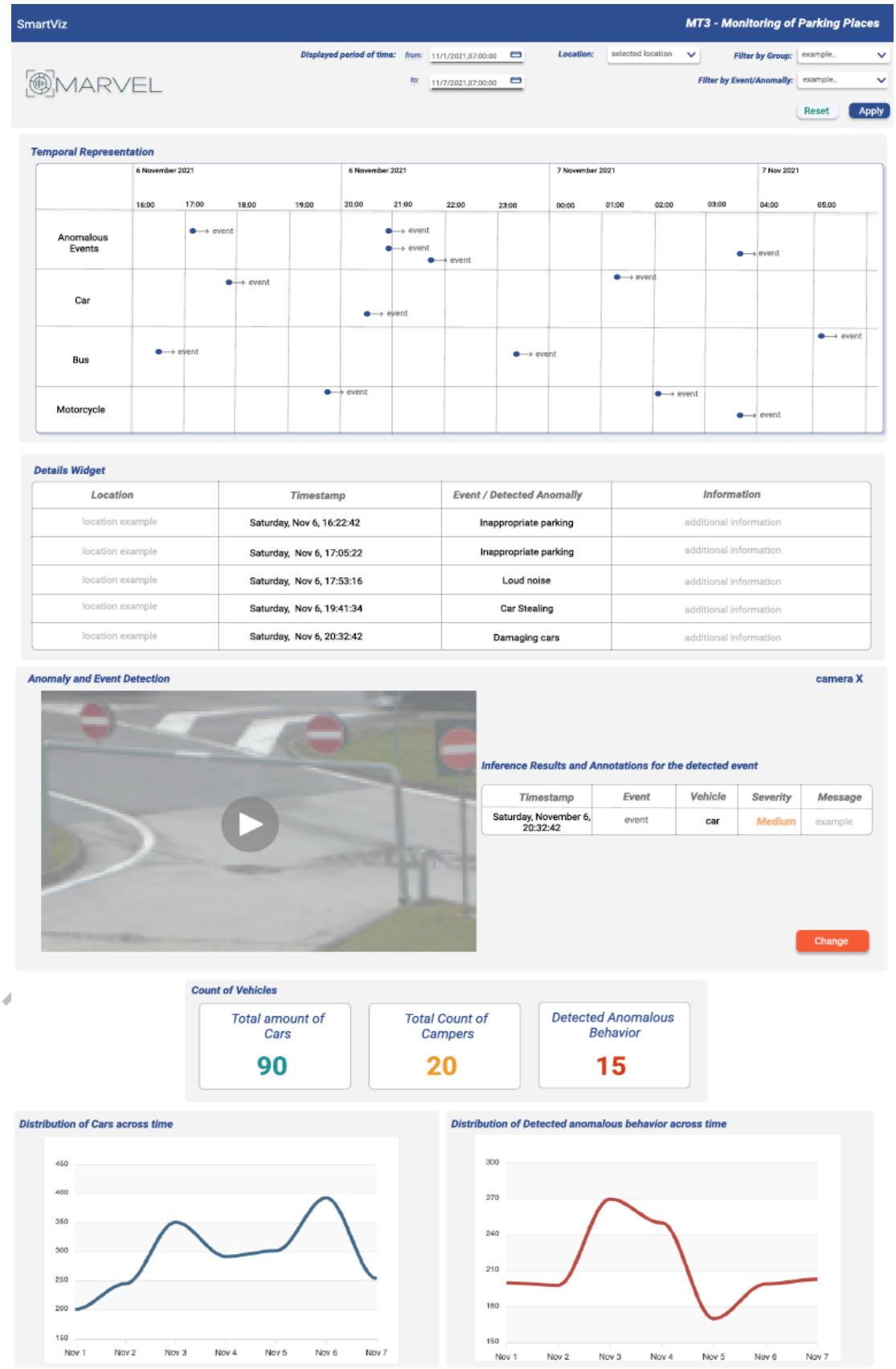

Figure 16: Mock-up screen of MT3 in DMT (R1)

To better address user intentions and requirements, several enhancements were made to the mock-up (Figure 17) for the MT3 use case in R2. These updates include the addition of new functionalities and widgets.

Firstly, the Alert functionality was incorporated to notify users of any detections by AVAD. Additionally, an Audio player was introduced, allowing users to listen to audio recordings. Moreover, the mock-up now includes the police intervention functionality. Lastly, a Weather widget was integrated into the mock-up, providing real-time weather information for the monitored area. Furthermore, download options were included, allowing users to easily export the visualised data in their preferred format.

By incorporating these additions and improvements, the updated mock-up for the MT3 use case offer enhanced functionality, increased usability, and a more comprehensive approach to monitoring and managing parking lots.

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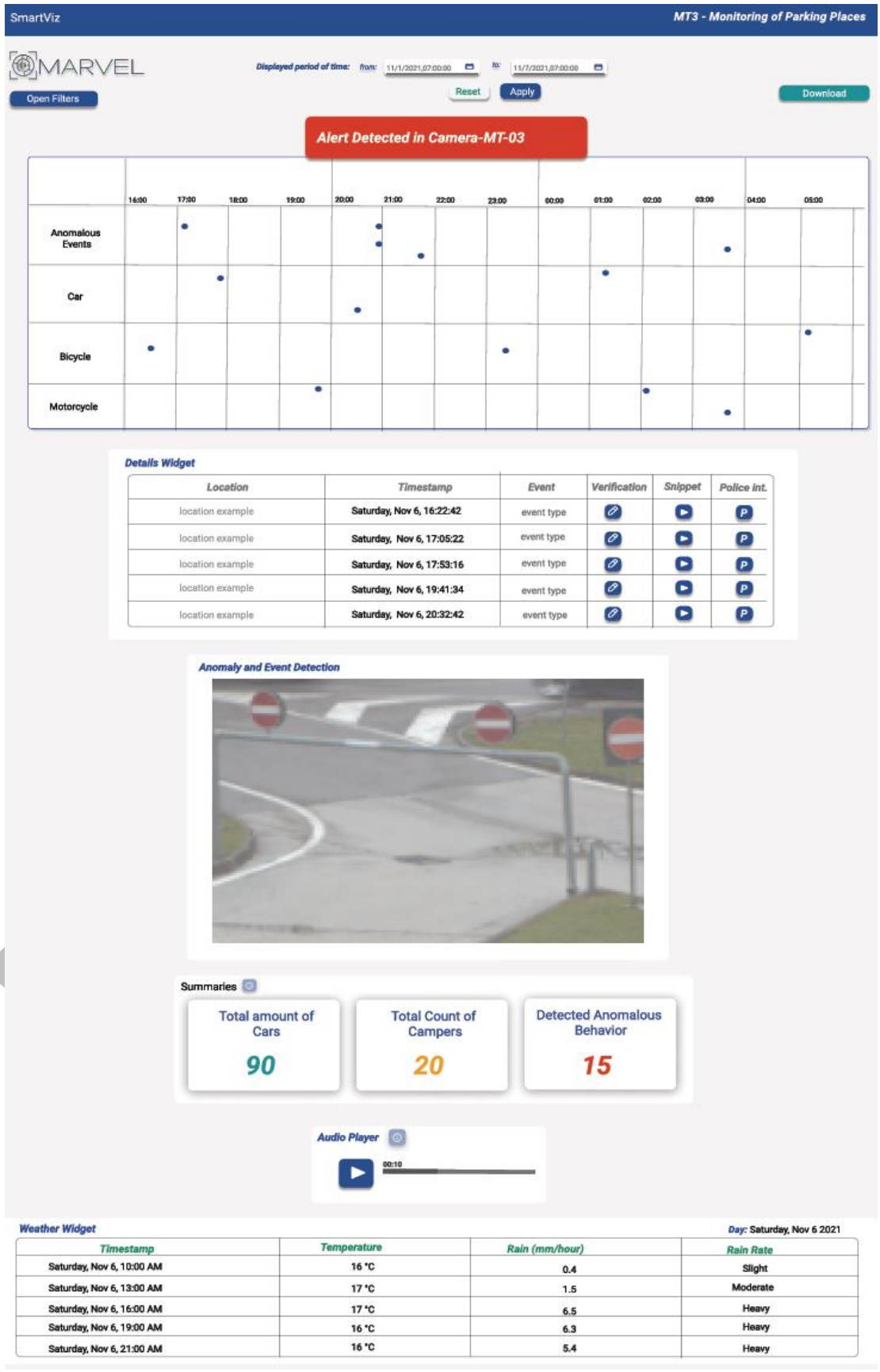

Figure 17: Mock-up screen of MT3 in DMT (R2)

3.2.1.5 UNS1 – Drone experiment – Mock-up screen

The pilot's vision on UNS1 aims to carry out crowd classification and crowd counting tasks. Please refer to section 3.1.9 for more information.

Within the user requirements set by the UNS team, the mock-up screen of this use case for R1 was formed as seen in Figure 18 below.

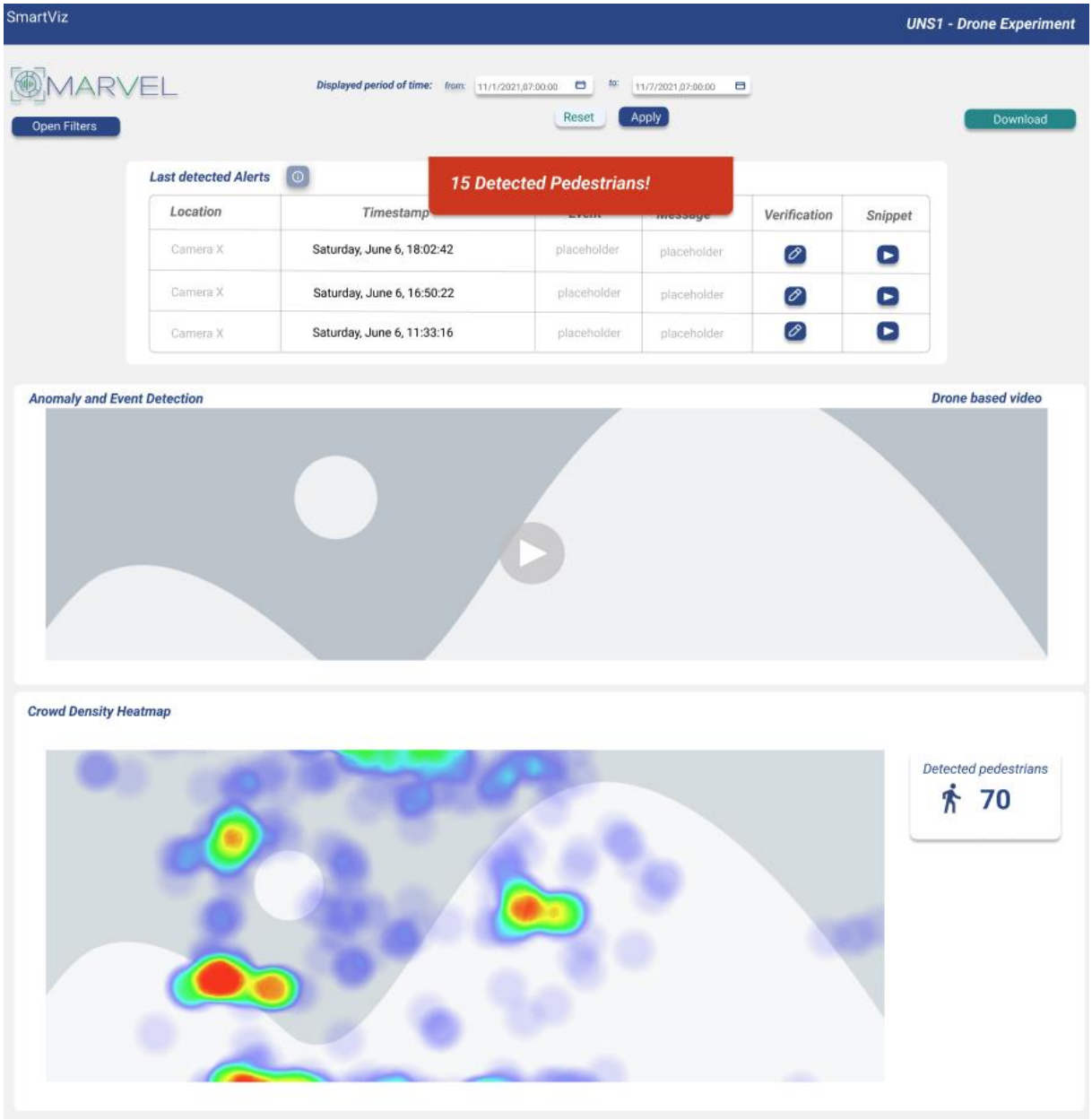

Figure 18: Mock-up screen of UNS1 in DMT (R1)

Based on valuable feedback from the pilots and to meet the user requirements for UNS1, the mock-up screen (Figure 19) has undergone several enhancements for R2. These updates specifically include the inclusion of an Audio player, Summaries widget and a Weather widget. The Audio player functionality has been incorporated to allow users to play audio recordings associated with specific events or incidents. These enhancements align with the feedback

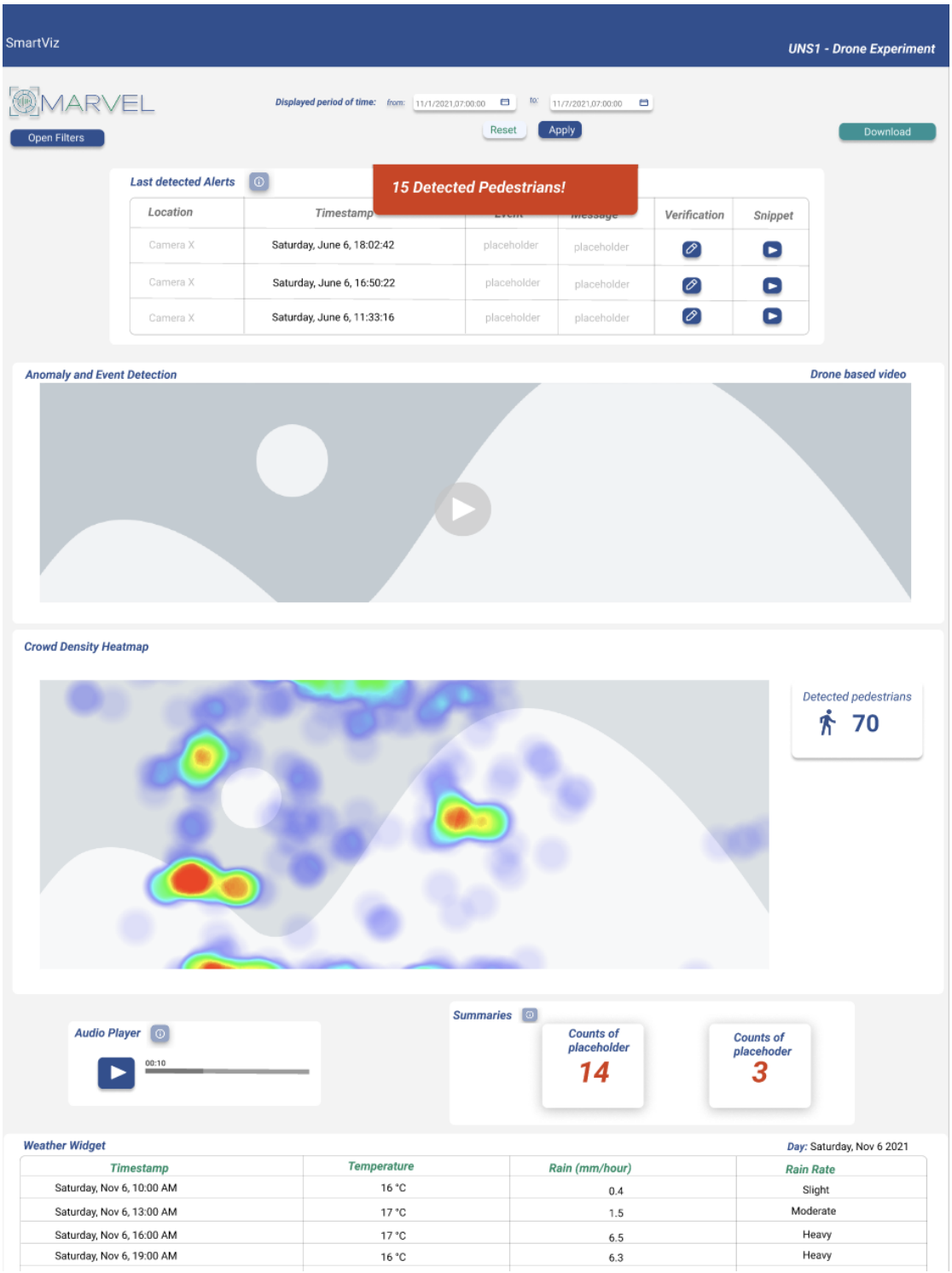

Figure 19: Mock-up screen of UNS1 in DMT (R2)

received from the pilots and aim to provide users with a more robust and user-friendly experience.

3.2.2 R2 use cases

3.2.2.1 GRN1– Safer Roads – Mock-up screen

The GRN1 use case aims at increasing safety for vulnerable road users and promoting active travel modes in Malta. The user journey for this use case was designed by GRN. Please refer to section 3.1.1 for more information. ZELUS interpreted the user journey and created a mock-up screen in order to address all the user requirements.

Then the collaboration between GRN and ZELUS involved discussions on layout, widgets, and visualisations that would effectively present the information to the users. By combining their expertise, the teams were able to finalise the mock-up screen of the DMT (Figure 20) to be developed by ZELUS that fulfils the needs of VRU and is aligned with the goals of the MARVEL platform. The dashboard layout, as seen in the mock-up screen, provides users with real-time alerts and detailed information through the MARVEL infrastructure. Users can view alerts in a detailed manner and request video snippets of the detected alerts, which can be played on the Video player. The Summary widget displays the total count of alerts for easy reference. Furthermore, users have the option to download the data for offline access. Additionally, the weather information widget provides users with relevant weather data for the monitored area.

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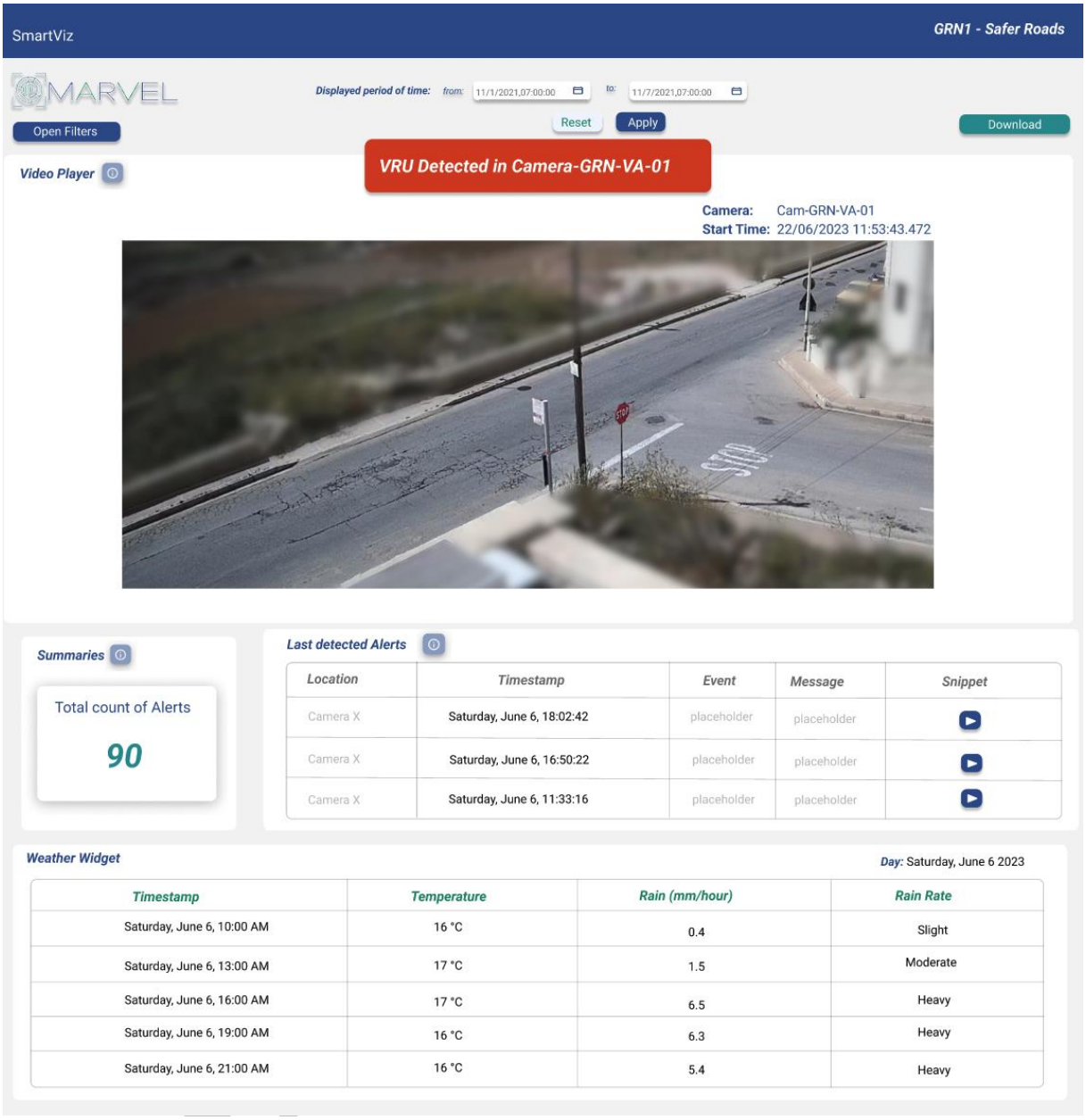

Figure 20: Mock-up screen of GRN1 in DMT (R2)

3.2.2.2 GRN2 – Road User Behaviour – Mock-up screen

As shown in Section 3.1.2, ZELUS interpreted this user journey and created a mock-up screen that addresses all the user requirements. The collaboration between GRN and ZELUS involved extensive discussions on layout, widgets, and visualisations that effectively present the information to the users. By combining their expertise, the teams finalised the mock-up screen of the DMT (Figure 21) to be developed by ZELUS, which fulfils the requirements of vulnerable road users and aligns with the objectives of the MARVEL platform.

The dashboard layout, showcased in the mock-up screen, offers users a comprehensive view of important information by enabling a side-by-side comparison of two time periods. It provides insights into the amounts of improper behaviour, as well as the counts of detected anomalies and events identified by MARVEL's AI models.

Graphs and tables are employed to present the detected events, and users have the option to request additional data from multiple time periods for further analysis. The dashboard also supports the downloading of visualised data and provides access to relevant weather information. Furthermore, users can delve deeper into the detections and access audio-visual results associated with them, enhancing their understanding of the detected incidents.

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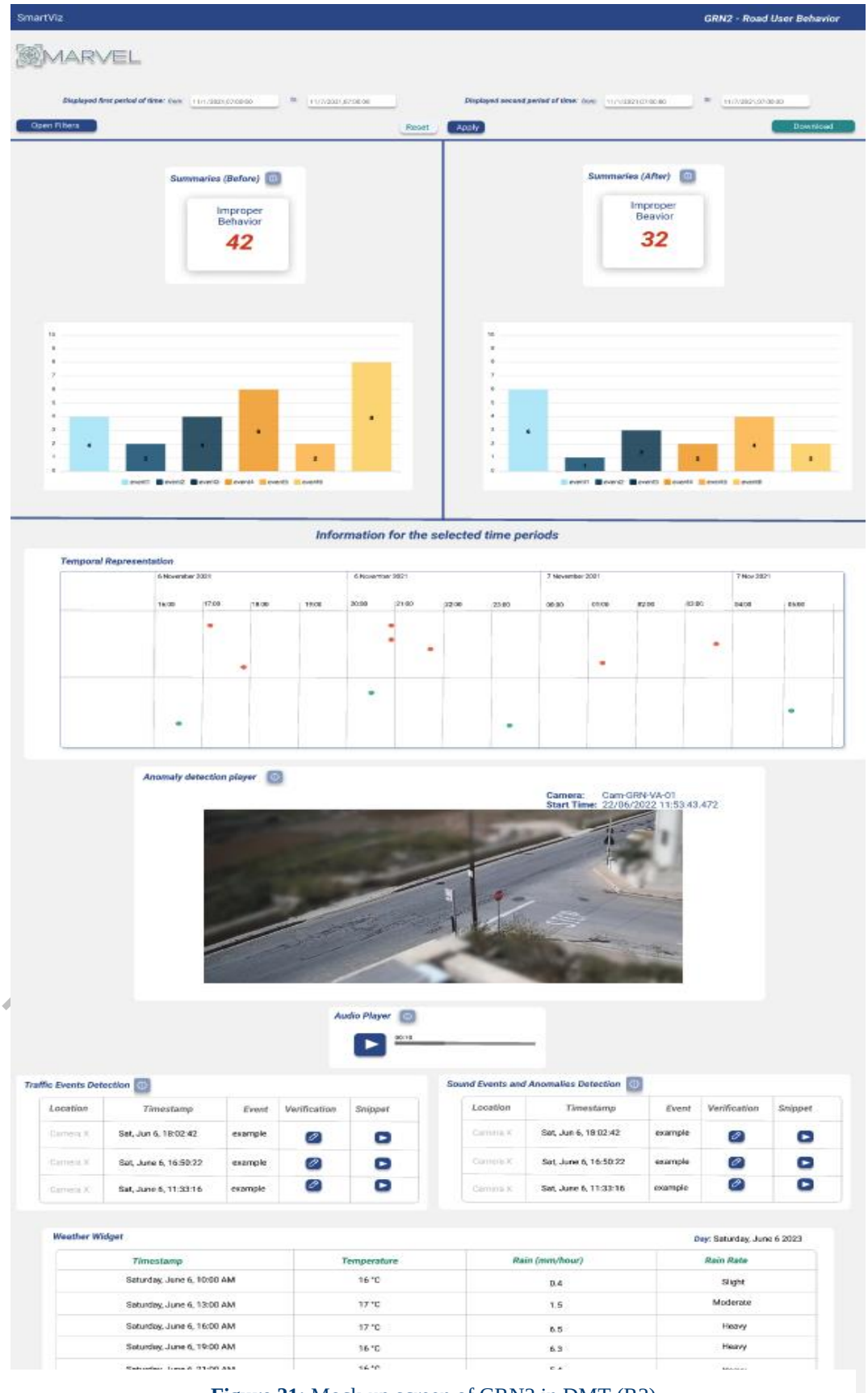

Figure 21: Mock-up screen of GRN2 in DMT (R2)

3.2.2.3 MT2 – Detecting criminal and anti-social behaviours – Mock-up screen

As mentioned in section 3.1.6, MT designed the user journey of the MT2 use case to meet the needs of the local police authorities in identifying potentially dangerous situations and monitoring criminal and antisocial behaviours.

ZELUS then interpreted this user journey and created a mock-up screen that addresses all the user requirements. The collaboration between MT and ZELUS involved extensive discussions on layout, widgets, and visualisations that effectively present the information to the users. The teams finalised the mock-up screen of the DMT (Figure 22) to be developed by ZELUS, which fulfils the requirements of vulnerable road users and aligns with the objectives of the MARVEL platform.

The mock-up screen of the DMT for the MT2 use case presents a comprehensive view of important information derived from detections. The Summaries widget was chosen to display total numbers of detected events and anomalies, along with the statistics for the detected behaviours within the selected time period. A Word Cloud widget is utilised to visualise information related to the most frequently used captions describing the detections. Additional details regarding anomalies and events are presented in a dedicated details widget. The dashboard also offers the functionality to download the visualised data and provides access to relevant weather information. The DMT mock-up also allows users to access audio-visual results associated with the detections.

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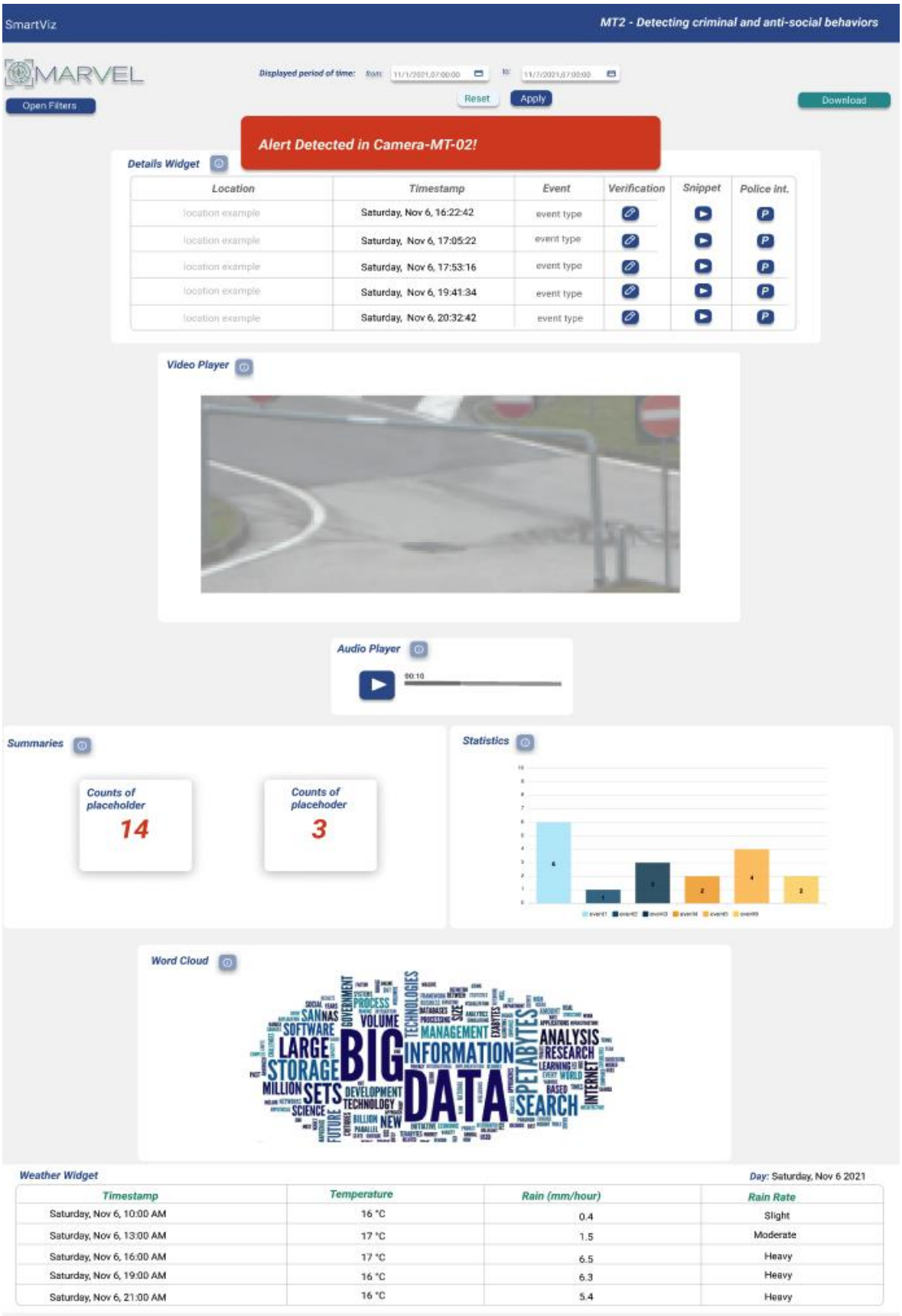

Figure 22: Mock-up screen of MT2 in DMT (R2)

3.2.2.4 MT4 – Analysis of a Specific Area – Mock-up screen

MT designed the user journey of the MT4 use case to meet the needs of the local police authorities and the MT Policy Maker/Mobility manager. Please refer to section 3.1.8 for more information

ZELUS then interpreted this user journey and created a mock-up screen that addresses all the user requirements. The collaboration between MT and ZELUS involved extensive discussions on layout, widgets, and visualisations that effectively present the information to the users. The teams finalised the mock-up screen of the DMT (Figure 23) to be developed by ZELUS.

The selected visualisation widgets showcased in the mock-up screen effectively address the user requirements for this use case. The timeline provides a clear distribution of the detected events across time. The Details widget presents comprehensive information about the detected anomalies and events. The Statistics widget visualises the statistics related to anomalies and events. The Trajectories widget allows users to observe the paths followed by the detected vehicles in the monitored area. The dashboard also offers the functionality to download the visualised data. Additionally, the integration of relevant weather information within the dashboard helps provide contextual information. The capability to access audio-visual results associated with detections enhances the user's understanding of the incidents.

Overall, the selected visualisation widgets effectively address the user requirements by providing comprehensive insights, facilitating data analysis, and enhancing decision-making in relation to the detected incidents.

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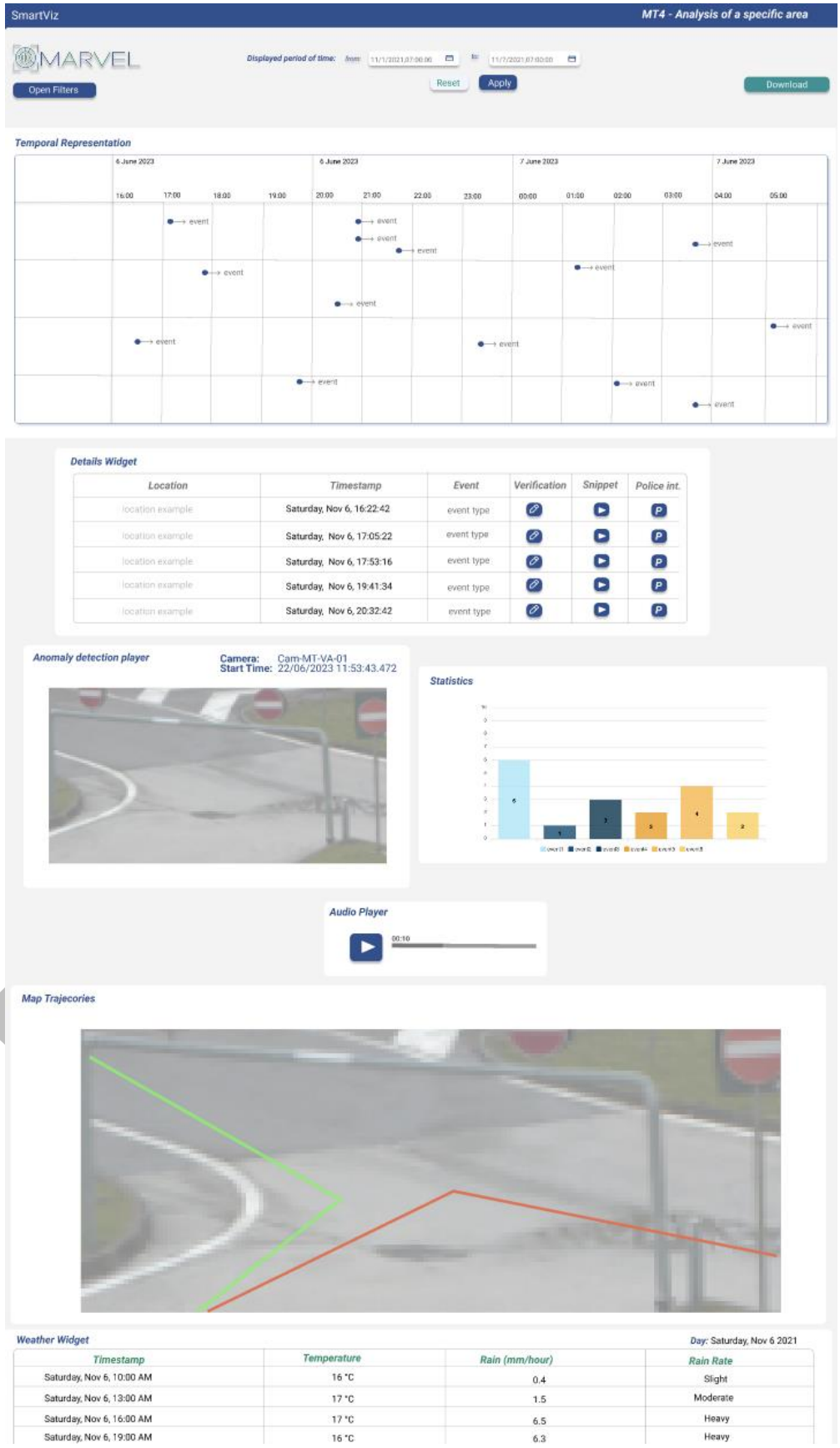

Figure 23: Mock-up screen of MT4 in DMT (R2)

3.2.2.5 UNS2 – Localising audio events in crowds – Mock-up screen

The objective of UNS2 for the R2 release is to provide sound event monitoring and alerts to the user. Please refer to section 3.1.10 for more information.

To address these user requirements, the collaboration between UNS and ZELUS resulted in the creation of a mock-up screen of the DMT (Figure 24) that effectively fulfils the needs of the users. Extensive discussions between the teams were conducted to determine the optimal layout, widgets, and visualisations that would present the information in the most effective manner.

This collaboration between UNS and ZELUS demonstrates a translation of user requirements into a practical mock-up screen design, ensuring that the DMT meets the needs of the users and supports the objectives of the MARVEL platform.

The dashboard layout, showcased in the mock-up screen, offers users a comprehensive view of important information by interpreting the user requirements. The creation of the Sound Localisation map widget allows the users to visualise the direction of the sound event detected. Additional information regarding the events is visualised through the Details widget. The dashboard also supports the download of visualised data and provides access to relevant weather information. Furthermore, users can delve deeper into the detections and access audio-visual results associated with them, enhancing their understanding of the detected incidents.

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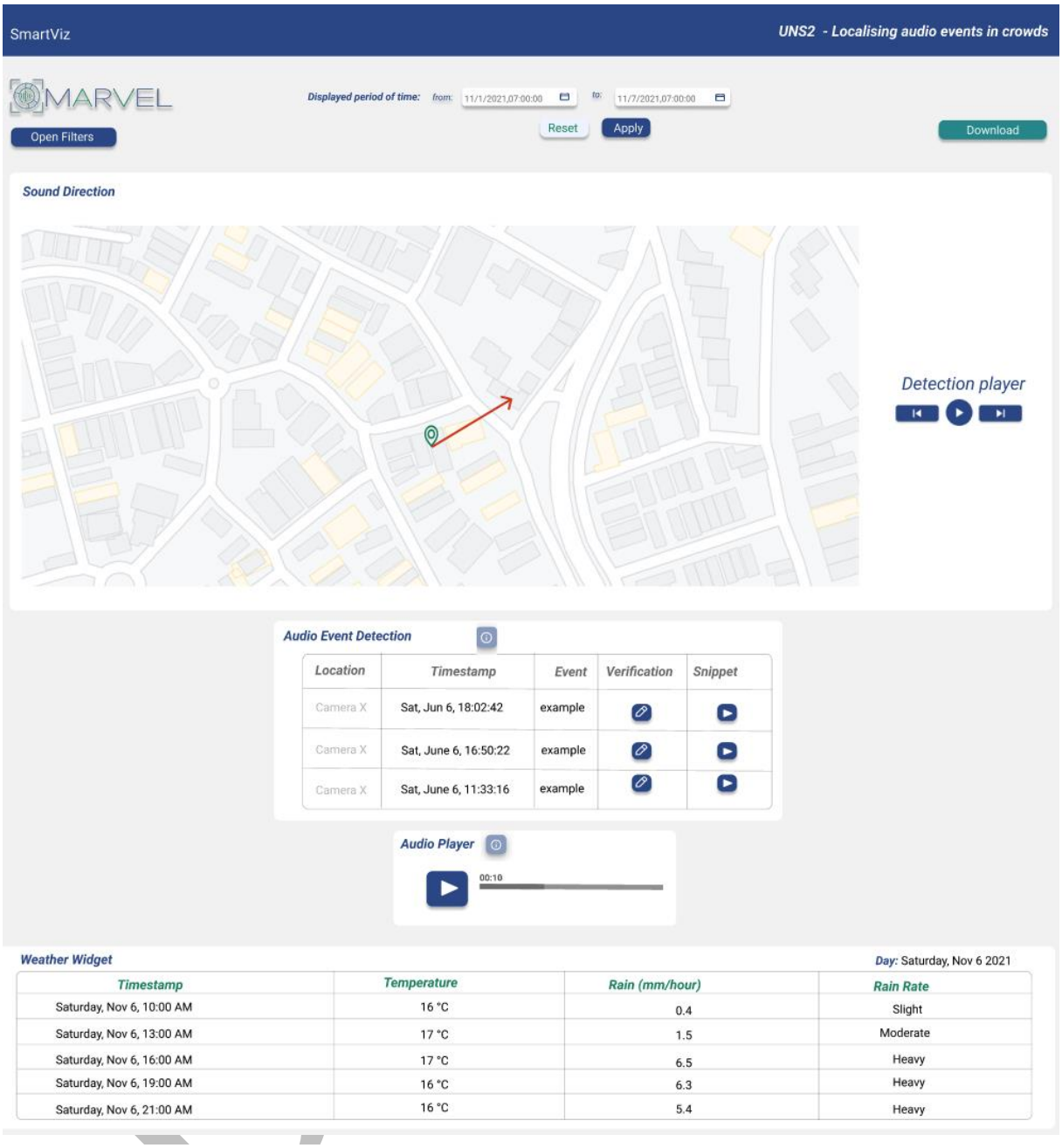

Figure 24: Mock-up screen of UNS2 in DMT (R2)

4 Demonstration

In this section, we present the demonstrator that emphasises the services offered from the perspective of end users. We highlight the role of the DMT as a tool for visualising the relevant data that has been collected, processed, and the detected events within the MARVEL project.

For each use case, we describe and showcase concrete screens from the DMT, demonstrating how the output of MARVEL's AI components is utilised and illustrating the final outcomes. The demonstrator showcases how the DMT acts as a user interface, enabling the visualisation of the data and events that are relevant to each specific use case.

4.1 GRN1 – Safer Roads

As described in section 3.1.1, GRN1 focuses on increasing safety for vulnerable road users, specifically cyclists and pedestrians in Malta with the aim of promoting active travel modes.

To achieve the goal of this use case, a low-latency road traffic sign is employed, which illuminates to alert drivers whenever a vulnerable road user is detected. The detections by YOLO-SED are also transmitted to the MARVEL platform for visualisation in SmartViz, enabling remote monitoring of the situation.

The dashboard of the DMT showcased in Figure 25 below links to the implemented user case.

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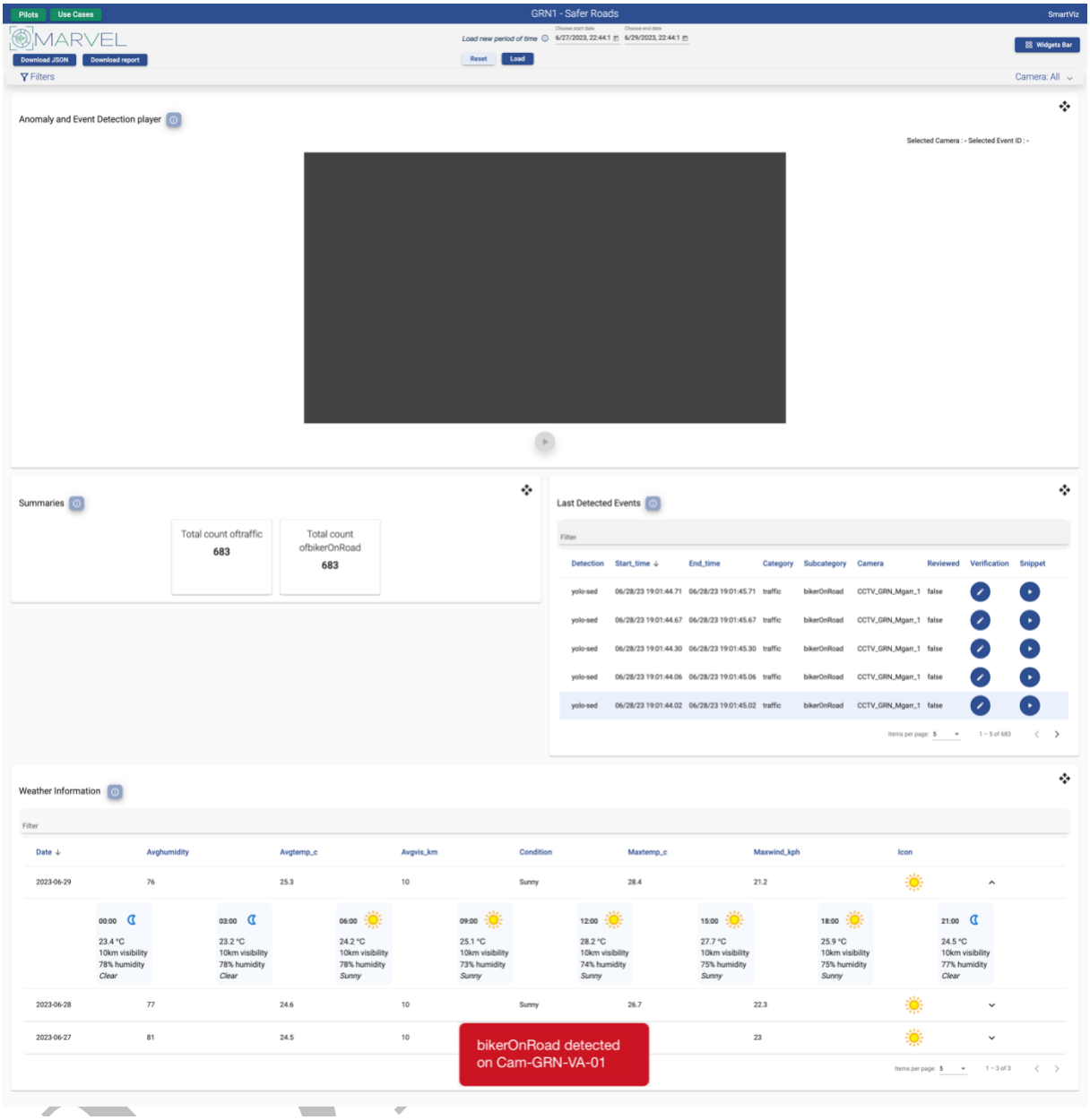

Figure 25: GRN1 dashboard on DMT

The real-time alerts are detected by YOLO-SED and served to SmartViz through Kafka messages by the Data Fusion Bus (DFB) component. Then they are visualised by the Alerts widget to facilitate a quick response from the users' perspective so they can take appropriate actions. The alerts are also visualised in a textual format in the Details widget with title "Last detected events". The data feeding this widget are historical and accessed through an Elastic search database which is constantly updated by the audio, visual, and multimodal AI subsystem components.

Within SmartViz, users have the capability to select an event displayed in the widget and play the corresponding video snippet. This functionality is facilitated by StreamHandler, which responds to the request by retrieving the video from the camera stream within the relevant time

period of the detection. The stream is segmented, and a URL containing the video for the selected event is generated. This video is then played in SmartViz within the "Anomaly and Event Detection player" widget.

When users view the video associated with the event, they can validate the inference result by marking them as accurate or not. This validation process contributes to the continuous improvement of the system and the training of AI models. The inference result verification is sent through Kafka messages by SmartViz to DFB which then updates the status of the corresponding event and stores them in an Elastic search index accessed by the Data Corpus.

In addition to rearranging and resizing widgets, the dashboard view also includes a functionality for users to download the visualised data in JSON format. This feature allows users to easily retrieve and utilise the data for further analysis and reference purposes. Furthermore, users have the option to save the entire dashboard as a PDF file, enabling offline access and sharing according to their individual preferences.

Finally, the Weather information widget included in this use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period. By visualising weather variables such as visibility, humidity, temperature, and overall weather conditions, users can gain insights and uncover hidden correlations between detections of events and anomalies and weather data that may influence them.

4.2 GRN2 – Road user behaviour

As described in section 3.1.2, the goal of GRN2 is to monitor the behaviour of road users at a junction in order to support law enforcement and educational campaigns focused on responsible driving, cycling, and other road uses.

The use of the AI models through MARVEL, enables the automatic detection of common bad behaviours, allowing for accurate counts and comparison of occurrences over time. The SmartViz platform (Figure 26) displays the detected behaviours, allowing users to select two time periods and access a Comparison view.

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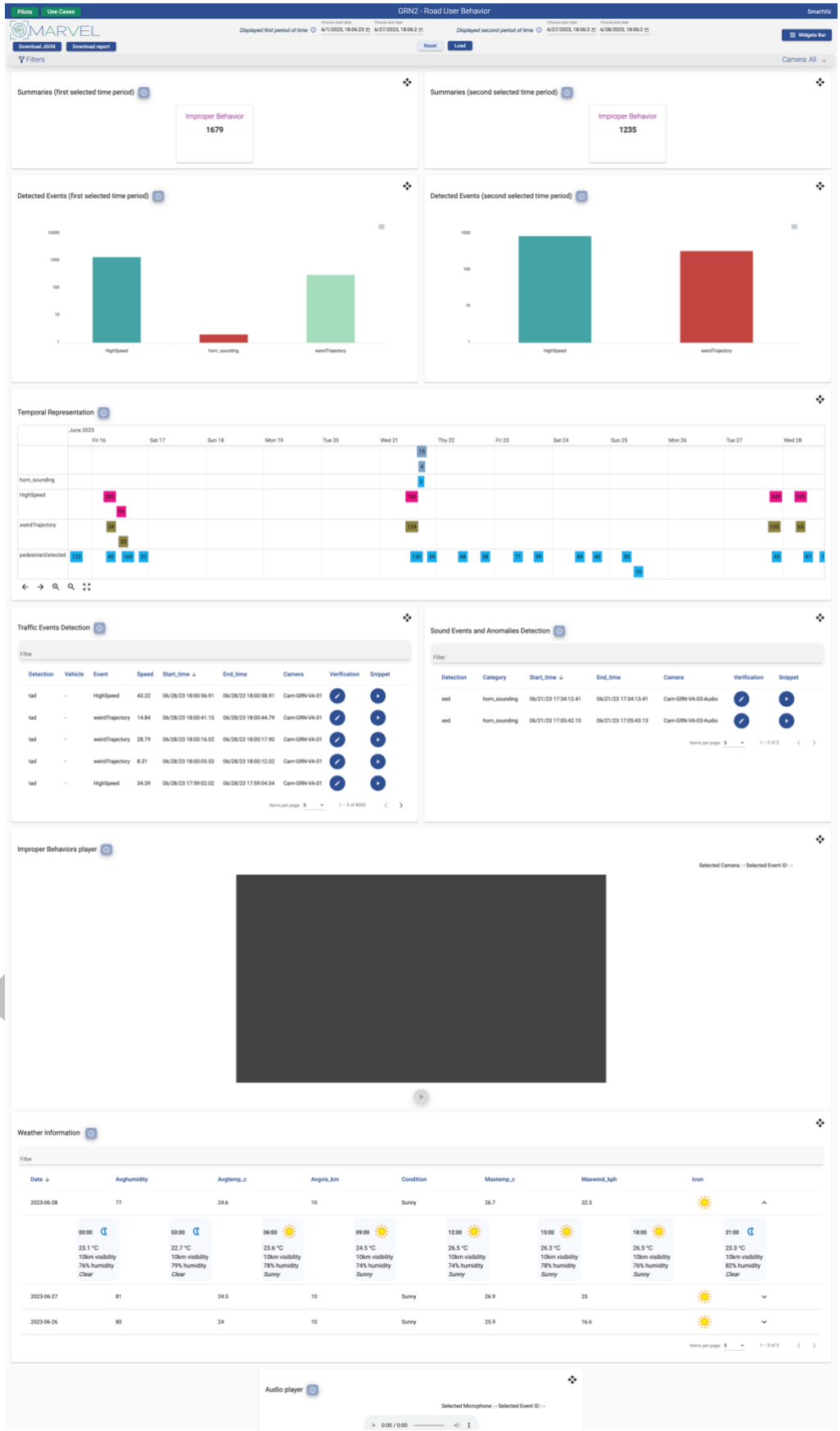

Figure 26: GRN2 dashboard on DMT

The Summaries widget showcases the total number of detected anomalies, utilising outputs from Sound Event Detection (SED), Rule-Based Anomaly Detection (RBAD), and only the anomalous events of Traffic Anomaly Detection (TAD). The Statistics widget presents bar charts indicating the total number of detections per anomalous event.

The Temporal Representation widget presents the information of detections by all AI components utilised in this use case in a temporal form. The Details widget visualises the detections in a textual format, with CATflow and TAD displayed in the “Traffic Events detection” table and RBAD and SED displayed in the "Sound events and anomalies detection."

The data feeding all widgets in this use case are historical and accessed through an Elastic search database which is constantly updated by the audio, visual, and multimodal AI subsystem components.

Within the audio and video player functionality in SmartViz, users can select an event and play the corresponding snippet. This feature is facilitated by the StreamHandler component, which retrieves a stream for the relevant time period of the detection. The stream is segmented, and a URL containing the snippet for the selected event is played in the Audio or Video player widget within SmartViz.

The users can validate the inference result by marking them as accurate or not. The inference result verification is sent through Kafka messages by SmartViz to DFB which then updates the status of the corresponding event and stores them in an Elastic search index accessed by the Data Corpus.

In addition to rearranging and resizing widgets, the dashboard view also includes functionality for users to download the visualised data in JSON format. Furthermore, users have the option to save the entire dashboard as a PDF file, enabling offline access and sharing according to their individual preferences.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period.

4.3 GRN3 – Traffic Conditions and Anomalous Events

The goal of GRN3, as part of the R1 integration, is to monitor traffic conditions and detect anomalous events. Please refer to section 3.1.3 for the description of this use case. The full version of the demonstrator for R1 can be found in Deliverable 4.3, Section 5.1.1.

In Figure 27 below you can see the final dashboard for GRN3.

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Figure 27: GRN3 dashboard on DMT

SmartViz in this use case incorporates both real-time and historical data feeds. The real-time messages generated by AVAD are transmitted to SmartViz through Kafka messages via the DFB. These real-time messages are utilised to populate and update the real-time map representation, providing immediate visibility into ongoing traffic anomalous events. On the other hand, the visualisations of the rest inference result in this use case draw upon the constantly updated historical data stored in the Elastic search database.

Building upon the feedback from end users, several changes and additions were made for the R2 integration. Most of the modifications were implemented in the statistics widget, which now includes multiple charts. The updated statistics widget features two line charts—one for Low-speed events and another for High-speed events—highlighting the five highest speeds detected. Users can zoom in and hover over the peaks to view additional information such as the exact speed and timestamp of each event. Additionally, a bar chart has been introduced to display the output of Low and High speed events, along with the calculated average speed detected by TAD. The pie chart for Audio-Tagging (AT) visualisation has been replaced with a bar chart, offering a more user-friendly and clear representation of the different entities and their corresponding numbers.

Furthermore, the total number of detected pedestrians, calculated by CATflow, has been included.

To enhance the organisation and relevance of events, the details widget has been split into two widgets: "Audio-visual anomaly detection," which visualises data from AVAD and AT, and "Traffic events detection," which visualises CATflow and TAD events.

The addition of the Audio player widget is also included in R2 for GRN3. Within the audio player functionality in SmartViz, users can select an event detected in a microphone stream and play the corresponding audio snippet. This feature is facilitated by the StreamHandler component, which retrieves the audio from the microphone stream for the relevant time period of the detection. The audio stream is segmented, and a URL containing the audio for the selected event is played in the Audio player widget within SmartViz.

The functionality to rearrange and resize widgets, download visualised data in JSON format, and save the dashboard as a PDF file has also been incorporated into this use case, providing users with greater flexibility and options for data analysis and offline access.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period. By visualising weather variables such as visibility, humidity, temperature, and overall weather conditions, users can gain insights and uncover hidden correlations between detections of events and anomalies and weather data that may influence them.

4.4 GRN4 – Junction Traffic Trajectory Collection

GRN4, as part of the MVP and R1 integration, is focused on the requirement of long-term data analytics that shed light on both the behaviour of road users (e.g., car drivers, motorcyclists, cyclists, pedestrians, etc.) and on gathering traffic statistics on road network junctions. The full version of the demonstrator for R1 can be found in Deliverable 4.3, Section 5.1.2.

Based on the feedback from end users, the R2 visualisations in SmartViz (Figure 28) of the use case involved some minor changes and additions.

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Figure 28: GRN4 dashboard on DMT

The updated statistics widget now features a bar chart instead of a pie chart for the visualisation of CATflow, offering a more user-friendly and clear representation of the different entities and their corresponding numbers. Additionally, the total number of detected pedestrians, calculated by CATflow, has been included as part of the use case. This provides users with a comprehensive overview of pedestrian-related data and insights.

To improve the organisation and relevance of events, the details widget has been divided into two separate ones. The "Sound Event detection" widget visualises data from SED, while the "Traffic events detection" widget displays CATflow and TAD events.

Moreover, the functionality to rearrange and resize widgets, download visualised data in JSON format, and save the dashboard as a PDF file has been incorporated, providing users with greater flexibility and options for data analysis and offline access.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period. By visualising weather variables such as visibility, humidity, temperature, and overall weather conditions, users can gain insights and uncover hidden correlations between detections of events and anomalies and weather data that may influence them.

4.5 MT1 – Monitoring of Crowded Areas

MT1, as part of the R1 integration, is focused on the selection of views of areas of interest for monitoring situations such as exceptional crowd, suspect or unusual crowd movements, etc. The full version of the demonstrator can be found in Deliverable 4.3, Section 5.1.3.

Building upon the feedback from end users, several changes and additions were made to the MT1 dashboard (Figure 29) for the R2 integration.

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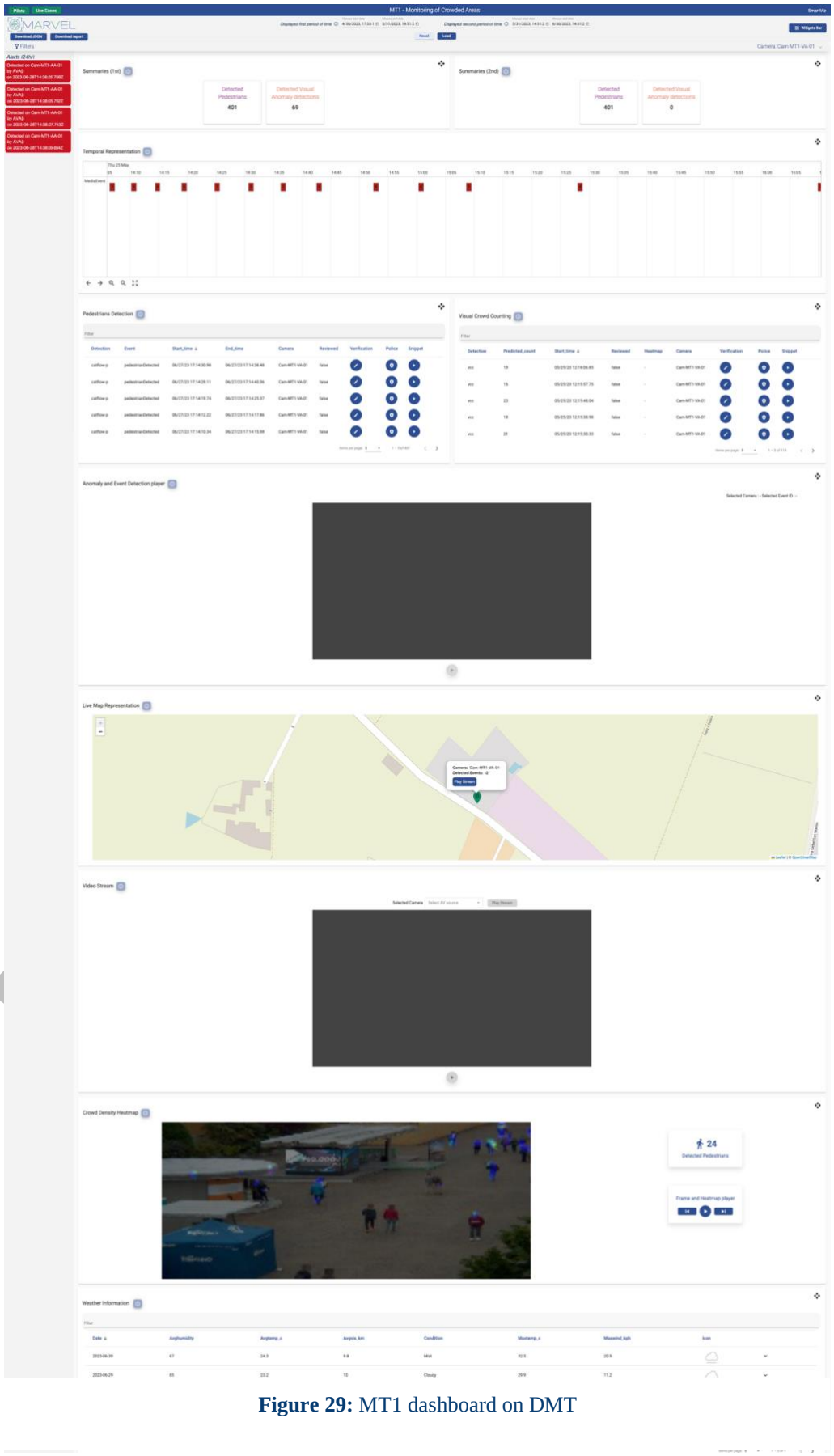

Figure 29: MT1 dashboard on DMT

The Alerts widget has been integrated into this use case to address the user's requirement of being alerted when the number of people present exceeds a predetermined maximum limit (80 people in Piazza Fiera and 80 in Piazza Duomo). Real-time alerts are detected by VCC and Visual Anomaly Detection (ViAD) and then transmitted to SmartViz through Kafka messages via the DFB component. These alerts are then visualised in the Alerts widget, enabling users to quickly respond and take appropriate actions based on the detected anomalies.

To facilitate comparative analysis, the comparison view has been integrated into the MT1. In SmartViz, users can select two different time periods and observe the events in different contexts, allowing for a comprehensive understanding of temporal patterns and changes.

The police intervention functionality is also included in the use case. After reviewing the events, users can mark an event as important and in need of police intervention.

In addition, the VCC component provides data on each frame of a video, indicating the likelihood of a pedestrian being present at that specific point. To visualise this data, the Crowd Density Heatmap has been added to the dashboard of this use case. The Crowd Density Heatmap widget overlays the heatmap onto the original frames, offering a visual representation of the crowd density.

Furthermore, the functionality to rearrange and resize widgets, download visualised data in JSON format, and save the dashboard as a PDF file has been incorporated into the system.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period. By visualising weather variables such as visibility, humidity, temperature, and overall weather conditions, users can gain insights and uncover hidden correlations between detections of events and anomalies and weather data that may influence them.

4.6 MT2 – Detecting Criminal and Anti-Social Behaviours

As was described in Section 3.1.6, this use case is focused on detecting criminal and anti-social behaviours, detecting possible dangerous situations such as robberies, aggressions, etc. In this use case, the integration of AI models through MARVEL allows for the automatic detection of criminal and anti-social behaviours. SmartViz displays these detections in a dedicated dashboard (Figure 30).

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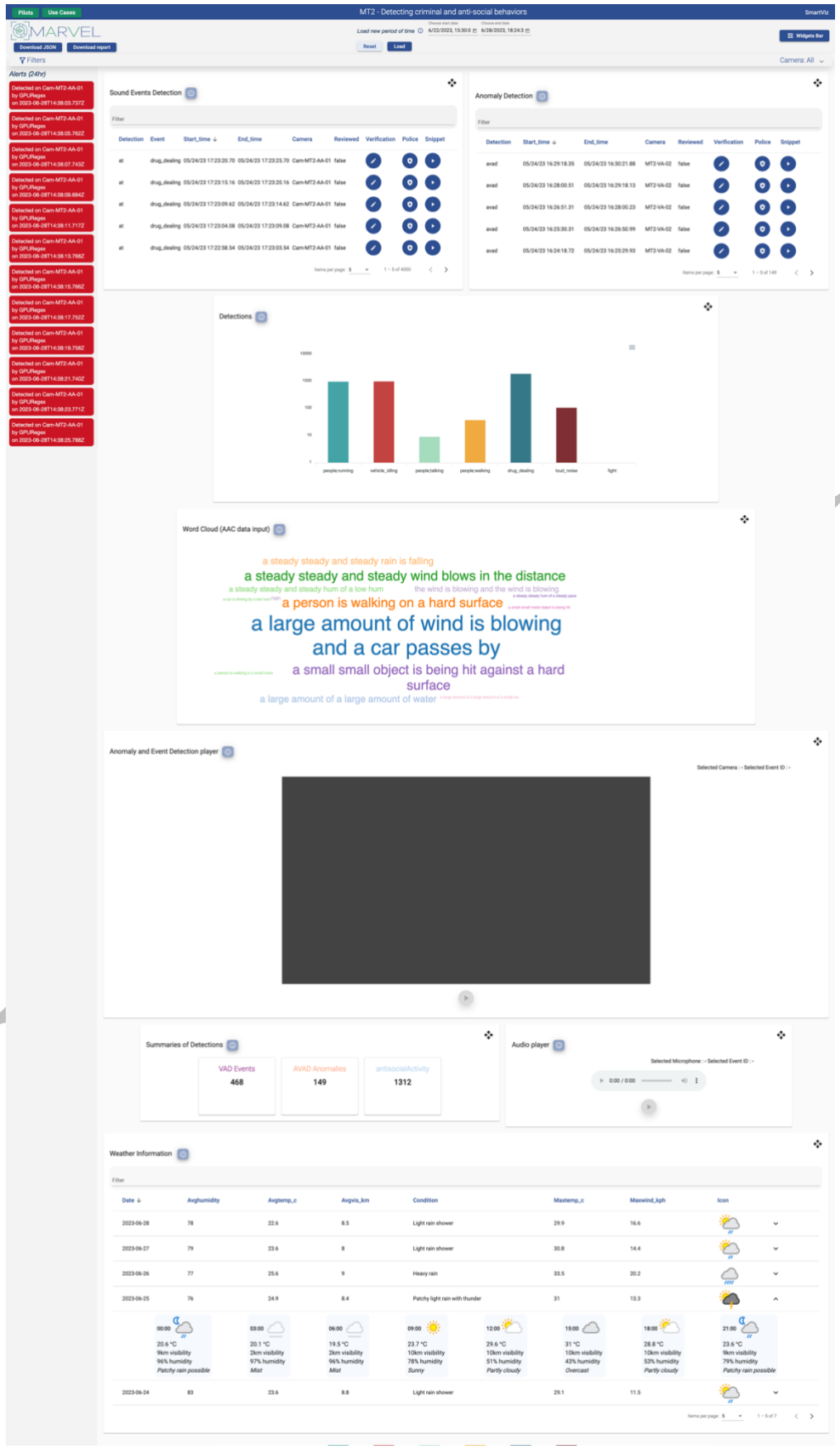

Figure 30: MT2 dashboard on DMT

The Alerts widget has been integrated into this use case to address the user's requirement of being alerted when an anomaly occurs. Real-time alerts are detected by GPURegex and transmitted to SmartViz through Kafka messages via the DFB component. These alerts are then visualised in the Alerts widget, enabling users to quickly respond and take appropriate actions based on the detected anomalies.

The Summaries widget provides an overview of the total number of detected anomalies and events, utilising outputs from SED, GPURegex and AVAD components.

The Word Cloud widget, developed specifically for the AAC component, allows users to visualise the most common keywords and descriptions associated with the detected events.

Within the audio and video player functionality in SmartViz, users can select an event and play the corresponding audio or video snippet. The StreamHandler component retrieves the stream for the relevant time period of the detection, segments it, and plays the snippet in the Audio or Video player widget within SmartViz.

The Details widget visualises the detections in a textual format, with SED and AT displayed in the "Sound events and anomalies detection" table and AAC displayed in the "Anomalous Audio Captioning" table.

Users have the ability to validate the inference results by marking them as accurate or not. The verification of inference results is sent through Kafka messages from SmartViz to the DFB, which then updates the status of the corresponding event and stores them in an Elasticsearch index accessed by the Data Corpus. The police intervention functionality is also included in the use case. After reviewing the events, users can mark an event as important and in need of police intervention, facilitating appropriate action.

In addition to rearranging and resizing widgets, the dashboard view offers the functionality to download the visualised data in JSON format. Furthermore, users have the option to save the entire dashboard as a PDF file, allowing for offline access and convenient sharing based on individual preferences.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period. By visualising weather variables such as visibility, humidity, temperature, and overall weather conditions, users can gain insights and uncover hidden correlations between detections of events and anomalies and weather data that may influence them.

4.7 MT3 – Monitoring of Parking Places

As was described in section 3.1.7, this use case is focused on the prevention of robberies or damages to vehicles parked in a monitored parking place and the examination of anomalous behaviours and events. This use case was integrated in R1 and has been updated for this release. The full version of the demonstrator of R1 can be found in Deliverable 4.3, Section 5.1.4. Building upon the feedback from end users, several changes and additions were made to the R2 dashboard of MT3 (Figure 31).

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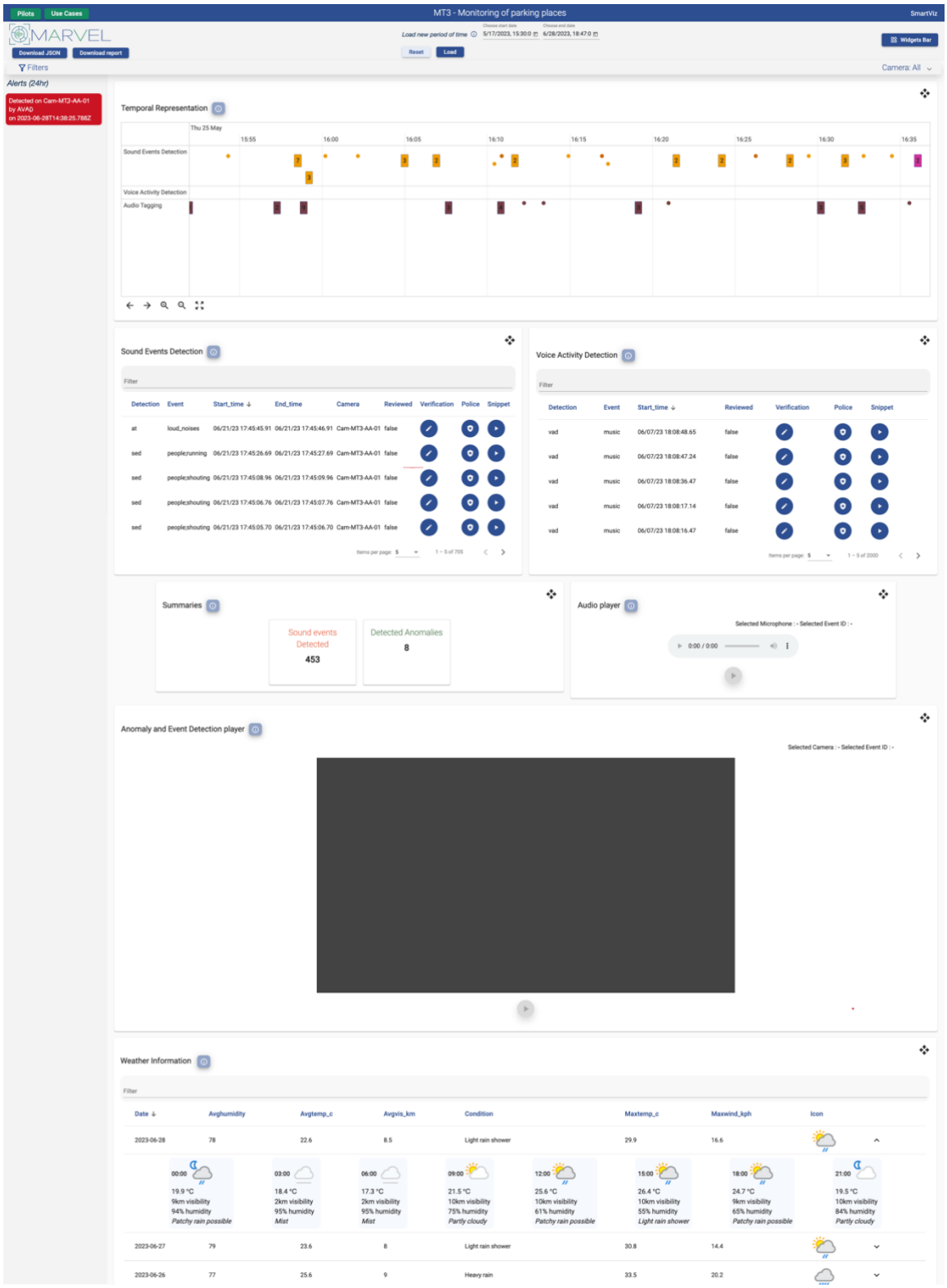

Figure 31: MT3 dashboard on DMT

The Alerts widget has been integrated into this use case to address the user's requirement of being alerted when an anomaly occurs. Real-time alerts are detected by AVAD and transmitted

to SmartViz through Kafka messages via the DFB component. These alerts are then visualised in the Alerts widget, enabling users to quickly respond and take appropriate actions based on the detected anomalies.

The addition of the Audio player widget is also included in R2 for MT3 since AT and SED are dealing particularly with audio streams. Within the audio player functionality in SmartViz, users can select an event detected in a microphone stream and play the corresponding audio snippet. This feature is facilitated by the StreamHandler component, which retrieves the audio from the microphone stream for the relevant time period of the detection. The audio stream is segmented, and a URL containing the audio for the selected event is played in the Audio player widget within SmartViz.

The police intervention functionality is also included in the use case. After reviewing the events, users have the ability to mark an event as important and in need of police intervention.

Moreover, the functionality to rearrange and resize widgets, download visualised data in JSON format, and save the dashboard as a PDF file has been incorporated, providing users with greater flexibility and options for data analysis and offline access.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period.

4.8 MT4 – Analysis of a Specific Area

The dashboard for the MT4 use case is offered to a policy-maker/mobility manager and also to a local police officer in a single dashboard depicted in Figure 32 to combine information and explore the available data and analysis. Please refer to section 3.1.8 for more information on the user requirements of this use case.

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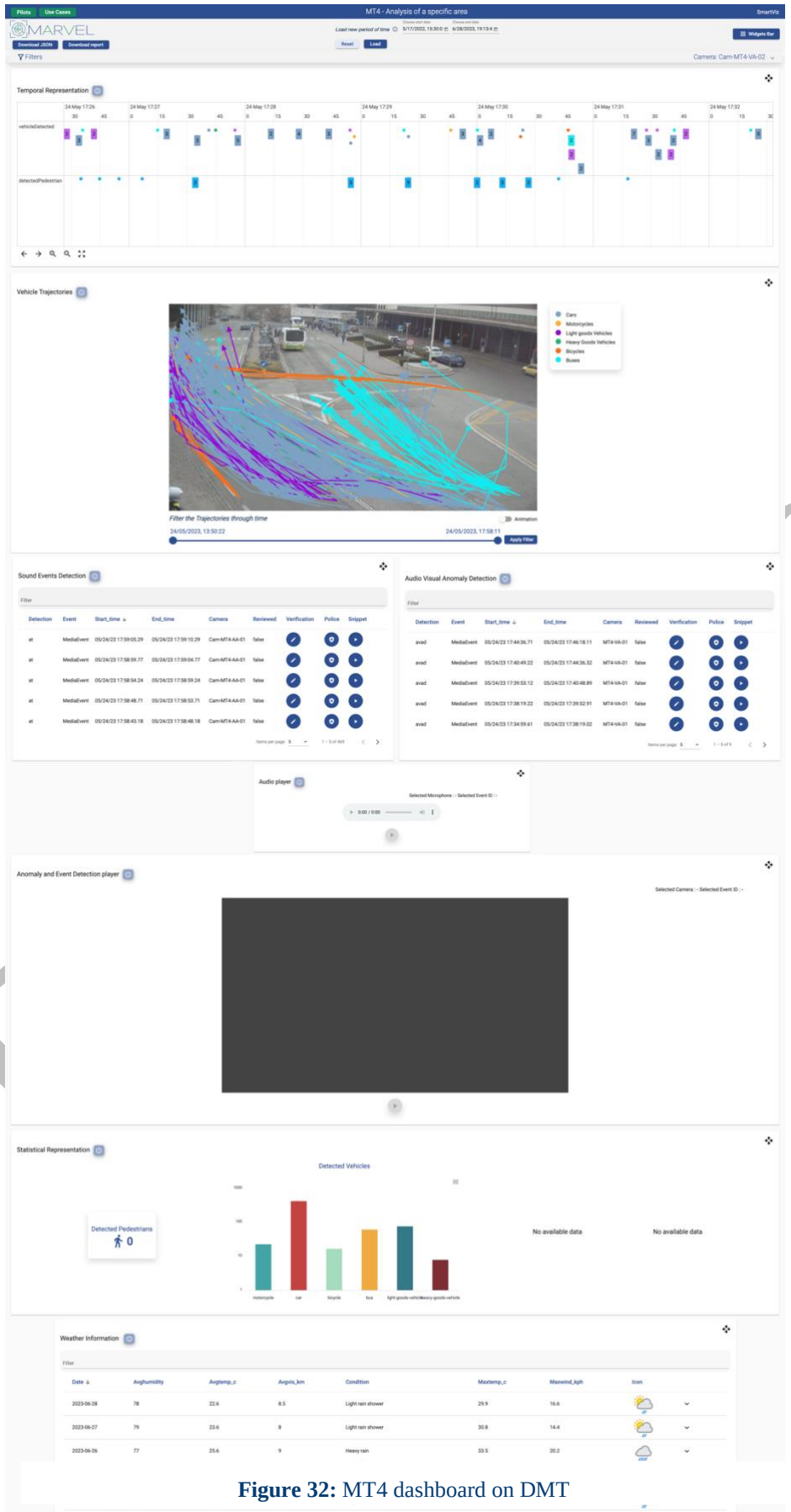

Figure 32: MT4 dashboard on DMT

The detections are visualised across time in order to be monitored and clustered using the temporal representation widget. To illustrate the trajectories of the detected vehicles and detailed information, we used the Vehicle Trajectories widget. In this widget, the paths of the passing vehicles that are detected by the CATflow component are drawn in the image of the camera feed that is recording them. The paths are grouped and colour-coded depicting different types of vehicles. The users are also able to change the time period and filter by the type of vehicle or lane to further investigate.

In the Statistics widget, available information regarding the AI models detections are visualised to give the users an analysis of the occurrences.

Furthermore, detailed available information about the detected incoming events is represented in a tabular form in the Details Widget. This widget also supports a standalone text filtering capability in order to facilitate a rapid search through the available information.

Within the audio and video player functionality in SmartViz, users can select an event and play the corresponding audio or video snippet. The StreamHandler component retrieves the stream for the relevant time period of the detection, segments it, and plays the snippet in the Audio or Video player widget within SmartViz.

Users have the ability to validate the inference results by marking them as accurate or not. The police intervention functionality is also included in the use case. After reviewing the events, users can mark an event as important and in need of police intervention, facilitating appropriate action.

In addition to rearranging and resizing widgets, the dashboard view offers the functionality to download the visualised data in JSON format. Furthermore, users have the option to save the entire dashboard as a PDF file, allowing for offline access and convenient sharing based on individual preferences.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period.

4.9 UNS1 – Drone Experiment

The purpose of this use case is to evaluate the potential of drones for monitoring large open-space public events. Please refer to section 3.1.9 for more information. This use case was integrated in R1 and has been updated in R2. The full version of the demonstrator can be found in Deliverable 4.3, Section 5.1.5. Building upon the feedback from end users, some additions were made to the R2 integration (Figure 33

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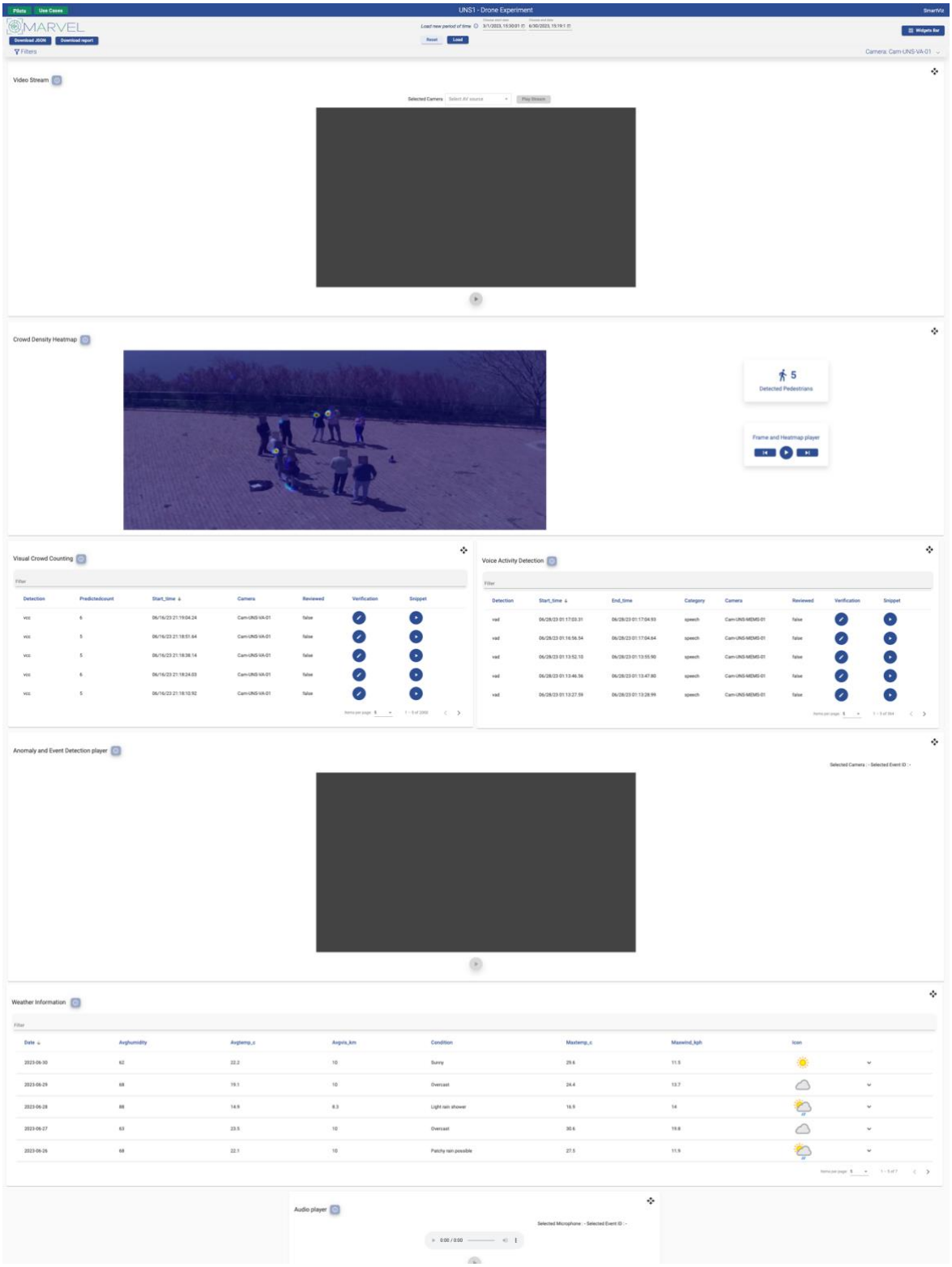

Figure 33: UNS1 dashboard on DMT

A Details widget has been incorporated into the dashboard to provide in-depth information about the VCC and Voice Activity Detection (VAD) components. Additionally, an audio player has been included in the UNS1 use case dashboard. Within SmartViz Audio and Video player functionality, users can select an event and play the corresponding audio or video snippet.

Users are empowered to validate the accuracy of the inference results by marking them as either accurate or inaccurate. Alongside the capability to rearrange and resize widgets, the dashboard view provides the functionality to download the visualised data in JSON format. Moreover, users have the option to save the entire dashboard as a PDF file, allowing for offline access and facilitating convenient sharing according to individual preferences.

Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period.

4.10 UNS2 – Localising audio events in crowds

The objective of UNS2 is to explore the feasibility of localising and detecting audio events within crowds using audio streams. Please refer to section 3.1.10 for more information.

In Figure 34 below, you can see the final dashboard for the UNS2 in R2.

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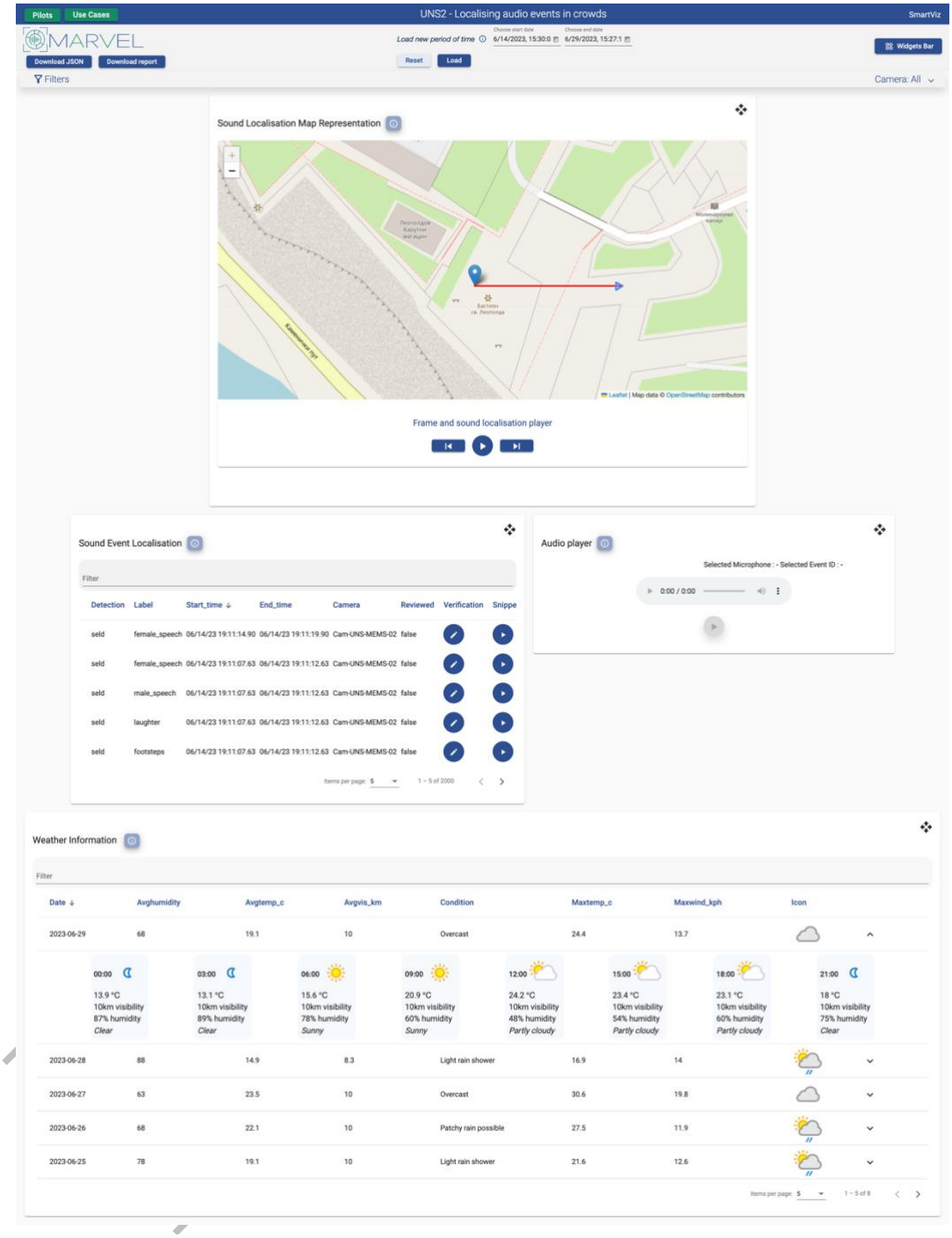

Figure 34: UNS2 dashboard on DMT

One of the key features of this use case is the Sound Localisation map, which visualises the outputs of the SELD component. Users can interact with this widget to observe consecutive detected events within a selected time period. Each event is represented by an arrow indicating its direction.

Additionally, these events along with the output of the VAD component are displayed in a Details widget. Users can request the corresponding audio snippet of an event and play it in the audio player.

To ensure the accuracy of the inference results, users have the ability to validate them as either accurate or inaccurate. The dashboard view offers flexibility with the option of rearranging and resizing the widgets. Furthermore, users can download the visualised data in JSON format and save the entire dashboard as a PDF file. This enables offline access and facilitates convenient sharing according to individual preferences. Finally, the Weather information widget in the use case provides users with a representation of weather-related data, allowing them to view and explore weather information for a selected time period.

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5 Contribution to MARVEL goals

5.1 Project related KPIs

The work undertaken in this task is directly aligned with the project-specific KPI-O3-E4-1, which targets "Detailed insights into more than 5 hidden correlations". This KPI is fundamentally connected to Enabler 4, "Complex decision-making and insights", that supports objective 3 of the project: "Break technological silos, converge diverse and innovative engineering paradigms, and establish a distributed and secure Edge-to-Fog-to-Cloud (E2F2C) ubiquitous computing framework in the big data value chain". Crucial to this mission are T4.2, T3.3, and WP6 tasks, as they collectively supply the data visualisations (T3.3 and T4.2), and subsequently evaluate these visualisations (WP6) to uncover hidden correlations. The monitoring of this KPI intensified after the release of the MVP, with users being encouraged to experiment and explore possibilities with the DMT MVP version.

Following user feedback and brainstorming discussions, additional potential areas of exploration have been identified in D4.3 to seek deeper insights into hidden correlations. Below, we provide an update on those identified in D4.3, as well as new potential areas of exploration.

i. Extend the investigation into the impact of time on the occurrence of traffic anomalies and unusual events in public safety-related use cases.

ii. Delve into analysing simultaneous events occurring in different parts of the city during the same time period based on historical data. The implementation of split screens fuelled by distinct data batches is a promising technique we are currently experimenting with.

iii. Investigate the correlations between the number of vehicles on a specific road or junction and the potential requirement for maintenance or repair alerts. After the release of the final, integrated version of the MARVEL framework, we plan to gather end user's feedback on potential alert thresholds and their visualisations.

iv. Explore the potential correlation between environmental parameters and traffic patterns: This hypothesis aims to examine the intricate relationship between environmental conditions, such as air quality, temperature, humidity, and even seasonal changes, with traffic patterns. The incorporation of the weather widget in the DMT is the preliminary stage of this exploration. For instance, it is plausible that increased smog or high temperatures could discourage motorists from travelling, thereby impacting the traffic volume. Similarly, sudden changes in weather, such as rain or snow, can significantly affect traffic speed and density. By understanding these relationships, we can predict traffic fluctuations based on environmental forecasts and implement proactive traffic-management strategies.

v. Assess the correlation between time-of-day, week, or month and the frequency of public safety incidents: Different periods might exhibit different frequencies and types of public safety incidents. For example, late night hours might increase the rate of certain types of crimes or accidents. Similarly, specific days of the week or even times of the year (e.g. holidays and festivities) may show a spike in public safety incidents. By understanding these correlations, we can better predict when and where these incidents are more likely to occur, leading to a more efficient allocation of resources, such as patrol units and emergency services, to prevent or quickly respond to these incidents.

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This type of temporal analysis offers significant insights for strategic planning and proactive public safety management.

vi. By integrating the public transport schedule into the dashboards for the specific monitored areas, the toolkit enables the verification of adherence to the schedule. The detection of vehicles further contributes to this verification process, providing additional evidence on whether scheduling is being followed. This information is particularly valuable for public transport managers, as it helps them assess the effectiveness and efficiency of transportation in these specific areas. It allows them to identify any deviations or irregularities in the transportation system, enabling timely interventions and adjustments as needed.

Each hypothesis not only has the potential to reveal more than one hidden correlation, but may also generate additional hypotheses for further exploration once the fully integrated version of the MARVEL framework is released, and users can interact with it extensively. Progress towards uncovering these hidden correlations will be routinely monitored, evaluated, and reported under WP6.

5.2 Component related KPIs

As already mentioned, SmartViz is the key component used for the development of the DMT. The baseline measures of the component-related KPIs, namely usability, scalability, availability, reliability, and performance were initially measured after the release of the MVP at M12. The results can be seen in detail in Deliverable D5.2[4]. Moving a few months forward to today and the upcoming release of the final integrated version of the MARVEL framework, there is already a number of improvements related to SmartViz since its MVP and R1 edition. These improvements will be validated on a wide scale when end users test the DMT and provide feedback. These will be reported under D5.5: Technical evaluation and progress against benchmarks – final version.

It is important to mention here that other than the already known component KPIs, qualitative component upgrades include the extension of the features, widgets, filtering options, and the overall capabilities of SmartViz since the beginning of the project as well as since R1; more specifically, ZELUS has developed eleven new widgets since the beginning of the project until M30 solely for the user requirements and visualisation needs of the MARVEL AI model outputs. The Real-time Crowd Density Heatmap, the Vehicle Trajectories, the Map Representation, and the Video and Audio Stream Player, the Comparison, the Weather Information, the Sound Localisation Map, the Alerts, the Police Intervention, the Inference Verification widgets were developed to support and represent data for detected anomalies, events, and so on. Equally important for enriching SmartViz's pool of widgets are the filtering options we adjusted and set for the meaningful analysis, investigation, and data exploration.

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[4]"D5.2: Technical evaluation and progress against benchmarks – initial version, 2021. https://doi.org/10.5281/zenodo.6322699

6 Conclusions

This deliverable presents the methodology for the design of the DMT and its building elements. More specifically, the document presented the outcomes of the involvement of end users in the initial stages of the development activities of MARVEL DMT. Having described the design and development process, we proceeded with an overview of the toolkit functionalities and the definition of the main use cases, user journeys, and intent behind each functionality. The tool comprising the DMT, SmartViz, was presented in detail, and its use inside the platform was set.

The next steps of this work include the continuous evaluation of the MARVEL framework, including the DMT, and validation of its functionalities in real-world scenarios. The evaluation process began immediately after the delivery of the MVP in M12 and continues after the release of the final version of the integrated MARVEL framework.

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